Chapter 13

Acids and Bases

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Introduction

- How do acids and bases differ from other substances?
- What determines the pH of a solution?

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Acids and Bases Affect Our Lives

Figure 13.1

Figure 13.2

Figure 13.3

Chapter 13 Topics

1. What are acids and bases?
2. Strong and weak acids and bases
3. Relative strengths of weak acids
4. Acidic, basic, and neutral solutions
5. The pH scale
6. Buffered solutions

Math Tools: Log and inverse log functions

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13.1 What are Acids and Bases?

- Acids and bases have properties that differ from other substances:
  - Acids taste sour
  - Bases taste bitter, feel slippery
  - Both change the color of some dyes
  - Acids cause many metals to corrode
  - Acids and bases combine to neutralize each other.

cabbage

rose

reactions

$CaCO_3$ + HCl

CO_2 + NaOH

CAUTION: Do not taste laboratory chemicals.

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Acid and Base Definitions

- 1800's Arrhenius Model
  - An acid in water produces hydrogen (H^+) ions.
  - A base in water produces hydroxide (OH^-) ions.

- $HCl(g) \rightarrow H^+(aq) + Cl^-(aq)$
- $NaOH(s) \rightarrow Na^+(aq) + OH^-(aq)$

- Arrhenius earned the Nobel prize for his work that showed that $H^+(aq)$ and $OH^-(aq)$ ions are important in acid-base chemistry.

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The Hydronium Ion

- Problem with Arrhenius Model:
  - H^+ does not exist completely free in aqueous solution. It associates strongly with other water molecules.
  - Chemists recognize this by representing an aqueous H^+ ion as H_3O^+(aq), the hydronium ion.

Figure 13.4

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Acid and Base Definitions

- 1923 Brønsted-Lowry definitions:
  - An acid donates an H^+ ion to another substance.
  - A base accepts an H^+ from another substance.

$$HCl(g) + H_2O(l) \rightarrow H_3O^+(aq) + Cl^-(aq)$$
$$NH_3(aq) + H_2O(l) \rightleftharpoons NH_4^+(aq) + OH^-(aq)$$

- In an acid-base reaction, the acid donates (transfers) an H^+ to a base.

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Acid-base reactions can take place without water:

- $NH_3(g) + HCl(g) \rightarrow NH_4^+(g) + Cl^-(g)$
- $NH_4^+(g) + Cl^-(g) \rightarrow NH_4Cl(s)$

Figure p. 492

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Brønsted-Lowry Acids and Bases

- Many anions from dissolved ionic compounds act as bases:

$$Na_2CO_3(s) \rightarrow 2Na^+(aq) + CO_3^{2-}(aq)$$

- The carbonate ion acts as a base in water:

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

- and with other acids:

$$\underset{\text{acid}}{HF(aq)} + \underset{\text{base}}{CO_3^{2-}(aq)} \rightleftharpoons F^-(aq) + HCO_3^-(aq)$$

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Conjugate Acid-Base Pairs

- Imagine the following reaction going in the reverse direction. What would be the acid and what would be the base?

$$HF(aq) + CO_3^{2-}(aq) \rightleftharpoons F^-(aq) + HCO_3^-(aq)$$

We call the acid and base products the conjugates of the base and acid that formed them.

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Conjugate Acid-Base Pairs

$$\underset{\text{acid}}{HF(aq)} + \underset{\text{base}}{CO_3^{2-}(aq)} \rightleftharpoons \underset{\text{conjugate base}}{F^-(aq)} + \underset{\text{conjugate acid}}{HCO_3^-(aq)}$$

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Conjugate Acid-Base Pairs Group Work

- Identify the acid and base reactants and their conjugate acid and base:
- $HCO_3^- + H_3PO_4 \rightleftharpoons H_2CO_3 + H_2PO_4^-$

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Conjugate Acid-Base Pairs

- Determine the formula of the conjugate base of each acid.
- <u>Acid Conjugate Base</u>

H_2CO_3
H_3PO_4
HPO_4^{2-}
NH_4^+
H_2O

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Conjugate Acid-Base Pairs

- Determine the formula of the conjugate acid of each base.
- <u>Base Conjugate Acid</u>

SO_4^{2-}
HCO_3^-
NH_2^-
ClO_2^-
$H_2PO_4^-$

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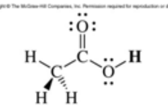
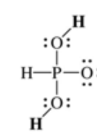
Acidic Hydrogen Atoms

- In oxoacids, the acidic hydrogen atoms are bonded to hydrogen atoms:

H3po2.ent H3po3.ent H3po4.ent Ch3co2h.ent C2h5co2h.ent H2so4.ent



acetic acid



phosphorous acid

Figure 13.5

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13.2 Strong and Weak Acids and Bases

- Strong and weak acids and bases differ in the extent of ionization.
  - Strong acids ionize completely.
  - Weak acids and bases ionize to only a small extent – a small fraction of the molecules ionize.

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Strong Acids

- Strong acids are strong electrolytes.

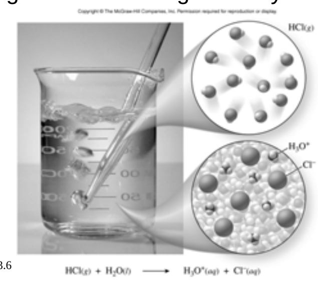

Figure 13.6

$HCl(g) + H_2O(l) \longrightarrow H_3O^+(aq) + Cl^-(aq)$

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Strong Acids (know these)

TABLE 13.1 Common Strong Acids

Formula	Name
HCl	hydrochloric acid
HBr	hydrobromic acid
HI	hydroiodic acid
HNO_3	nitric acid
$HClO_3$	chloric acid
$HClO_4$	perchloric acid
H_2SO_4	sulfuric acid (only one H^+ ionizes completely)

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Strong Bases

- Strong bases are strong electrolytes.

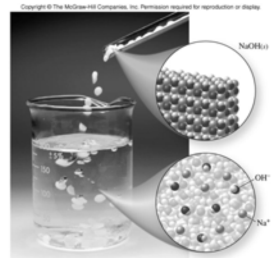

Figure 13.7 $NaOH(s) \xrightarrow{H_2O} Na^+(aq) + OH^-(aq)$

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Strong Bases (know these)

TABLE 13.2 Common Strong Bases

Formula	Name	Formula*	Name
LiOH	lithium hydroxide	$Mg(OH)_2$	magnesium hydroxide
NaOH	sodium hydroxide	$Ca(OH)_2$	calcium hydroxide
KOH	potassium hydroxide	$Ba(OH)_2$	barium hydroxide

* Although the group IIA metal hydroxides are not completely water soluble, they are strong bases because the amount that dissolves dissociates almost completely.

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Weak Acids

- Weak acids are weak electrolytes

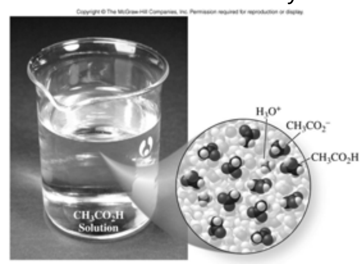

Figure 13.8 $CH_3CO_2H(aq) + H_2O(l) \rightleftharpoons CH_3CO_2^-(aq) + H_3O^+(aq)$

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Weak Acids and Where they are Commonly Found

TABLE 13.3 Common Weak Acids

Name	Formula	Occurrence
Acetic acid	CH_3CO_2H	Vinegar, sour wine
Carbonic acid	H_2CO_3	Soda, blood
Citric acid	$H_3C_6H_5O_7$	Fruit, soda
Hydrofluoric acid	HF	Used in glass etching and semiconductor manufacturing
Hypochlorous acid	HOCl	Used to sanitize pool and drinking water
Lactic acid	$HC_3H_5O_3$	Milk
Malic acid	$HC_4H_4O_5$	Fruit
Oxalic acid	$H_2C_2O_4$	Nuts, cocoa, parsley, rhubarb
Phosphoric acid	H_3PO_4	Soda, blood
Tartaric acid	$H_2C_4H_4O_6$	Candy, wine, grapes

Weak Bases

- Weak bases are weak electrolytes

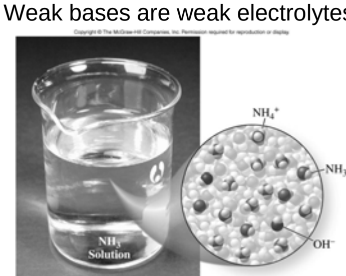

Figure 13.9 $NH_3(aq) + H_2O(l) \rightleftharpoons NH_4^+(aq) + OH^-(aq)$

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Weak Bases and where they are commonly found:

TABLE 13.4 Common Weak Bases

Name	Formula	Occurrence
Ammonia	NH_3	Glass cleaners
Calcium carbonate	$CaCO_3$	Antacids, minerals
Calcium hypochlorite	$Ca(OCl)_2$	Chlorine source for swimming pools
Methylamine	CH_3NH_2	Herring brine
Trimethylamine	$(CH_3)_3N$	Rotting fish

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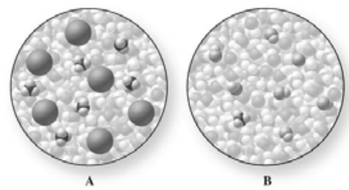
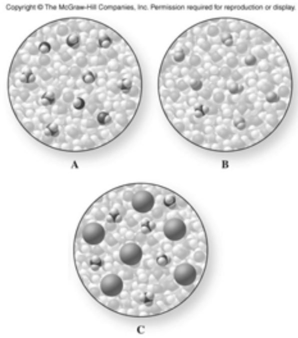
Strong and Weak Acids and Bases

EXAMPLE 13.5 Molecular-level Representations of Strong and Weak Acids

One of the diagrams shown represents a solution of HF, and the other represents an aqueous solution of HCl. Which is which? Explain your reasoning.



Identify each as a strong or weak acid or base:



Question 13.27

13.4 Acidic, Basic, and Neutral Solutions

- Neutral Solution: $[H_3O^+] > [OH^-]$
- Acidic Solution: $[H_3O^+] > [OH^-]$
- Basic Solution: $[OH^-] > [H_3O^+]$

- Why would there be hydronium ions in a basic solution?
- Why would there be hydroxide ions in an acidic solution?
- Why would either be present in a neutral solution?

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The Ion-Product Constant of Water, K_w

- Water self-ionizes to a very small extent:
  $$H_2O(l) + H_2O(l) \rightleftharpoons H_3O^+(aq) + OH^-(aq)$$
- The product of $[H_3O^+]$ and $[OH^-]$ is a constant at a given temperature:
  $$K_w = [H_3O^+][OH^-]$$
- At 25°C, the value of K_w is 1.0×10^{-14}, so in a neutral solution:
  $$[H_3O^+] = [OH^-] = 1.0\times10^{-7}$$

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The Ion-Product Constant of Water, K_w

$$K_w = [H_3O^+][OH^-] = 1.0\times10^{-14}$$

- In an acidic solution, there is excess H_3O^+, so OH^- goes down.
- In a basic solution there is excess OH^-, so H_3O^+ goes down.

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The Ion-Product Constant of Water, K_w

TABLE 13.7 Definitions of Neutral, Acidic, and Basic Solutions in Aqueous Solution

Type of Solution	Relative Concentrations	$[H_3O^+]$	$[OH^-]$	K_w
Neutral	$[H_3O^+] = [OH^-]$	$= 1.0 \times 10^{-7}\,M$	$= 1.0 \times 10^{-7}\,M$	1.0×10^{-14}
Acidic	$[H_3O^+] > [OH^-]$	$> 1.0 \times 10^{-7}\,M$	$< 1.0 \times 10^{-7}\,M$	1.0×10^{-14}
Basic	$[OH^-] > [H_3O^+]$	$< 1.0 \times 10^{-7}\,M$	$> 1.0 \times 10^{-7}\,M$	1.0×10^{-14}

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Calculating H_3O^+ and OH^- Concentrations

- When the H_3O^+ concentration is known:

$$[OH^-] = \frac{K_w}{[H_3O^+]} = \frac{1.0\times10^{-14}}{[H_3O^+]}$$

- When the OH^- concentration is known:

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

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$[H_3O^+]$ and $[OH^-]$ Relationships Fill in the blanks

$[H_3O^+]$	$[OH^-]$
10^{-5} M	
10^{-12} M	
	10^{-6} M
	10^{-12} M

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Strong Acid and Base Solutions

- What is the $[H_3O^+]$ and $[OH^-]$ for each solution?

- 0.10 *M* HCl
- 0.10 *M* NaOH
- 0.00010 *M* HCl

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13.5 The pH Scale

- The **pH** of a solution is defined as the negative logarithm (base 10) of the H_3O^+ concentration:

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

- What is the pH of solutions with the following hydronium ion concentrations?

a) $[H_3O^+] = 10^{-1}$ M
b) $[H_3O^+] = 10^{-5}$ M
c) $[H_3O^+] = 10^{-7}$ M
d) $[H_3O^+] = 10^{-11}$ M

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The pH

- Most aqueous solutions have pH values that range from 1-14.
- However, some concentrated solutions fall outside of this range.
  - What is the pH of a 1.0 *M* HCl solution?

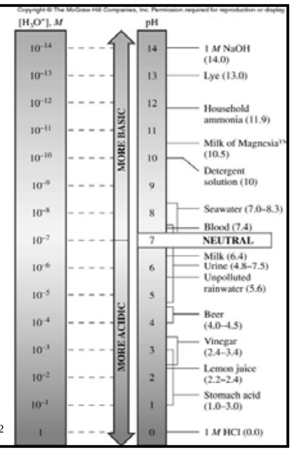

Figure 13.12

The pH

- By what factor does $[H_3O^+]$ change when the pH changes
- from 8.0 to 9.0?
- from 4.0 to 2.0?

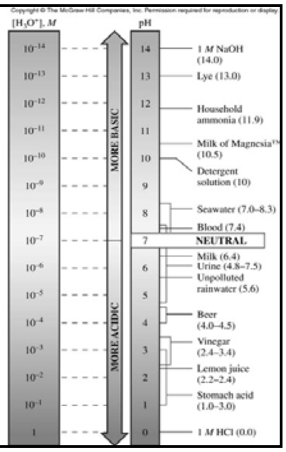

Figure 13.12

Calculating pH

- The hydroxide ion concentration in a soil sample was determined to be 5.0×10^{-7} M.

a) What is the pH of the soil?

b) Is the soil acidic or basic?

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Calculating pOH

$pOH = -log[OH^-]$

$pH + pOH = 14.00$

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Calculating Concentrations from pH or pOH

- $[H_3O^+] = 10^{-pH}$
- $[OH^-] = 10^{-pOH}$

- What is the H_3O^+ concentration in a soil sample if the pH is measured to be 6.20?

Figure 13.13

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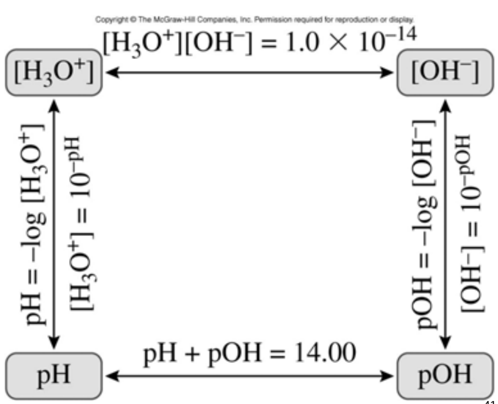

Figure 13.14

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Measuring pH

Figure 13.17

Figure 13.15

pH meter

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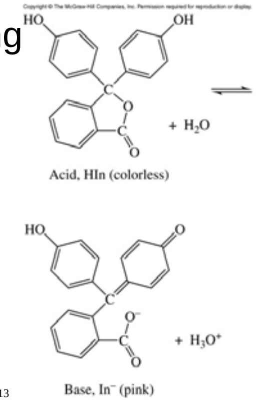
Measuring



- Indicators are brightly colored organic dyes that are weak acids or bases.
- Phenolphthalein has an acid form that is colorless and a conjugate base form that is bright pink.

Figure p. 513

indicator

Acid-Base Indicators and their Colors Change Ranges

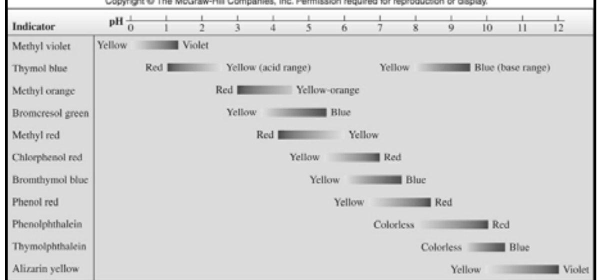


Figure 13.16

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13.6 Buffered Solutions

- **A buffer (also known as a buffer system) is a combination of a weak acid and its conjugate base (or a weak base and its conjugate acid) in about equal concentrations.**
- **The main buffer system in blood is made of H_2CO_3/HCO_3^- :**

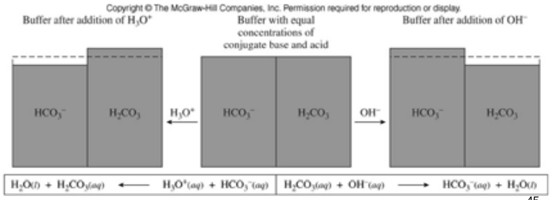

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Figure 13.18

Buffer Systems

- **Which of the following systems, when added to water, can act as a buffer system? For each buffer system, write a balanced equation.**
  - **a) HCl and NaOH**
  - **b) CH_3CO_2H and $NaCH_3CO_2$**
  - **c) HBr and KBr**

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