Electrolytes, Acids, and Bases

(Which compounds produce ions when dissolved in water?)

Suggested Demonstration: Electrolytes

Model 1: Electrolytes

Only separate, charged particles (such as ions) can carry electrical currents.

Electrolytes can carry an electrical current when dissolved in water.

Critical Thinking Question:

1. What happens to electrolytes when they dissolve in water?

Model 2: Types of electrolytes

In water solution, *strong electrolytes* dissociate completely into ions, *weak electrolytes* dissociate only slightly, and *nonelectrolytes* dissociate undetectably or not at all.

Critical Thinking Question:

2. Describe a method by which you could tell if a particular solution contains a strong electrolyte, weak electrolyte, or nonelectrolyte.

Model 3: Some common acids and bases

Type of electrolyte	Acids	Bases
Strong (any acid or base not listed here is weak)	HCl HBr HI H_2SO_4 HNO_3 $HClO_4$	$LiOH$ $NaOH$ KOH $Ca(OH)_2$ $Sr(OH)_2$ $Ba(OH)_2$
Weak	$HC_2H_3O_2$ HCN	$Mg(OH)_2$

Acids dissociate in water to give hydrogen (H^+) ions and an anion. Bases dissociate in water to give hydroxide (OH^-) ions and a cation. *Strong* acids and bases dissociate *completely*. Note that the acids are molecules, while the bases are ionic compounds.

Critical Thinking Questions:

6. Recalling that strong acids dissociate completely in water, draw a large 'X' through the species in Model 2 that is not present in any significant amount.
7. Why is a forward arrow used in Model 2 (ssd) instead of an equilibrium arrow (qwe)?
8. Explain the following statement: There is no species in Model 2 that can neutralize added hydronium ion.

Information: A summary

A solution containing both a **weak** acid and its **conjugate base** is resistant to changes in pH when small amounts of acid or base are added. This solution is called a **buffer**.

A solution of a **strong** acid and its conjugate base is **not** a buffer, since any added strong acid will not be neutralized and will just increase the H_3O^+ concentration. Similarly, a solution of a **strong base** and its conjugate acid is **not** a buffer.

Exercises:

1. State if each solutions would be useful as a buffer or not. Then explain the reason for your choice.
   a. A solution containing 0.08 M NaCN and 0.10 M HCN
   b. A solution containing 0.05 M NaOH in H_2O
   c. A solution containing 0.25 M HCl and 0.20 M NaCl
   d. A solution containing 0.05 M NH_4Cl and 0.10 M NH_3
   e. A solution containing 0.20 M KF and 0.15 M HF
2. Considering the solution in Exercise 1b.
   a. Write the three species that would be present in significant amounts.
   b. Is there any species present that can neutralize added hydroxide? Explain.
3. Complete ChemWorksheet 3, Stoichiometry Practice Worksheet 2.
4. Read the assigned pages in your textbook, and work the assigned problems.

Critical Thinking Questions:

3. Consider Model 3. What do all the molecular formulas of the acids have in common?

4. How can you recognize an acid from the molecular formula?

5. How can you recognize a base from its formula?

6. What happens to strong acids when dissolved in water?

7. What happens to weak acids when dissolved in water?

8. Are all acids strong electrolytes? Explain.

9. Describe what happens to the ions in solid sodium hydroxide (NaOH) during the process of dissolving in water.

Model 4: Solubilities of some ionic compounds

Ionic compound	Solubility in water	Type of electrolyte	Major species present when dissolved in water
$MgCl_2$	soluble	strong	$Mg^{2+}(aq)$, $Cl^-(aq)$
MgO	insoluble	nonelectrolyte	MgO(s)
K_2S	soluble	strong	$K^+(aq)$, $S^{2-}(aq)$
CuS	insoluble	nonelectrolyte	CuS(s)
$Ca(NO_3)_2$	soluble	strong	$Ca^{2+}(aq)$, $NO_3^-(aq)$
$Ca_3(PO_4)_2$	insoluble	nonelectrolyte	$Ca_3(PO_4)_2(s)$

Molecular compounds other than acids and bases, and *insoluble ionic compounds* do not dissociate in water and so are nonelectrolytes.

The phase label *(aq)*, meaning "aqueous," can be used to show that a species is dissolved in water. **We will not consider how to predict if an ionic compound is soluble in water until later in the course.**

Critical Thinking Questions:

10. A solution of $MgCl_2$ in water could be written as $MgCl_2(aq)$. Besides water, what species would actually be present in the solution?

11. MgO is an ionic compound that does not dissolve in water, it would just collect as a solid—*i. e.,* MgO(s)—at the bottom of the container. Would there be any ions dissolved in the water? Explain.

12. Describe a method by which you could tell if an ionic compound is soluble in water.

13. Consider Model 4. How is the solubility of an ionic compound related to its classification as an electrolyte?

14. The following compounds from Model 4 are placed in water. Add the phase labels (s) or (aq) to represent whether the compounds are soluble or not:

    K_2S CuS $Ca(NO_3)_2$ $Ca_3(PO_4)_2$

15. Suppose that each compound in the table below is placed in water. The phase labels given describe whether the compound dissolves or not. Fill in the table with the properties for each compound.

Compound	**Acid**, other **molecule**, **base**, or other **ionic compound**	**Strong**, **weak**, or **non**electrolyte
HBr(aq)		
KOH(aq)		
$CH_2O(aq)$		
$Ca_3(PO_4)_2(s)$		
$Al(OH)_3(s)$		
HOCl(aq)		
$H_2S(aq)$		
$Fe_2O_3(s)$		
$Na_2S(aq)$		

Exercises:

1. Write formulas for the major species present in the solutions from CTQ 15.

Compound	Major species present when dissolved in water (or "need more information")
$HBr(aq)$	
$KOH(aq)$	
$CH_2O(aq)$	
$Ca_3(PO_4)_2(s)$	
$Al(OH)_3(s)$	
$HOCl(aq)$	
$H_2S(aq)$	
$Fe_2O_3(s)$	
$Na_2S(aq)$	

2. Read the assigned pages in your text, and work the assigned problems.

Acids and Bases

(What happens when hydrogen ions are transferred between species?)

Information: Two definitions of acids and bases

Arrhenius definitions

An acid is a species that dissociates into H^+ (hydrogen) ions and anions when dissolved in water.

A base is a species that dissociates into OH^- (hydroxide) ions and cations when dissolved in water.

Brønsted-Lowry definitions

An acid donates a proton (H^+ ion) to another species.

A base accepts a proton (H^+ ion) from another species.

The Brønsted-Lowry definition explains why the hydrogen ions (H^+) in water are actually hydronium ions—a water molecule (H_2O) has accepted the proton to become hydronium (H_3O^+).

Table 1: Some common acids and bases

Type of electrolyte	Acids	Bases
Strong (all not listed here are weak)	HCl	LiOH
	HBr	NaOH
	HI	KOH
	H_2SO_4	$Ca(OH)_2$
	HNO_3	$Sr(OH)_2$
	$HClO_4$	$Ba(OH)_2$
Weak	$HC_2H_3O_2$	$Mg(OH)_2$
	HCN	

Recall that when strong acids and bases dissolve in water, they dissociate completely into ions, while weak acids and bases dissociate only slightly.

Critical Thinking Questions:

1. Write the three species that actually exist in significant amounts in a one-tenth molar aqueous solution of HCl.

2. Explain why hydrogen ion (H^+) is *not* one of the three species in CTQ 1.

3. Write the three species that actually exist in significant amounts in a one-tenth molar aqueous solution of LiOH.

Information: Hydronium-hydroxide balance

In pure water, a small amount of self ionization occurs, with one water molecule acting as an acid (donating a proton) and another as a base (accepting a proton):

$$H_2O(l) + H_2O(l) \text{ qwe } H_3O^+(aq) + OH^-(aq)$$

In pure water, the concentrations of hydronium ion and hydroxide ion are each 1.0×10^{-7} M. Furthermore, the product of the concentrations of hydronium ion and hydroxide ion in aqueous solution at 25°C is always 1.0×10^{-14} M.

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

This means that if the hydronium ion concentration $[H_3O^+]$ increases, the hydroxide ion concentration $[OH^-]$ decreases. This relationship allows us to calculate the amounts of hydronium ion and hydroxide ion in any solution of strong acid or base.

Critical Thinking Questions:

4. What is the hydronium ion concentration in a 1.0×10^{-5} M aqueous solution of HCl?

5. What is the hydroxide ion concentration in an aqueous solution if the hydronium ion concentration is 1.0×10^{-5} M?

Information: pH

pH (the "power of hydrogen") is defined as the negative of the logarithm of the molar concentration of hydronium ions (without units):

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

Therefore, in pure water, the pH is $-\log(1.0\times10^{-7})$, which equals 7. pH values below 7 are called *acidic*; those above 7 are termed *basic* or *alkaline*. pH values can actually go below 0 and above 14, though this is not commonly seen.

Table 2: The relationship between acidity, pH, and the hydronium and hydroxide ion concentrations of a solution.

Relative Concentrations	pH	Solution
$[H_3O^+] > [OH^-]$	< 7	acidic
$[H_3O^+] < [OH^-]$	> 7	basic
$[H_3O^+] = [OH^-]$	= 7	neutral

Critical Thinking Questions:

6. What is the pH of the 1.0×10^{-5} M aqueous solution of HCl from CTQ 3? (Be sure you can enter this into your calculator correctly, *e. g.*, `1 . 0 EE 5 ± log ±`)

7. According to Table 2, which ion does the solution in CTQ 5 contain more of:

   hydronium or **hydroxide** (circle one)?

8. Does your answer to CTQ 7 agree with your answers to CTQs 4 and 5?

9. a. If the pH of a cola drink is 3.2, what is the hydronium ion concentration? Be sure you can enter this into your calculator correctly, *e. g.*, `3 . 2 ± 10^x` (the `10^x` key is often an `inverse` or 2^{nd} `log`).

   b. What is the hydroxide ion concentration in the cola?

10. a. What is the hydroxide ion concentration in a 1.0×10^{-5} M aqueous solution of **NaOH**?

    b. What is the pH of this solution? (Careful!)

Model: Conjugate acid-base pairs

According to the Brønsted-Lowry theory, a reaction of an acid and a base involves a proton (*i. e.,* hydrogen ion) transfer from the acid to the base. Two ions or molecules that *differ only by that one hydrogen ion* make up a **conjugate acid-base pair**. Three example pairs are shown below:

H_3O^+ and H_2O $\qquad$ H_2O and OH^- $\qquad$ NH_4^+ and NH_3

The **conjugate acids** have one more proton (H^+) than the **conjugate bases**. For example, consider the reaction below:

conjugate acid-base pair (CH₃COOH / CH₃COO⁻)

$CH_3COOH + H_2O$ qwe $CH_3COO^- + H_3O^+$

acetic acid + water $\qquad$ acetate + hydronium ion

conjugate acid-base pair (H_2O / H_3O^+)

Sometimes we simplify the naming by saying an acid and a base react to give a conjugate acid and conjugate base.

$CH_3COOH + H_2O$ qwe $CH_3COO^- + H_3O^+$

acid $\quad$ base $\qquad$ conjugate base $\quad$ conjugate acid

- The conjugate base is what results after the acid gives up a hydrogen ion; so we say that *acetate is the conjugate base of acetic acid.*
- The conjugate acid is what results after the base picks up a hydrogen ion; so we say that *hydronium ion is the conjugate acid of water.*

Critical Thinking Questions:

11. For the equations below, identify the acid and base on the reactant side and the conjugate acid and conjugate base on the product side. Draw a line to connect conjugate acid-base pairs together.

    a. $HCN(aq) + OH^-(aq)$ qwe $H_2O(l) + CN^-(aq)$

    b. $F^-(aq) + H_3O^+(aq)$ qwe $H_2O(aq) + HF(aq)$

    c. $NH_3(aq) + HCl(aq)$ qwe $NH_4^+(aq) + Cl^-(aq)$

Exercises:

1. Which definition of an acid—Arrhenius or Brønsted—is more complete for aqueous solutions? Explain.

2. Calculate the pH of each of the following aqueous solutions.
   a. 1.0×10^{-4} M nitric acid
   b. 5.0×10^{-3} M hydrobromic acid
   c. a 1.0×10^{-6} M solution of the diprotic acid H_2SO_4 (diprotic means that each molecule of H_2SO_4 donates <u>two</u> hydrogen ions to water molecules)
   d. 0.0012 M $Ca(OH)_2$

3. Calculate the hydroxide ion concentrations of the solutions in Exercise 2.

4. Write formulas for the conjugate bases of the acids in Exercises 2a and 2b.

5. Read the assigned pages in your textbook, and work the assigned problems.

Buffers

(How do acids and bases react together?)

Model 1: A buffer system

Consider a solution containing both the **weak** acid acetic acid and its **conjugate base,** sodium acetate. This sets up the equilibrium shown below. (The sodium ion is just a spectator, and does not show up in the equilibrium expression.)

CH_3COOH	+	H_2O	qwe	CH_3COO^-	+	H_3O^+
acetic acid		water		acetate		hydronium ion
(acid)		(base)		(conjugate base)		(conjugate acid)

Critical Thinking Questions:

1. Suppose some strong base (hydroxide ion) is added to the buffer system in Model 1. Circle the two species in the model that could react with the hydroxide.
2. Write a chemical equation for the reaction of hydroxide ion being neutralized by reacting with acetic acid, producing acetate and water.
3. Explain why addition of strong base (hydroxide ion) to the solution in Model 1 will not cause a great change in the pH of the solution, as long as the acetic acid is not used up.
4. Draw a <u>box</u> around the one species in Model 1 that could react with and neutralize any added hydronium ion.
5. Explain why addition of strong acid will not cause the pH of the solution in Model 1 to change much, as long as plenty of acetate is present.

Model 2: A solution of a strong acid and its conjugate base

Consider a solution containing both the **strong** acid hydrochloric acid and its **conjugate base**, sodium chloride. This sets up the system shown below.

HCl	+	H_2O	ssd	Cl^-	+	H_3O^+
hydrochloric acid		water		chloride		hydronium ion
(acid)		(base)		(conjugate base)		(conjugate acid)