

EBBING • GAMMON

General  
**Chemistry**  
ELEVENTH EDITION

# Chemical Reactions

## ➤ Ions in Aqueous Solution

A **solution** is a homogenous mixture of 2 or more substances.

The **solute** is (are) the substance(s) present in the smaller amount(s).

The **solvent** is the substance present in the larger amount.

<u>Solution</u>	<u>Solvent</u>	<u>Solute</u>
Soft drink (l)	H <sub>2</sub> O	Sugar, CO <sub>2</sub>
Air (g)	N <sub>2</sub>	O <sub>2</sub> , Ar, CH <sub>4</sub>
Soft solder (s)	Pb	Sn



aqueous solutions  
of KMnO<sub>4</sub>

## 4.1 Ionic Theory of Solutions and Solubility Rules

✓ Arrhenius proposed the *ionic theory of solutions* to account for the conductivity of water solutions.

“Certain substances produce freely moving ions when they dissolve in water, and these ions conduct an electric current”

✓ Pure H<sub>2</sub>O doesn't contain ions → not conductive

✓ An aqueous solution of ions (aq) is conductive

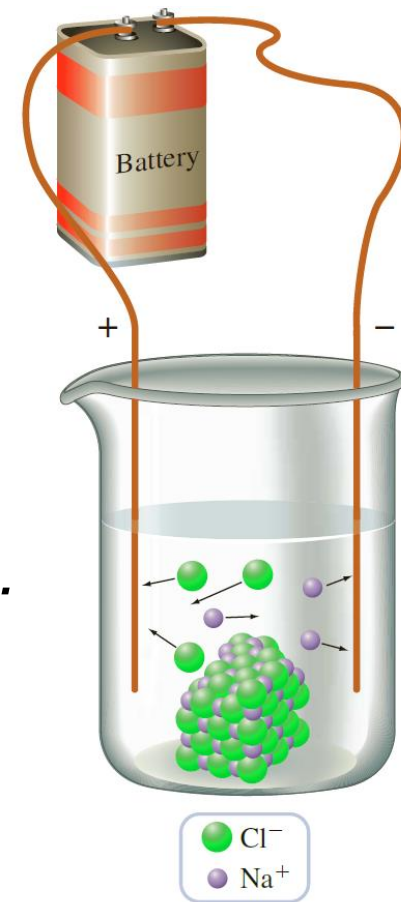
➤ Electrolytes and Nonelectrolytes:

✓ An **electrolyte** is a substance that dissolves in water to give an electrically conducting solution.

✓ *ionic solids that dissolve in water are electrolytes.*

✓ Not all electrolytes are ionic substances

✓ molecular substances that dissolve in water **to form ions are electrolytes**



# Electrolytes in Aqueous Solution

- Ionic compounds conduct electricity
- **Generally** Molecular compounds don't conduct electricity.  
Why?

**Bright  
light**

**Ions  
present**



Michael Watson

(a)

**$\text{CuSO}_4$  and water**

**No  
light**

**Molecular**



Michael Watson

(b)

**Sugar and water**

# Ionic Compounds (Salts) in Water

- Water molecules arrange themselves around ions and remove them from lattice.

## Dissociation

- Salts break apart into ions when entering solution

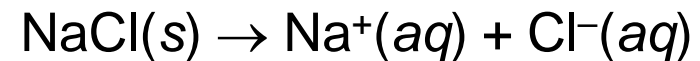
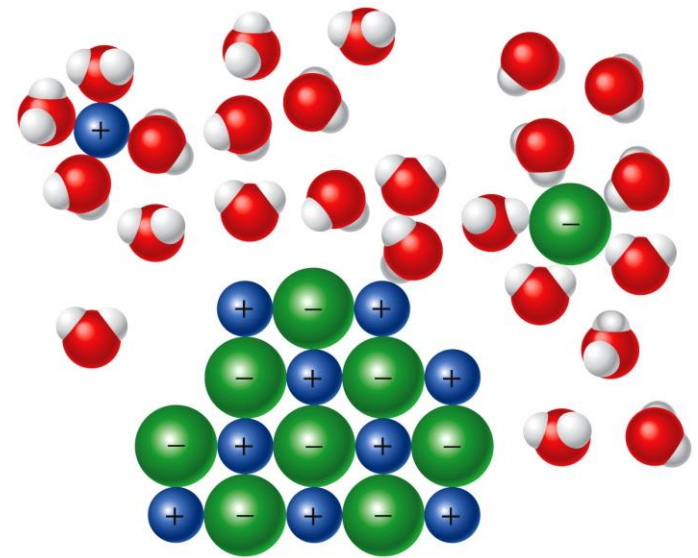
## Separated ions

- Hydrated**

- Conduct electricity

- Note:** Polyatomic ions remain intact

- e.g.**,  $\text{KIO}_3 \rightarrow \text{K}^+ + \text{IO}_3^-$

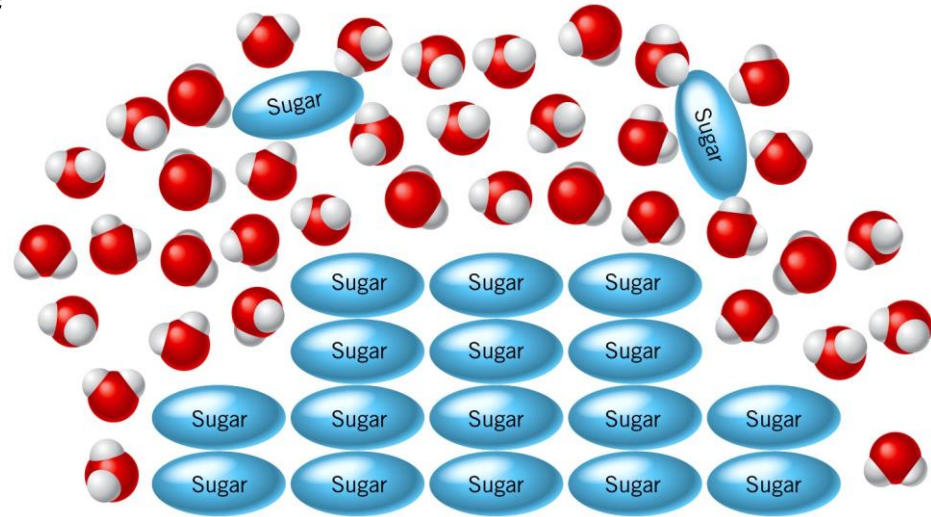


(Q) How many ions form on the dissociation of  $\text{Na}_3\text{PO}_4$ ?

(Q) How many ions form on the dissociation of  $\text{Al}_2(\text{SO}_4)_3$ ?

# Molecular Compounds In Water

- When molecules dissolve in water
  - Solute particles are surrounded by water
  - Molecules do not dissociate



# Electrical Conductivity

## Electrolyte

- Solute that yield electrically conducting solutions
- Separate into ions when enter into solution

## Strong electrolyte

- Electrolyte that dissociates 100% in water
- Yields aqueous solution that conducts electricity
- Ionic compounds, **e.g.**, NaCl, KNO<sub>3</sub>
- Strong acids and bases, **e.g.**, HClO<sub>4</sub>, HCl

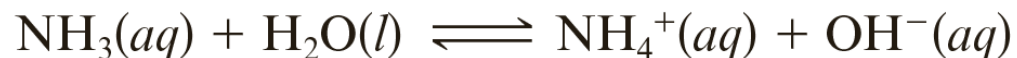
## Non-electrolyte

- Aqueous solution that doesn't conduct electricity
- Molecules remain intact in solution **e.g.**,  
Sugar (glucose, sucrose),  
Alcohol(Methanol, ethanol), Urea

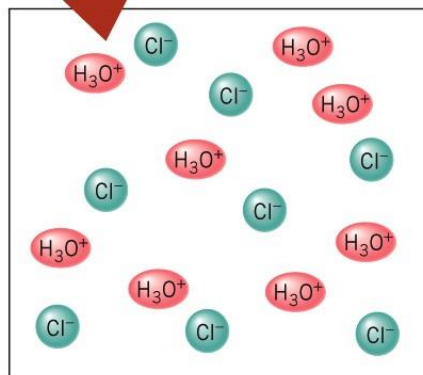
Strong Acids	Strong Bases
HClO <sub>4</sub>	LiOH
H <sub>2</sub> SO <sub>4</sub>	NaOH
HI	KOH
HBr	Ca(OH) <sub>2</sub>
HCl	Sr(OH) <sub>2</sub>
HNO <sub>3</sub>	Ba(OH) <sub>2</sub>

## Weak electrolyte

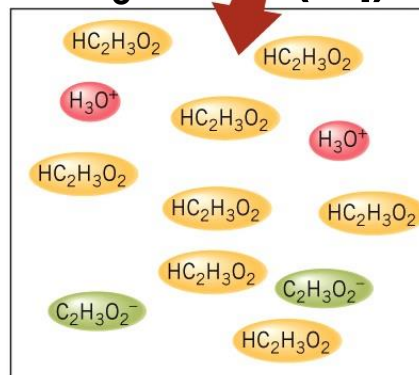
- When dissolved in water a small percentage of molecules ionize
- Common examples are **weak acids and bases**
- Solutions weakly conduct electricity
- **e.g.**, Acetic acid ( $\text{CH}_3\text{COOH}$ ), ammonia ( $\text{NH}_3$ )



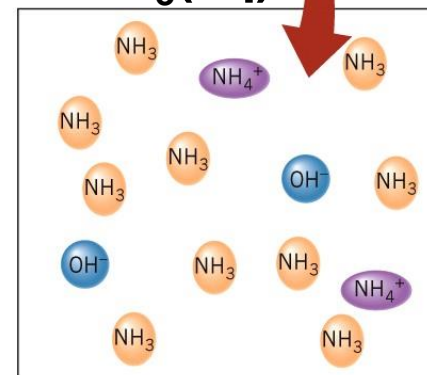
(a) **HCl(aq)**



(b) **CH<sub>3</sub>COOH(aq)**



(c) **NH<sub>3</sub>(aq)**





# ➤ Solubility Rules

- ✓ Soluble: NaCl, CH<sub>3</sub>CH<sub>2</sub>OH, CH<sub>3</sub>OH
- ✓ Insoluble: benzene (C<sub>6</sub>H<sub>6</sub>), hexane (C<sub>6</sub>H<sub>14</sub>)

Table 4.1 Solubility Rules for Ionic Compounds

Rule	Applies to	Statement	Exceptions
1	Li <sup>+</sup> , Na <sup>+</sup> , K <sup>+</sup> , NH <sub>4</sub> <sup>+</sup>	Group 1A and ammonium compounds are soluble.	—
2	C <sub>2</sub> H <sub>3</sub> O <sub>2</sub> <sup>-</sup> , NO <sub>3</sub> <sup>-</sup>	Acetates and nitrates are soluble.	—
3	Cl <sup>-</sup> , Br <sup>-</sup> , I <sup>-</sup>	Most chlorides, bromides, and iodides are soluble.	AgCl, Hg <sub>2</sub> Cl <sub>2</sub> , PbCl <sub>2</sub> , AgBr, HgBr <sub>2</sub> , Hg <sub>2</sub> Br <sub>2</sub> , PbBr <sub>2</sub> , AgI, HgI <sub>2</sub> , Hg <sub>2</sub> I <sub>2</sub> , PbI <sub>2</sub>
4	SO <sub>4</sub> <sup>2-</sup>	Most sulfates are soluble.	CaSO <sub>4</sub> , SrSO <sub>4</sub> , BaSO <sub>4</sub> , Ag <sub>2</sub> SO <sub>4</sub> , Hg <sub>2</sub> SO <sub>4</sub> , PbSO <sub>4</sub>
5	CO <sub>3</sub> <sup>2-</sup>	Most carbonates are insoluble.	Group 1A carbonates, (NH <sub>4</sub> ) <sub>2</sub> CO <sub>3</sub>
6	PO <sub>4</sub> <sup>3-</sup>	Most phosphates are insoluble.	Group 1A phosphates, (NH <sub>4</sub> ) <sub>3</sub> PO <sub>4</sub>
7	S <sup>2-</sup>	Most sulfides are insoluble.	Group 1A sulfides, (NH <sub>4</sub> ) <sub>2</sub> S
8	OH <sup>-</sup>	Most hydroxides are insoluble.	Group 1A hydroxides, Ca(OH) <sub>2</sub> , Sr(OH) <sub>2</sub> , Ba(OH) <sub>2</sub>

(Q) Which of the following would you expect to be strong electrolyte when placed in water?

NH<sub>4</sub>Cl, MgBr<sub>2</sub>, H<sub>2</sub>O, HCl, Ca<sub>3</sub>(PO<sub>4</sub>)<sub>2</sub>, CH<sub>3</sub>OH

Example 4.1 Determine whether the following compounds are soluble or insoluble in water.

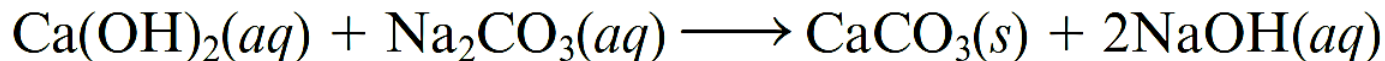
a.  $\text{Hg}_2\text{Cl}_2$     b.  $\text{KI}$     c. lead(II) nitrate

Which of the following compounds are expected to be soluble in water? a.  $\text{Ca}(\text{C}_2\text{H}_3\text{O}_2)_2$     b.  $\text{FeCO}_3$     c.  $\text{AgCl}$

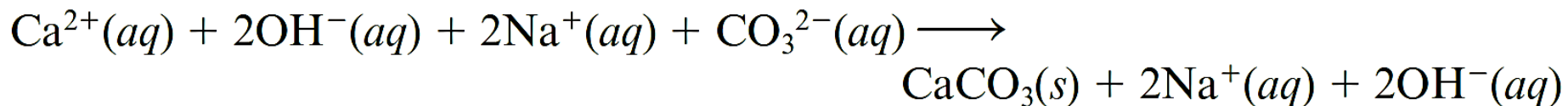
a.  $\text{NaBr}$     b.  $\text{Ba}(\text{OH})_2$     c. calcium carbonate    d.  $\text{Ag}_2\text{SO}_4$

## 4.2 Molecular and Ionic Equations

➤ Molecular Equation:

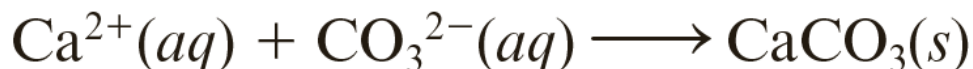
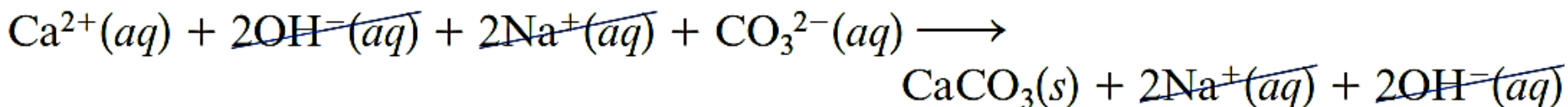


➤ Complete Ionic Equation:

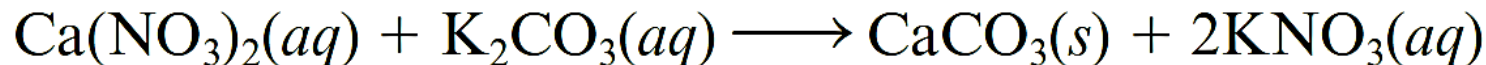


➤ Net Ionic Equation:

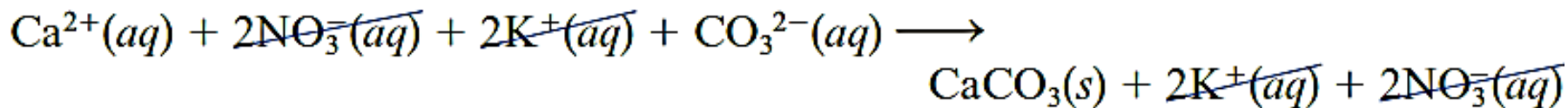
**spectator ions:  $\text{OH}^{-}$  and  $\text{Na}^{+}$**



➤ Molecular Equation:



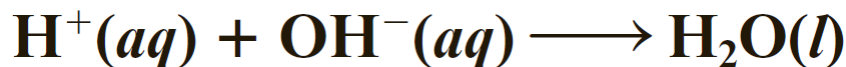
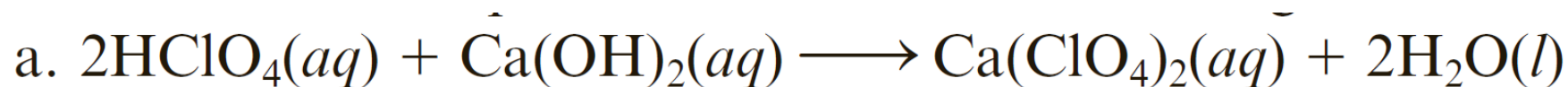
➤ Complete Ionic Equation:

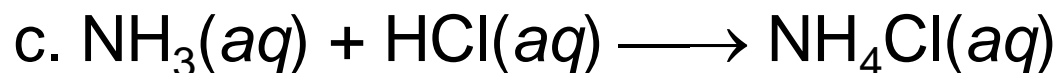
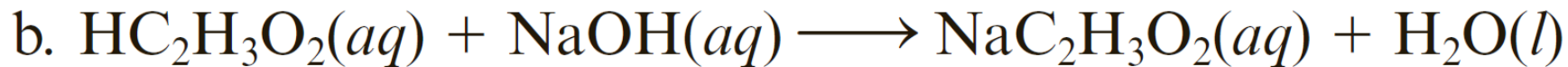


➤ Net Ionic Equation:



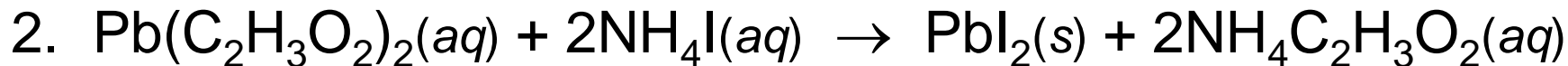
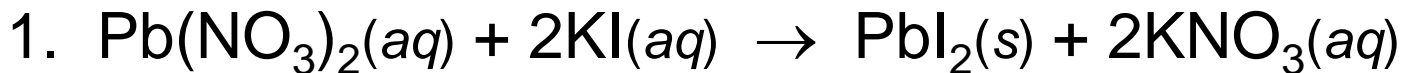
## Example 4.2 Writing Net Ionic Equations



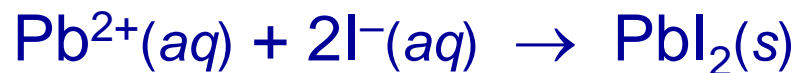


**Write weak electrolytes in “molecular form”**

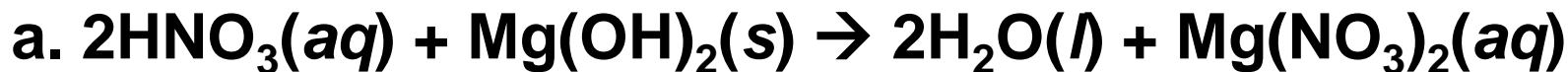
✓ **Many ways to make  $\text{PbI}_2$**



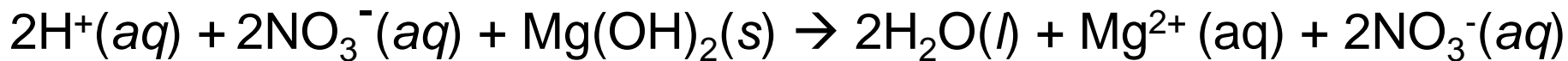
Different starting reagents Same net ionic equation



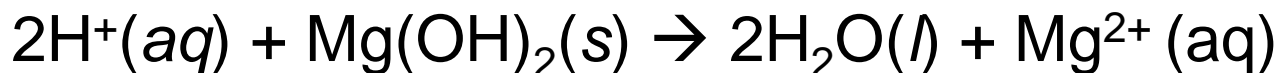
Exercise 4.2 Write complete ionic and net ionic equations for each of the following molecular equations.



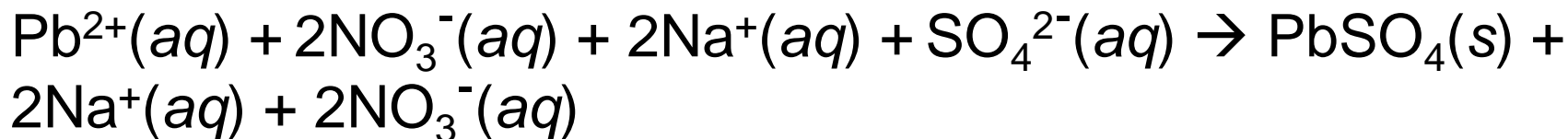
Ionic:



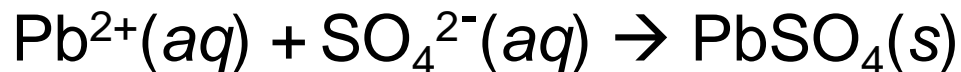
Net Ionic:



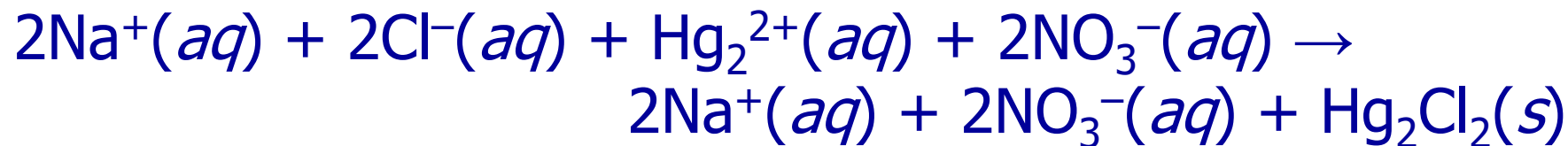
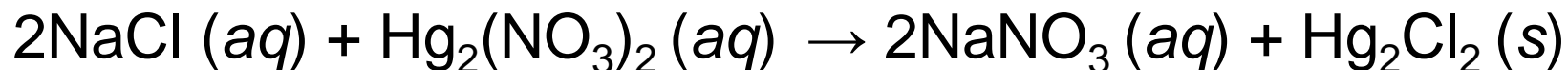
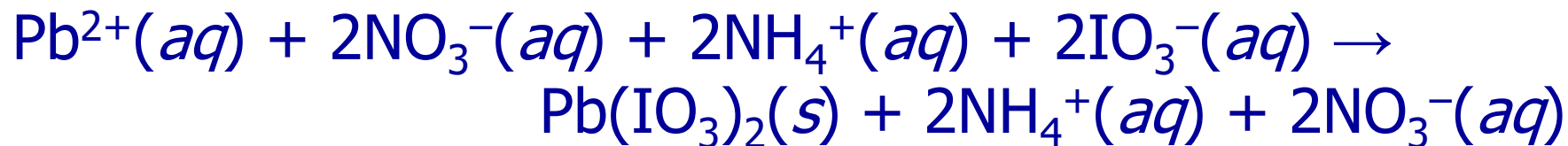
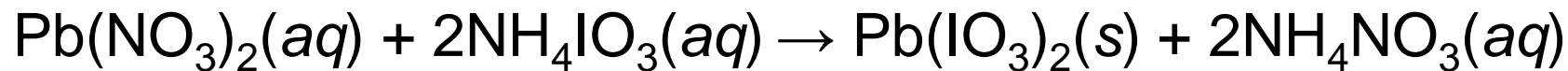
Ionic:



Net Ionic:



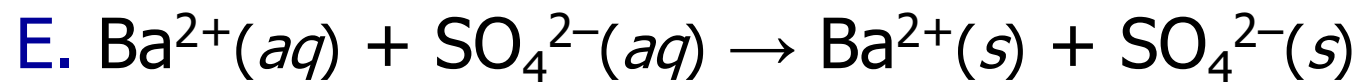
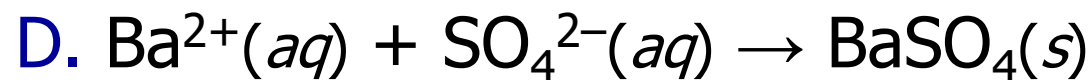
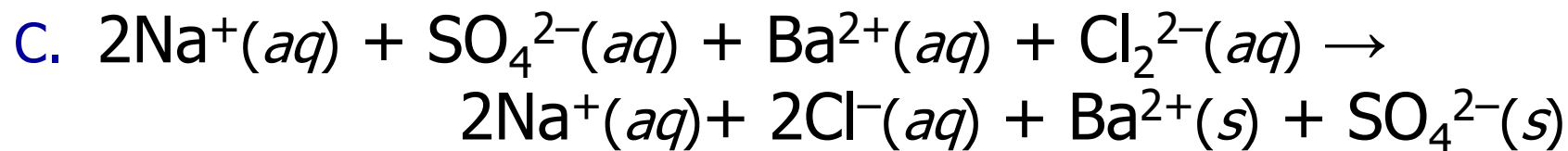
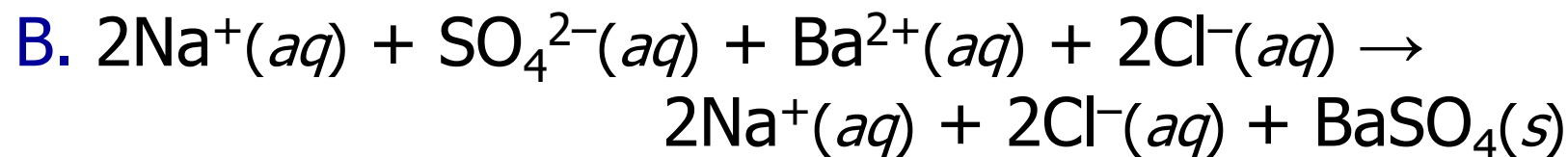
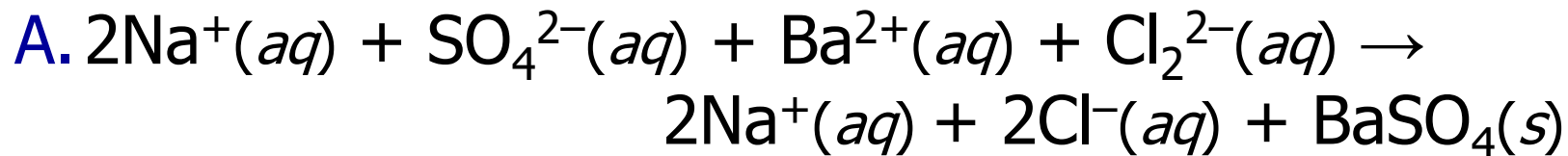
(Q) Write the correct ionic equation for each:



(Q) Consider the following reaction :

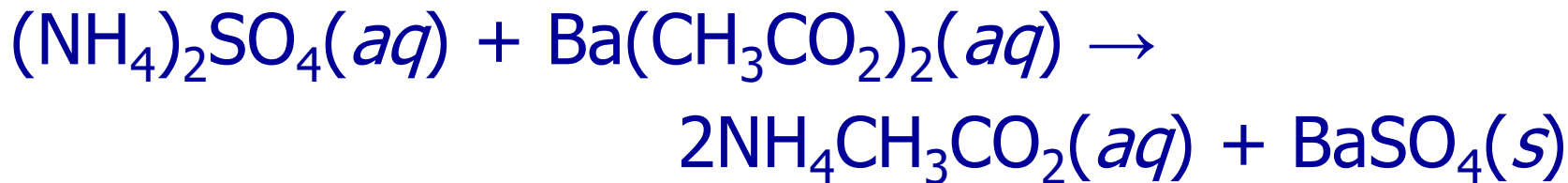


Write the correct **ionic** equation.

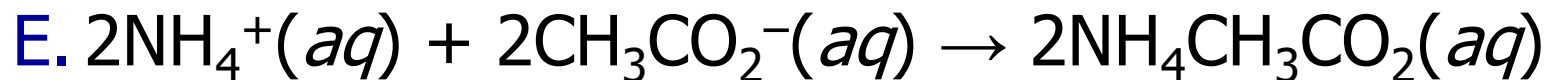
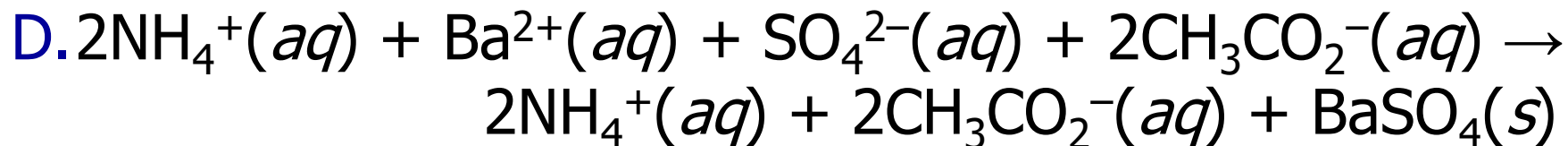
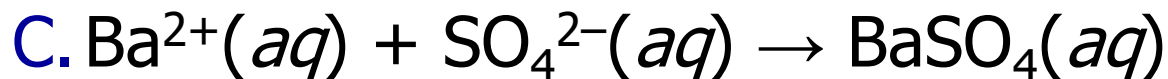
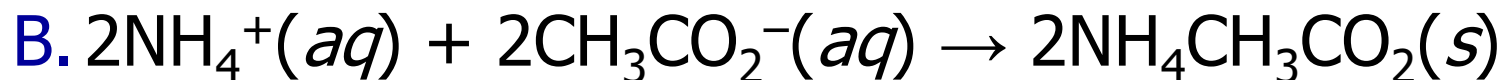
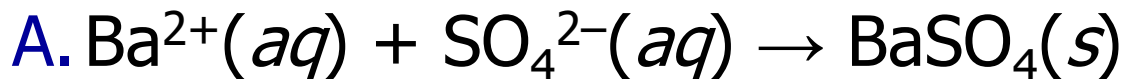




Consider the following molecular equation:

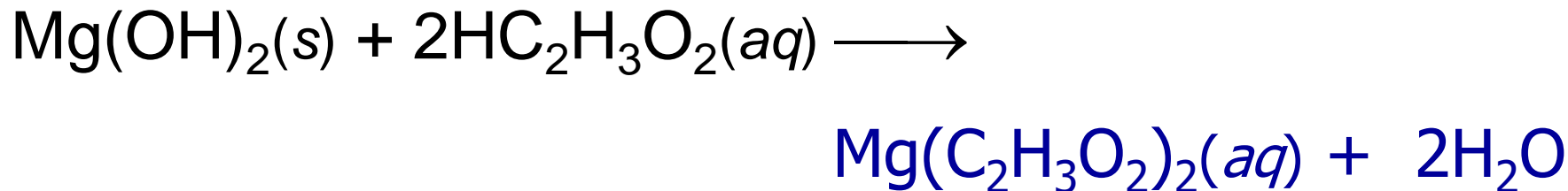


Write the correct **net** ionic equation.

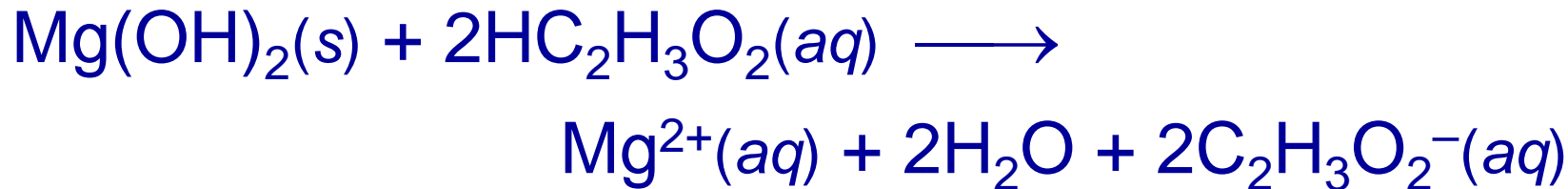


What is the net ionic equation for the following reaction?

### Molecular equation



### Ionic equation



- There are NO spectator ions!
- So net ionic and ionic equations are the **same**

## ➤ **Types of Chemical Reactions**

1. **Precipitation reactions.** In these reactions, you mix solutions of two ionic substances, and a solid ionic substance (a precipitate) forms.
2. **Acid–base reactions.** An acid substance reacts with a substance called a base. Such reactions involve the transfer of a proton between reactants.
3. **Oxidation–reduction reactions.** These involve the transfer of electrons between reactants.

## 4.3 Precipitation Reactions

- ✓ A precipitation reaction occurs in aqueous solution because one product is insoluble.

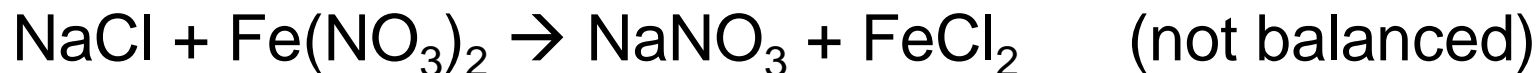


- ✓ An **exchange (or metathesis) reaction** is *a reaction between compounds that, when written as a molecular equation, appears to involve the exchange of parts between the two reactants*

### Example 4.3 Deciding Whether a Precipitation Reaction Occurs

For each of the following, decide whether a precipitation reaction occurs. If it does, write the balanced molecular equation and then the net ionic equation. If no reaction occurs, write the compounds followed by an arrow and then *NR* (no reaction).

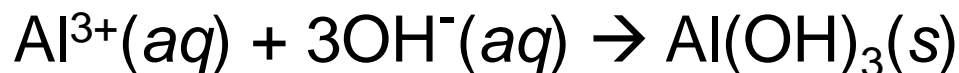
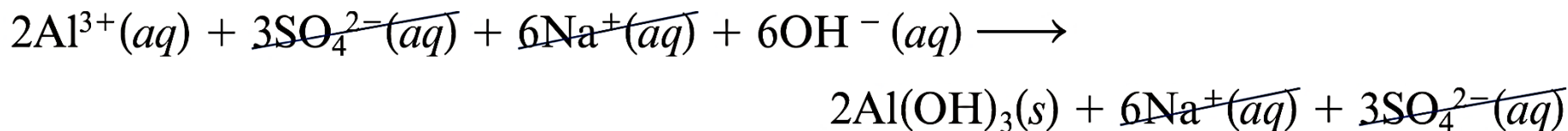
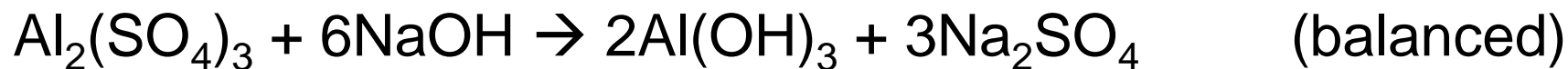
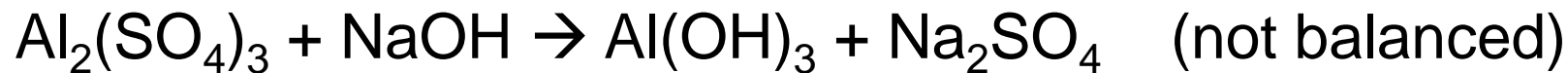
a. Aqueous solutions of sodium chloride and iron(II) nitrate are mixed.



soluble    soluble            soluble    soluble



b. Aqueous solutions of aluminum sulfate and sodium hydroxide are mixed.



## 4.4 Acid–Base Reactions

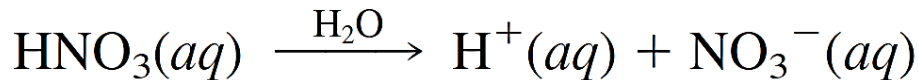
- ✓ Acids have sour taste. Bases have bitter taste & soapy feel.
- ✓ An **acid–base indicator** is *a dye used to distinguish between acidic and basic solutions by means of color change*
- ✓ Litmus: in acidic solution = red & in basic solution = blue
- ✓ Phenolphthalein: in acidic solution = colorless & in basic solution = pink

Table 4.2 Common Acids and Bases

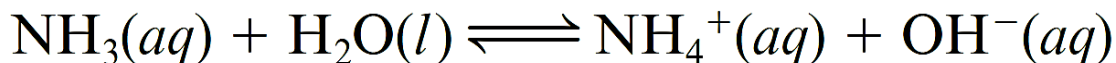
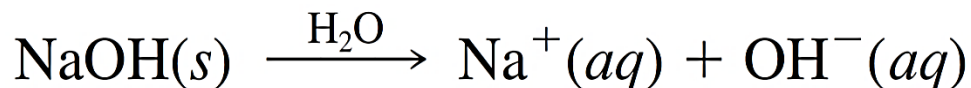
Name	Formula	Remarks
Acids		
Acetic acid	$\text{HC}_2\text{H}_3\text{O}_2$	Found in vinegar
Acetylsalicylic acid	$\text{HC}_9\text{H}_7\text{O}_4$	Aspirin
Ascorbic acid	$\text{H}_2\text{C}_6\text{H}_6\text{O}_6$	Vitamin C
Citric acid	$\text{H}_3\text{C}_6\text{H}_5\text{O}_7$	Found in lemon juice
Hydrochloric acid	$\text{HCl}$	Found in gastric juice (digestive fluid in stomach)
Sulfuric acid	$\text{H}_2\text{SO}_4$	Battery acid
Bases		
Ammonia	$\text{NH}_3$	Aqueous solution used as a household cleaner
Calcium hydroxide	$\text{Ca}(\text{OH})_2$	Slaked lime (used in mortar for building construction)
Magnesium hydroxide	$\text{Mg}(\text{OH})_2$	Milk of magnesia (antacid and laxative)
Sodium hydroxide	$\text{NaOH}$	Drain cleaners, oven cleaners

## ➤ Definitions of Acid and Base

✓ Arrhenius **acid**: a substance that produces hydrogen ions,  $\text{H}^+$ , when it dissolves in water.

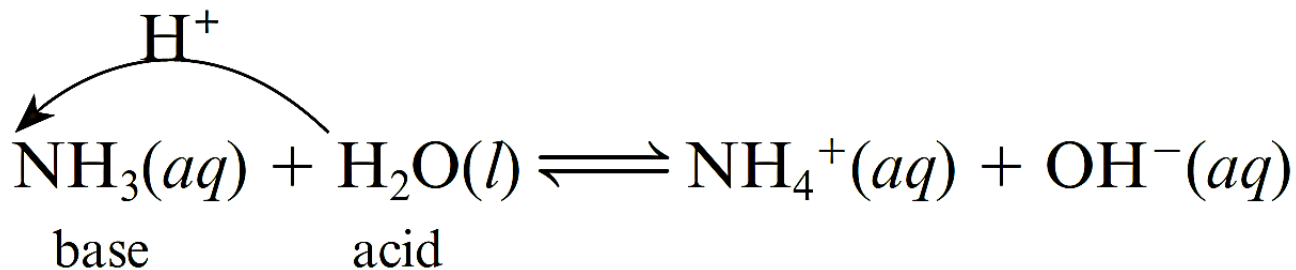


✓ Arrhenius **base**: a substance that produces hydroxide ions,  $\text{OH}^-$ , when it dissolves in water.



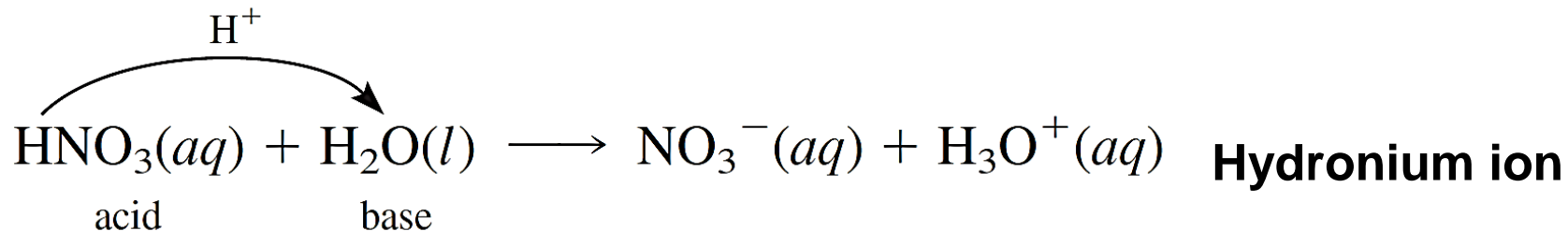
✓ Brønsted and Lowry **acid**: a species (molecule or ion) that donates a **proton** to another species in a proton-transfer reaction

✓ Brønsted and Lowry **base**: a species (molecule or ion) that accepts a **proton** from another species.





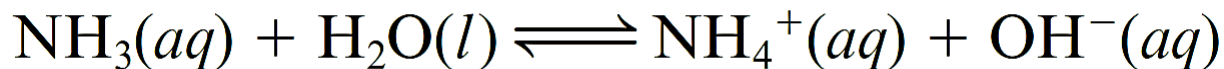
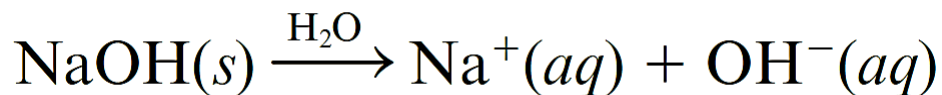
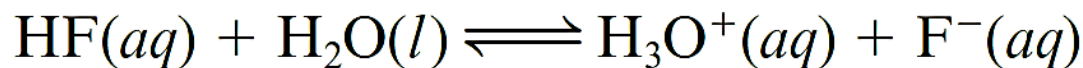
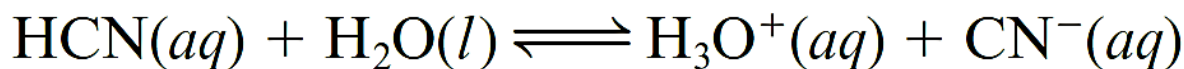
- ✓ The dissolution of  $\text{HNO}_3$  in water is actually a proton-transfer reaction.



- ✓ The Arrhenius definitions and those of Brønsted and Lowry are essentially equivalent for aqueous solutions
- ✓  $\text{NaOH}$  and  $\text{NH}_3$  are bases in the Arrhenius view because they increase the percentage of  $\text{OH}^-$  ion in the aqueous solution.
- ✓  $\text{NaOH}$  and  $\text{NH}_3$  are bases in the Brønsted–Lowry view because they provide species that can accept protons.

## ➤ Strong and Weak Acids and Bases

- ✓ A **strong acid or base** *ionizes completely in water.*
- ✓ A **weak acid or base** *only partly ionizes in water.*



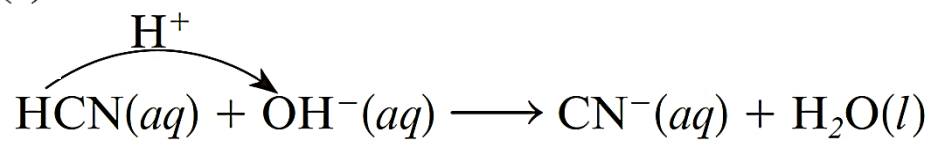
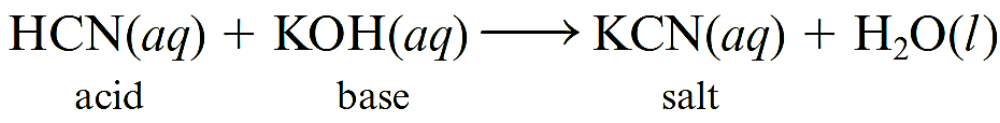
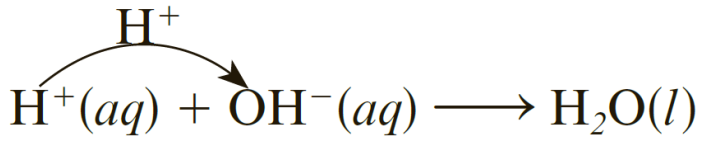
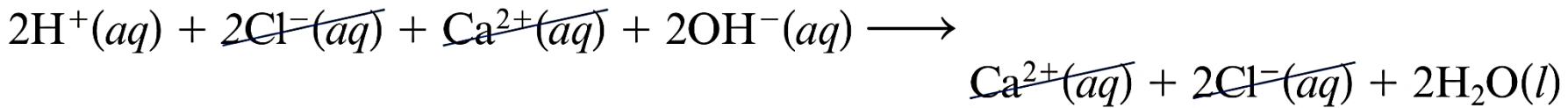
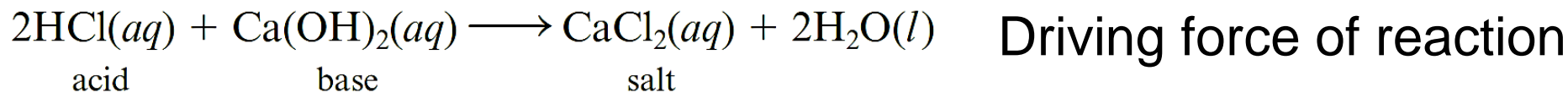
- ✓ The hydroxides of Groups 1A and 2A elements are strong bases. **Except** for beryllium hydroxide ( $\text{Be}(\text{OH})_2$ )
- ✓ Some weak acids:  $\text{CH}_3\text{COOH}$ ,  $\text{HNO}_2$ ,  $\text{HClO}$ ,  $\text{H}_3\text{PO}_4$ ,

Table 4.3 Common Strong Acids and Bases

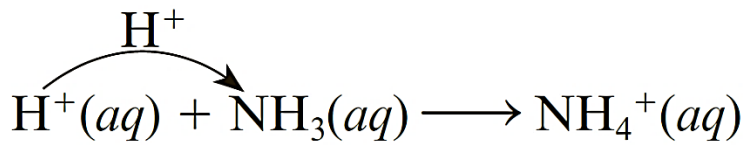
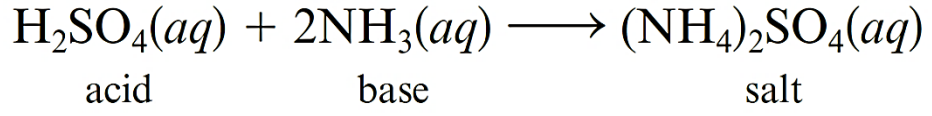
Strong Acids	Strong Bases
$\text{HClO}_4$	$\text{LiOH}$
$\text{H}_2\text{SO}_4$	$\text{NaOH}$
$\text{HI}$	$\text{KOH}$
$\text{HBr}$	$\text{Ca}(\text{OH})_2$
$\text{HCl}$	$\text{Sr}(\text{OH})_2$
$\text{HNO}_3$	$\text{Ba}(\text{OH})_2$

# ➤ Neutralization Reactions

- ✓ A **neutralization reaction** is a reaction of an acid and a base that results in an ionic compound (salt) and possibly water.
- ✓ Most ionic compounds other than hydroxides & oxides are salts

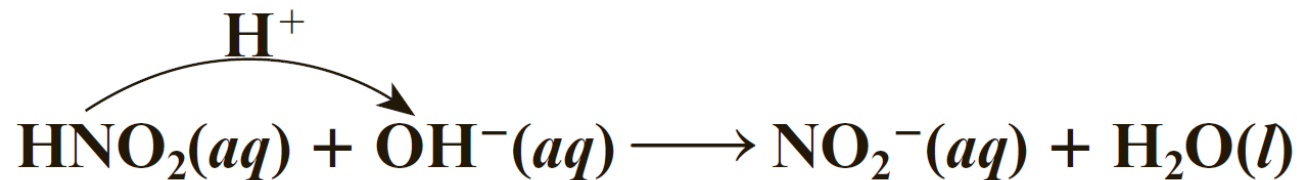
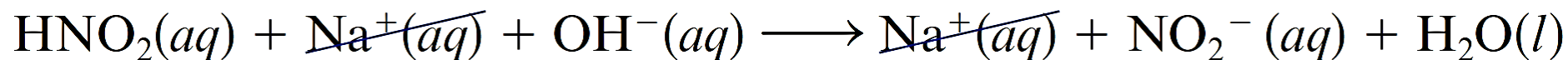
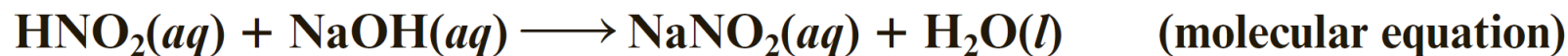


Reactions with  $\text{NH}_3$   
Do not produce  
 $\text{H}_2\text{O}$



## Example 4.5 Writing an Equation for a Neutralization

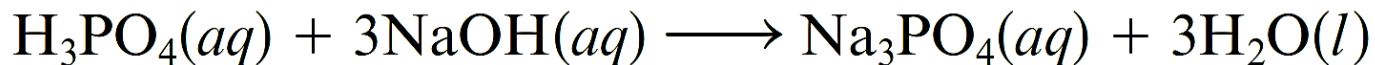
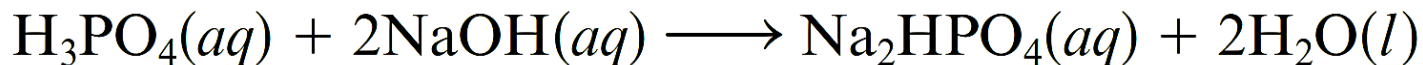
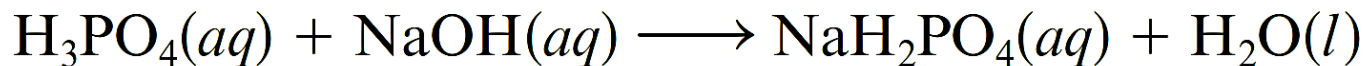
(Q) Write the molecular equation and then the net ionic equation for the neutralization of nitrous acid by sodium hydroxide, both in aqueous solution.



Exercise 4.5 Write the molecular equation and the net ionic equation for the neutralization of hydrocyanic acid, HCN, by lithium hydroxide, LiOH, both in aqueous solution

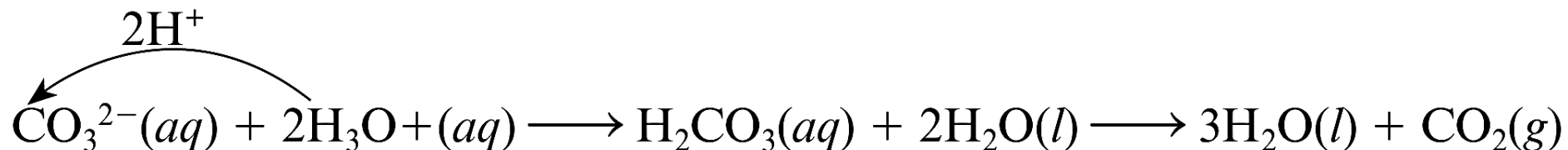
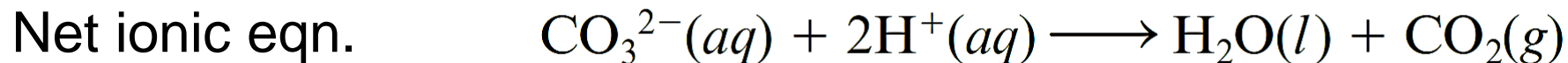
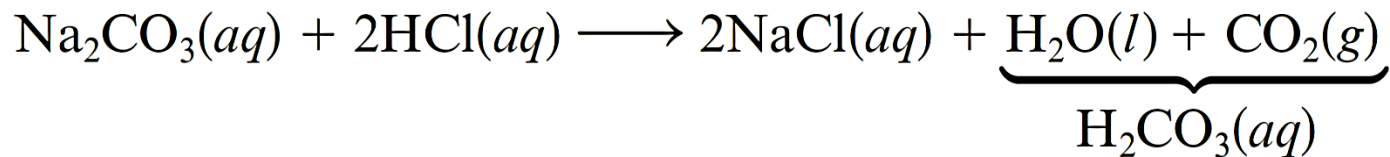
Exercise 4.6 Write molecular and net ionic equations for the successive neutralizations of each of the acidic hydrogens of sulfuric acid with potassium hydroxide.

- ✓ *monoprotic* acids: one acidic hydrogen; HCl, HNO<sub>3</sub>
- ✓ *polyprotic* acids: *two or more acidic hydrogens*; H<sub>2</sub>SO<sub>4</sub>, H<sub>3</sub>PO<sub>4</sub>
- ✓ H<sub>3</sub>PO<sub>4</sub> : triprotic acid
- ✓ By reacting this acid with different amounts of a base, you can obtain a series of salts:



- ✓ Salts such as NaH<sub>2</sub>PO<sub>4</sub> and Na<sub>2</sub>HPO<sub>4</sub> that have acidic hydrogen atoms and can undergo neutralization with bases are called ***acid salts***

## ➤ Acid–Base Reactions with Gas Formation

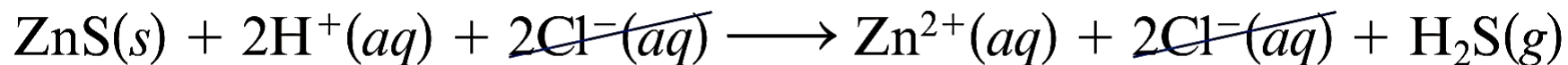


**Table 4.4** Some Ionic Compounds That Evolve Gases When Treated with Acids

Ionic Compound	Gas	Example
Carbonate ( $\text{CO}_3^{2-}$ )	$\text{CO}_2$	$\text{Na}_2\text{CO}_3 + 2\text{HCl} \longrightarrow 2\text{NaCl} + \text{H}_2\text{O} + \text{CO}_2$
Sulfite ( $\text{SO}_3^{2-}$ )	$\text{SO}_2$	$\text{Na}_2\text{SO}_3 + 2\text{HCl} \longrightarrow 2\text{NaCl} + \text{H}_2\text{O} + \text{SO}_2$
Sulfide ( $\text{S}^{2-}$ )	$\text{H}_2\text{S}$	$\text{Na}_2\text{S} + \text{H}_2\text{SO}_4 \longrightarrow \text{Na}_2\text{SO}_4 + \text{H}_2\text{S}$

## Example 4.6 Writing an Equation for a Reaction with Gas Formation

(Q) Write the molecular equation and the net ionic equation for the reaction of zinc sulfide with hydrochloric acid.



Exercise 4.7 Write the molecular equation and the net ionic equation for the reaction of calcium carbonate with nitric acid.

