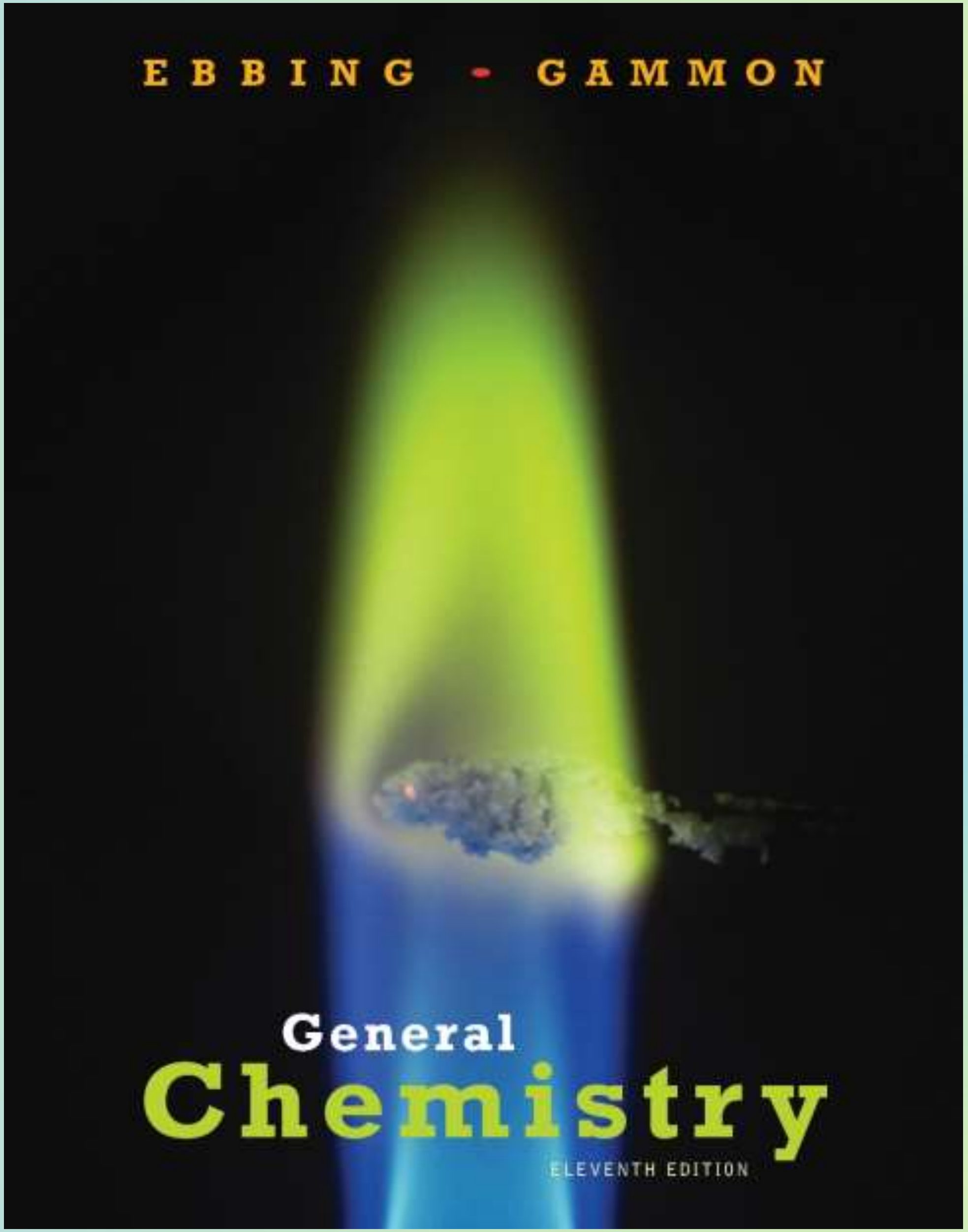


Chemical Reactions

©2017 Cengage Learning. All Rights Reserved. May not be copied, scanned, or duplicated, in whole or in part, except for use as permitted in a license distributed with a certain product or service or otherwise on a password-protected website for classroom use.

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.

Solution	Solvent	Solute
Soft drink (*l*)	H_2O	Sugar, CO_2
Air (*g*)	N_2	O_2, Ar, CH_4
Soft solder (*s*)	Pb	Sn

aqueous solutions of $KMnO_4$

4.1 Ionic Theory of Solutions and Solubility Rules

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

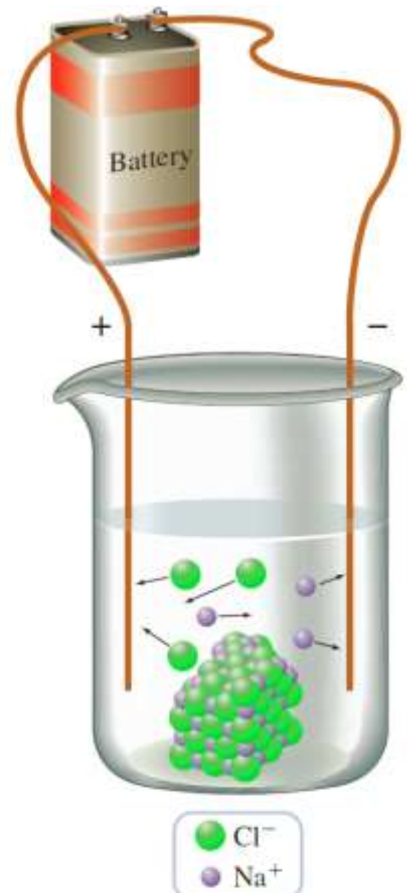
"Certain substances produce freely moving ions when they dissolve in water, and these ions conduct an electric current"

- ✓ Pure H_2O 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

(*a*)

$CuSO_4$ and water

No light

Molecular

(*b*)

Sugar and water

Ionic Compounds (Salts) in Water

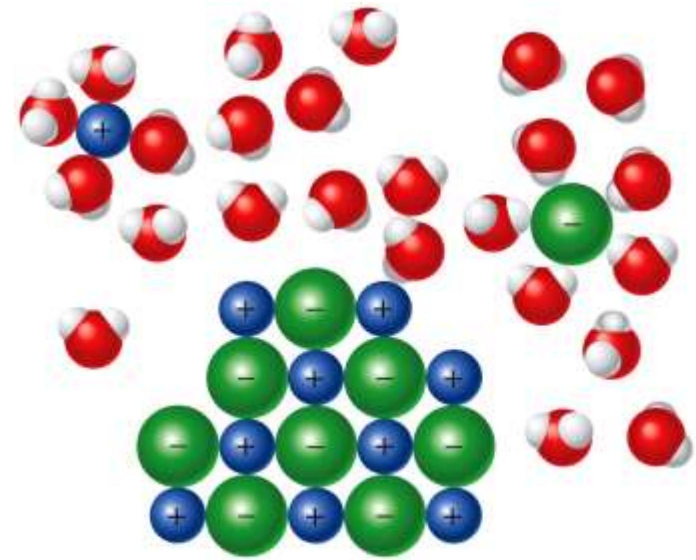
- Water molecules arrange themselves around ions and remove them from lattice.

Dissociation

- Salts break apart into ions when entering solution

Separated ions

- **Hydrated**
- Conduct electricity



$NaCl(s) \rightarrow Na^{+}(aq) + Cl^{-}(aq)$

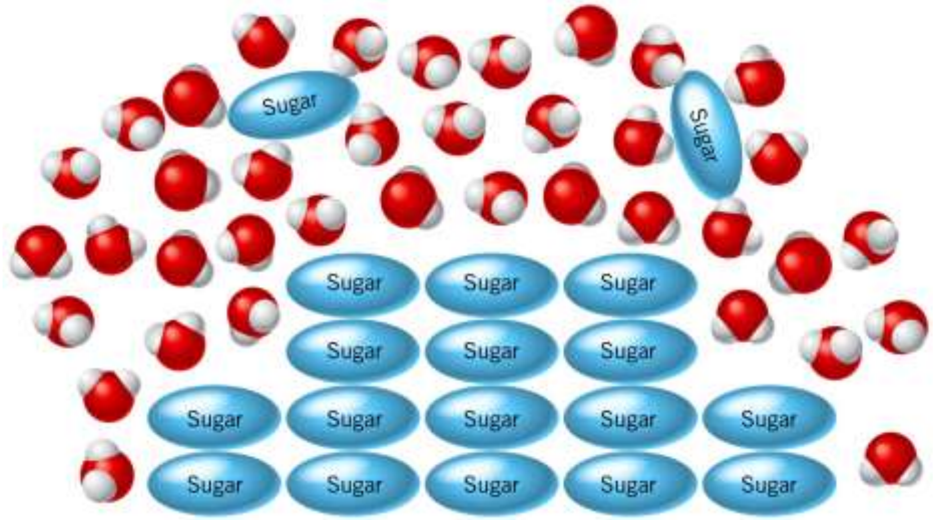
- **Note:** Polyatomic ions remain intact
  - **e.g.,** $KIO_3 \rightarrow K^{+} + IO_3^{-}$

(Q)How many ions form on the dissociation of Na_3PO_4?

(Q)How many ions form on the dissociation of $Al_2(SO_4)_3$?

Molecular Compounds In Water

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



Electrical Conductivity

Electrolyte

–Solutes 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_3

–Strong acids and bases, **e.g.,** $HClO_4$, HCl

Non-electrolyte

"A nonelectrolyte is a substance that dissolves in water to give a nonconducting or very poorly conducting solution

–Molecules remain intact in solution **e.g.,** Sugar (glucose, sucrose), Alcohol(Methanol, ethanol), Urea

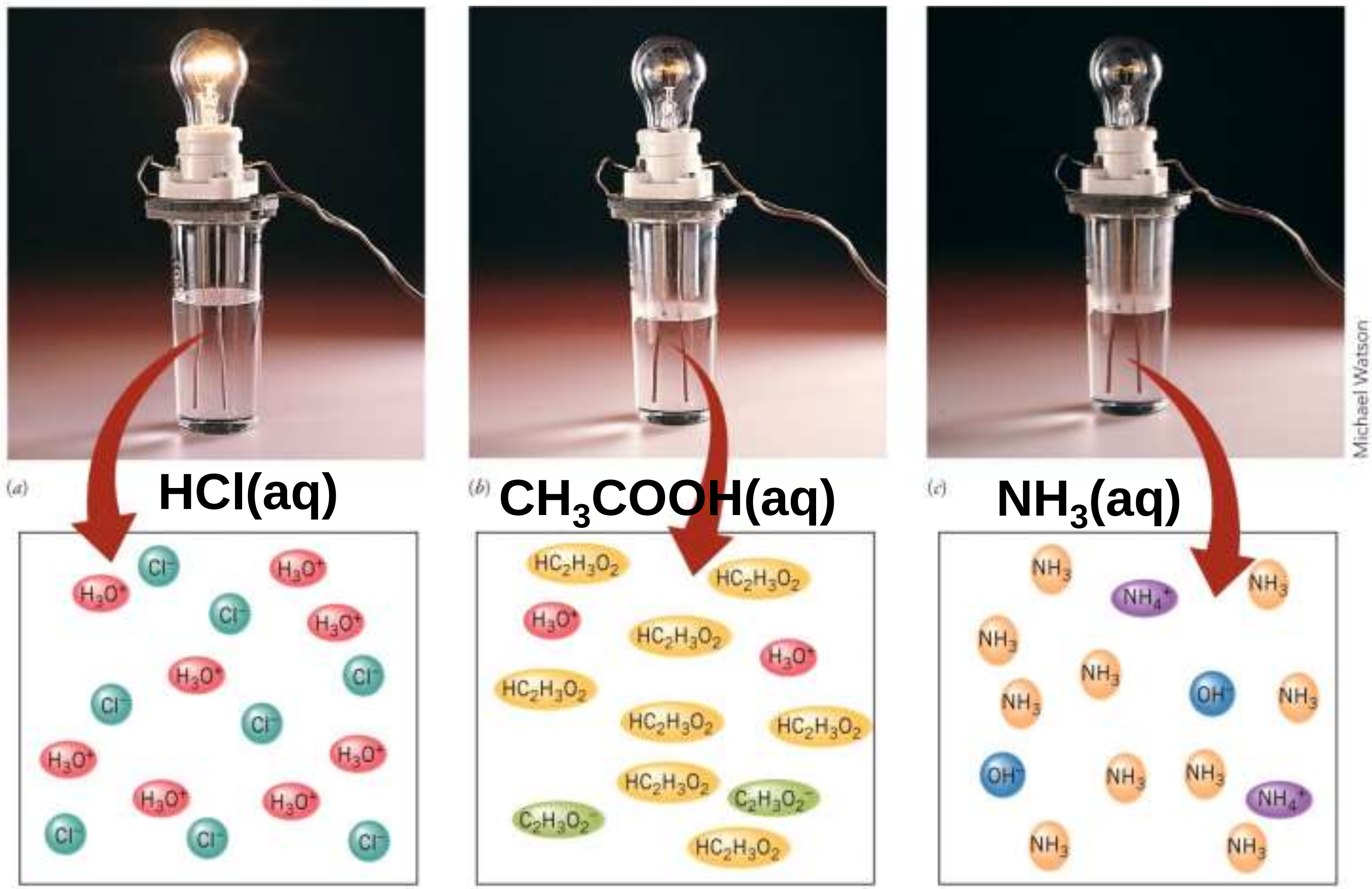
Table 4.3 Common Strong Acids and Bases

Strong Acids	Strong Bases
$HClO_4$	LiOH
H_2SO_4	NaOH
HI	KOH
HBr	$Ca(OH)_2$
HCl	$Sr(OH)_2$
HNO_3	$Ba(OH)_2$

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 (CH_3COOH), ammonia (NH_3)

$HCl(aq) \longrightarrow H^+(aq) + Cl^-(aq)$ $\qquad$ $NH_3(aq) + H_2O(l) \rightleftharpoons NH_4^+(aq) + OH^-(aq)$



➢ Solubility Rules

- ✓ Soluble: NaCl, CH_3CH_2OH, CH_3OH
- ✓ Insoluble: benzene (C_6H_6), hexane (C_6H_{14})

Table 4.1 Solubility Rules for Ionic Compounds

Rule	Applies to	Statement	Exceptions
1	Li^+, Na^+, K^+, NH_4^+	Group 1A and ammonium compounds are soluble.	—
2	$C_2H_3O_2^-$, NO_3^-	Acetates and nitrates are soluble.	—
3	Cl^-, Br^-, I^-	Most chlorides, bromides, and iodides are soluble.	AgCl, Hg_2Cl_2, $PbCl_2$, AgBr, $HgBr_2$, Hg_2Br_2, $PbBr_2$, AgI, HgI_2, Hg_2I_2, PbI_2
4	SO_4^{2-}	Most sulfates are soluble.	$CaSO_4$, $SrSO_4$, $BaSO_4$, Ag_2SO_4, Hg_2SO_4, $PbSO_4$
5	CO_3^{2-}	Most carbonates are insoluble.	Group 1A carbonates, $(NH_4)_2CO_3$
6	PO_4^{3-}	Most phosphates are insoluble.	Group 1A phosphates, $(NH_4)_3PO_4$
7	S^{2-}	Most sulfides are insoluble.	Group 1A sulfides, $(NH_4)_2S$
8	OH^-	Most hydroxides are insoluble.	Group 1A hydroxides, $Ca(OH)_2$, $Sr(OH)_2$, $Ba(OH)_2$

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

NH_4Cl, $MgBr_2$, H_2O, HCl, $Ca_3(PO_4)_2$, CH_3OH

Main-Group Elements

Main-Group Elements

Transition Metals

1 H 1.00794	
Atomic number	1
Symbol	H
Atomic mass	1.00794

	1 IA	2 IIA	3 IIIB	4 IVB	5 VB	6 VIB	7 VIIB	8	9 VIIIB	10	11 IB	12 IIB	13 IIIA	14 IVA	15 VA	16 VIA	17 VIIA	18 VIIIA
1	1 **H** 1.00794																	2 **He** 4.002602
2	3 **Li** 6.941	4 **Be** 9.012182											5 **B** 10.811	6 **C** 12.0107	7 **N** 14.0067	8 **O** 15.9994	9 **F** 18.9984032	10 **Ne** 20.1797
3	11 **Na** 22.98976928	12 **Mg** 24.3050											13 **Al** 26.9815386	14 **Si** 28.0855	15 **P** 30.973762	16 **S** 32.065	17 **Cl** 35.453	18 **Ar** 39.948
4	19 **K** 39.0983	20 **Ca** 40.078	21 **Sc** 44.955912	22 **Ti** 47.867	23 **V** 50.9415	24 **Cr** 51.9961	25 **Mn** 54.938045	26 **Fe** 55.845	27 **Co** 58.933195	28 **Ni** 58.6934	29 **Cu** 63.546	30 **Zn** 65.409	31 **Ga** 69.723	32 **Ge** 72.64	33 **As** 74.92160	34 **Se** 78.96	35 **Br** 79.904	36 **Kr** 83.798
5	37 **Rb** 85.4678	38 **Sr** 87.62	39 **Y** 88.90585	40 **Zr** 91.224	41 **Nb** 92.90638	42 **Mo** 95.94	43 **Tc** (98)	44 **Ru** 101.07	45 **Rh** 102.90550	46 **Pd** 106.42	47 **Ag** 107.8682	48 **Cd** 112.411	49 **In** 114.818	50 **Sn** 118.710	51 **Sb** 121.760	52 **Te** 127.60	53 **I** 126.90447	54 **Xe** 131.293
6	55 **Cs** 132.9054519	56 **Ba** 137.327	71 **Lu** 174.967	72 **Hf** 178.49	73 **Ta** 180.94788	74 **W** 183.84	75 **Re** 186.207	76 **Os** 190.23	77 **Ir** 192.217	78 **Pt** 195.084	79 **Au** 196.966569	80 **Hg** 200.59	81 **Tl** 204.3833	82 **Pb** 207.2	83 **Bi** 208.98040	84 **Po** (209)	85 **At** (210)	86 **Rn** (222)
7	87 **Fr** (223)	88 **Ra** (226)	103 **Lr** (262)	104 **Rf** (261)	105 **Db** (262)	106 **Sg** (266)	107 **Bh** (264)	108 **Hs** (277)	109 **Mt** (268)	110 **Ds** (281)	111 **Rg** (272)	112 **Uub** (285)	113 **Uut** (284)	114 **Uuq** (289)	115 **Uup** (288)	116 **Uuh** (291)		118 **Uuo** (294)

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

a. Hg_2Cl_2 b. KI c. lead(II) nitrate

Which of the following compounds are expected to be soluble in water? a. $Ca(C_2H_3O_2)_2$ b. $FeCO_3$ c. AgCl

a. NaBr b. $Ba(OH)_2$ c. calcium carbonate d. Ag_2SO_4

4.2 Molecular and Ionic Equations

- Molecular Equation:

$$Ca(OH)_2(aq) + Na_2CO_3(aq) \longrightarrow CaCO_3(s) + 2NaOH(aq)$$

- Complete Ionic Equation:

$$Ca^{2+}(aq) + 2OH^-(aq) + 2Na^+(aq) + CO_3^{2-}(aq) \longrightarrow CaCO_3(s) + 2Na^+(aq) + 2OH^-(aq)$$

- Net Ionic Equation:

spectator ions: OH^- and Na^+

$$Ca^{2+}(aq) + \cancel{2OH^-(aq)} + \cancel{2Na^+(aq)} + CO_3^{2-}(aq) \longrightarrow CaCO_3(s) + \cancel{2Na^+(aq)} + \cancel{2OH^-(aq)}$$

$$Ca^{2+}(aq) + CO_3^{2-}(aq) \longrightarrow CaCO_3(s)$$

- Molecular Equation:

$$Ca(NO_3)_2(aq) + K_2CO_3(aq) \longrightarrow CaCO_3(s) + 2KNO_3(aq)$$

- Complete Ionic Equation:

$$Ca^{2+}(aq) + \cancel{2NO_3^-(aq)} + \cancel{2K^+(aq)} + CO_3^{2-}(aq) \longrightarrow CaCO_3(s) + \cancel{2K^+(aq)} + \cancel{2NO_3^-(aq)}$$

- Net Ionic Equation:

$$Ca^{2+}(aq) + CO_3^{2-}(aq) \longrightarrow CaCO_3(s)$$

Example 4.2 Writing Net Ionic Equations

a. $2HClO_4(aq) + Ca(OH)_2(aq) \longrightarrow Ca(ClO_4)_2(aq) + 2H_2O(l)$

$$2H^+(aq) + \cancel{2ClO_4^-(aq)} + \cancel{Ca^{2+}(aq)} + 2OH^-(aq) \longrightarrow \cancel{Ca^{2+}(aq)} + \cancel{2ClO_4^-(aq)} + 2H_2O(l)$$

$$\mathbf{H^+(aq) + OH^-(aq) \longrightarrow H_2O(l)}$$

b. $HC_2H_3O_2(aq) + NaOH(aq) \longrightarrow NaC_2H_3O_2(aq) + H_2O(l)$

$$HC_2H_3O_2(aq) + \cancel{Na^+(aq)} + OH^-(aq) \longrightarrow \cancel{Na^+(aq)} + C_2H_3O_2^-(aq) + H_2O(l)$$

$$\mathbf{HC_2H_3O_2(aq) + OH^-(aq) \longrightarrow C_2H_3O_2^-(aq) + H_2O(l)}$$

c. $NH_3(aq) + HCl(aq) \longrightarrow NH_4Cl(aq)$

Ionic: $NH_3(aq) + H^+(aq) + Cl^-(aq) \rightarrow NH_4^+(aq) + Cl^-(aq)$

Net ionic: $NH_3(aq) + H^+(aq) \longrightarrow NH_4^+(aq)$

Write weak electrolytes in "molecular form"

✓ **Many ways to make PbI_2**

1. $Pb(NO_3)_2(aq) + 2KI(aq) \rightarrow PbI_2(s) + 2KNO_3(aq)$
2. $Pb(C_2H_3O_2)_2(aq) + 2NH_4I(aq) \rightarrow PbI_2(s) + 2NH_4C_2H_3O_2(aq)$

Different starting reagents Same net ionic equation

$Pb^{2+}(aq) + 2I^-(aq) \rightarrow PbI_2(s)$

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

a. $2HNO_3(aq) + Mg(OH)_2(s) \rightarrow 2H_2O(l) + Mg(NO_3)_2(aq)$

Ionic:

$2H^+(aq) + 2NO_3^-(aq) + Mg(OH)_2(s) \rightarrow 2H_2O(l) + Mg^{2+}(aq) + 2NO_3^-(aq)$

Net Ionic:

$2H^+(aq) + Mg(OH)_2(s) \rightarrow 2H_2O(l) + Mg^{2+}(aq)$

b. $Pb(NO_3)_2(aq) + Na_2SO_4(aq) \rightarrow PbSO_4(s) + 2NaNO_3(aq)$

Ionic:

$Pb^{2+}(aq) + 2NO_3^-(aq) + 2Na^+(aq) + SO_4^{2-}(aq) \rightarrow PbSO_4(s) + 2Na^+(aq) + 2NO_3^-(aq)$

Net Ionic:

$Pb^{2+}(aq) + SO_4^{2-}(aq) \rightarrow PbSO_4(s)$

(Q) Write the correct ionic equation for each:

$Pb(NO_3)_2(aq) + 2NH_4IO_3(aq) \rightarrow Pb(IO_3)_2(s) + 2NH_4NO_3(aq)$

$Pb^{2+}(aq) + 2NO_3^{-}(aq) + 2NH_4^{+}(aq) + 2IO_3^{-}(aq) \rightarrow$
$Pb(IO_3)_2(s) + 2NH_4^{+}(aq) + 2NO_3^{-}(aq)$

$2NaCl\ (aq) + Hg_2(NO_3)_2\ (aq) \rightarrow 2NaNO_3\ (aq) + Hg_2Cl_2\ (s)$

$2Na^{+}(aq) + 2Cl^{-}(aq) + Hg_2^{2+}(aq) + 2NO_3^{-}(aq) \rightarrow$
$2Na^{+}(aq) + 2NO_3^{-}(aq) + Hg_2Cl_2(s)$

(Q) Consider the following reaction :

$$Na_2SO_4(aq) + BaCl_2(aq) \rightarrow 2NaCl(aq) + BaSO_4(s)$$

Write the correct **ionic** equation.

A. $2Na^+(aq) + SO_4^{2-}(aq) + Ba^{2+}(aq) + Cl_2^{2-}(aq) \rightarrow 2Na^+(aq) + 2Cl^-(aq) + BaSO_4(s)$

B. $2Na^+(aq) + SO_4^{2-}(aq) + Ba^{2+}(aq) + 2Cl^-(aq) \rightarrow 2Na^+(aq) + 2Cl^-(aq) + BaSO_4(s)$

C. $2Na^+(aq) + SO_4^{2-}(aq) + Ba^{2+}(aq) + Cl_2^{2-}(aq) \rightarrow 2Na^+(aq) + 2Cl^-(aq) + Ba^{2+}(s) + SO_4^{2-}(s)$

D. $Ba^{2+}(aq) + SO_4^{2-}(aq) \rightarrow BaSO_4(s)$

E. $Ba^{2+}(aq) + SO_4^{2-}(aq) \rightarrow Ba^{2+}(s) + SO_4^{2-}(s)$

Consider the following molecular equation:

$$(NH_4)_2SO_4(aq) + Ba(CH_3CO_2)_2(aq) \rightarrow 2NH_4CH_3CO_2(aq) + BaSO_4(s)$$

Write the correct **net** ionic equation.

A. $Ba^{2+}(aq) + SO_4^{2-}(aq) \rightarrow BaSO_4(s)$

B. $2NH_4^+(aq) + 2CH_3CO_2^-(aq) \rightarrow 2NH_4CH_3CO_2(s)$

C. $Ba^{2+}(aq) + SO_4^{2-}(aq) \rightarrow BaSO_4(aq)$

D. $2NH_4^+(aq) + Ba^{2+}(aq) + SO_4^{2-}(aq) + 2CH_3CO_2^-(aq) \rightarrow 2NH_4^+(aq) + 2CH_3CO_2^-(aq) + BaSO_4(s)$

E. $2NH_4^+(aq) + 2CH_3CO_2^-(aq) \rightarrow 2NH_4CH_3CO_2(aq)$

What is the net ionic equation for the following reaction?

Molecular equation

$Mg(OH)_2(s) + 2HC_2H_3O_2(aq) \longrightarrow$

$Mg(C_2H_3O_2)_2(aq) + 2H_2O$

Ionic equation

$Mg(OH)_2(s) + 2HC_2H_3O_2(aq) \longrightarrow$

$Mg^{2+}(aq) + 2H_2O + 2C_2H_3O_2^{-}(aq)$

- 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.

$$MgCl_2(aq) + 2AgNO_3(aq) \rightarrow 2AgCl(s) + Mg(NO_3)_2(aq)$$

- ✓ 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.

$NaCl + Fe(NO_3)_2 \rightarrow NaNO_3 + FeCl_2$ (not balanced)

$2NaCl + Fe(NO_3)_2 \rightarrow 2NaNO_3 + FeCl_2$ (balanced)

soluble soluble soluble soluble

$2Na^+ + 2Cl^- + Fe^{2+} + 2NO_3^- \rightarrow 2Na^+ + 2NO_3^- + Fe^{2+} + 2Cl^-$

$\mathbf{NaCl(\mathit{aq}) + Fe(NO_3)_2(\mathit{aq}) \rightarrow NR}$

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

$$Al_2(SO_4)_3 + NaOH \rightarrow Al(OH)_3 + Na_2SO_4 \quad \text{(not balanced)}$$

$$Al_2(SO_4)_3 + 6NaOH \rightarrow 2Al(OH)_3 + 3Na_2SO_4 \quad \text{(balanced)}$$

$$2Al^{3+}(aq) + \cancel{3SO_4^{2-}(aq)} + \cancel{6Na^+(aq)} + 6OH^-(aq) \longrightarrow 2Al(OH)_3(s) + \cancel{6Na^+(aq)} + \cancel{3SO_4^{2-}(aq)}$$

$$Al^{3+}(aq) + 3OH^-(aq) \rightarrow Al(OH)_3(s)$$

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	$HC_2H_3O_2$	Found in vinegar
Acetylsalicylic acid	$HC_9H_7O_4$	Aspirin
Ascorbic acid	$H_2C_6H_6O_6$	Vitamin C
Citric acid	$H_3C_6H_5O_7$	Found in lemon juice
Hydrochloric acid	HCl	Found in gastric juice (digestive fluid in stomach)
Sulfuric acid	H_2SO_4	Battery acid
Bases		
Ammonia	NH_3	Aqueous solution used as a household cleaner
Calcium hydroxide	$Ca(OH)_2$	Slaked lime (used in mortar for building construction)
Magnesium hydroxide	$Mg(OH)_2$	Milk of magnesia (antacid and laxative)
Sodium hydroxide	$NaOH$	Drain cleaners, oven cleaners

➢ Definitions of Acid and Base

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

$$HNO_3(aq) \xrightarrow{H_2O} H^+(aq) + NO_3^-(aq)$$

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

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

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

✓ 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.*

$$H^+$$

$$\underset{\text{base}}{NH_3(aq)} + \underset{\text{acid}}{H_2O(l)} \rightleftharpoons NH_4^+(aq) + OH^-(aq)$$

- ✓ The dissolution of HNO_3 in water is actually a proton-transfer reaction.

$$HNO_3(aq) \xrightarrow{H_2O} H^+(aq) + NO_3^-(aq)$$

$$\overbrace{\underset{\text{acid}}{HNO_3(aq)} + \underset{\text{base}}{H_2O(l)}}^{H^+} \longrightarrow NO_3^-(aq) + H_3O^+(aq)$$

Hydronium ion

- ✓ The Arrhenius definitions and those of Brønsted and Lowry are essentially equivalent for aqueous solutions

- ✓ NaOH and NH_3 are bases in the Arrhenius view because they increase the percentage of OH^- ion in the aqueous solution.

- ✓ NaOH and 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.*

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

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

Table 4.3 Common Strong Acids and Bases

Strong Acids	Strong Bases
$HClO_4$	$LiOH$
H_2SO_4	$NaOH$
HI	KOH
HBr	$Ca(OH)_2$
HCl	$Sr(OH)_2$
HNO_3	$Ba(OH)_2$

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

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

- ✓ The hydroxides of Groups 1A and 2A elements are strong bases. **Except** for $Be(OH)_2$ and $Mg(OH)_2$
- ✓ Some weak acids: CH_3COOH, HNO_2, $HClO$, H_3PO_4,

➢ 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

$$\underset{\text{acid}}{2HCl(aq)} + \underset{\text{base}}{Ca(OH)_2(aq)} \longrightarrow \underset{\text{salt}}{CaCl_2(aq)} + 2H_2O(l)$$

Driving force of reaction

$$2H^+(aq) + \cancel{2Cl^-(aq)} + \cancel{Ca^{2+}(aq)} + 2OH^-(aq) \longrightarrow \cancel{Ca^{2+}(aq)} + \cancel{2Cl^-(aq)} + 2H_2O(l)$$

$$H^+(aq) + OH^-(aq) \xrightarrow{} H_2O(l) \quad (H^+)$$

$$\underset{\text{acid}}{HCN(aq)} + \underset{\text{base}}{KOH(aq)} \longrightarrow \underset{\text{salt}}{KCN(aq)} + H_2O(l)$$

$$HCN(aq) + OH^-(aq) \longrightarrow CN^-(aq) + H_2O(l) \quad (H^+)$$

Reactions with NH_3 Do not produce H_2O

$$\underset{\text{acid}}{H_2SO_4(aq)} + \underset{\text{base}}{2NH_3(aq)} \longrightarrow \underset{\text{salt}}{(NH_4)_2SO_4(aq)}$$

$$H^+(aq) + NH_3(aq) \longrightarrow NH_4^+(aq) \quad (H^+)$$

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.

$$HNO_2(aq) + NaOH(aq) \longrightarrow NaNO_2(aq) + H_2O(l) \qquad \textbf{(molecular equation)}$$

$$HNO_2(aq) + \cancel{Na^+(aq)} + OH^-(aq) \longrightarrow \cancel{Na^+(aq)} + NO_2^-(aq) + H_2O(l)$$

(net ionic equation) $HNO_2(aq) + OH^-(aq) \longrightarrow NO_2^-(aq) + H_2O(l)$

$$\mathbf{H^+}$$

$$\mathbf{HNO_2(aq) + OH^-(aq) \longrightarrow NO_2^-(aq) + H_2O(l)}$$

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_3
- ✓ *polyprotic* acids: *two or more acidic hydrogens;* H_2SO_4, H_3PO_4
- ✓ H_3PO_4 : triprotic acid
- ✓ By reacting this acid with different amounts of a base, you can obtain a series of salts:

$$H_3PO_4(aq) + NaOH(aq) \longrightarrow NaH_2PO_4(aq) + H_2O(l)$$

$$H_3PO_4(aq) + 2NaOH(aq) \longrightarrow Na_2HPO_4(aq) + 2H_2O(l)$$

$$H_3PO_4(aq) + 3NaOH(aq) \longrightarrow Na_3PO_4(aq) + 3H_2O(l)$$

- ✓ Salts such as NaH_2PO_4 and Na_2HPO_4 that have acidic hydrogen atoms and can undergo neutralization with bases are called ***acid salts***

Acid–Base Reactions with Gas Formation

$$Na_2CO_3(aq) + 2HCl(aq) \longrightarrow 2NaCl(aq) + \underbrace{H_2O(l) + CO_2(g)}_{H_2CO_3(aq)}$$

Net ionic eqn. $$CO_3^{2-}(aq) + 2H^+(aq) \longrightarrow H_2O(l) + CO_2(g)$$

$$CO_3^{2-}(aq) + 2H_3O^+(aq) \longrightarrow H_2CO_3(aq) + 2H_2O(l) \longrightarrow 3H_2O(l) + CO_2(g)$$

2H$^+$

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

Ionic Compound	Gas	Example
Carbonate (CO_3^{2-})	CO_2	$Na_2CO_3 + 2HCl \longrightarrow 2NaCl + H_2O + CO_2$
Sulfite (SO_3^{2-})	SO_2	$Na_2SO_3 + 2HCl \longrightarrow 2NaCl + H_2O + SO_2$
Sulfide (S^{2-})	H_2S	$Na_2S + H_2SO_4 \longrightarrow Na_2SO_4 + H_2S$

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.

$$ZnS(s) + 2HCl(aq) \longrightarrow ZnCl_2(aq) + H_2S(g)$$

$$ZnS(s) + 2H^+(aq) + \cancel{2Cl^-(aq)} \longrightarrow Zn^{2+}(aq) + \cancel{2Cl^-(aq)} + H_2S(g)$$

$$ZnS(s) + 2H^+(aq) \longrightarrow Zn^{2+}(aq) + H_2S(g)$$

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

$$CaCO_3\,(s) + 2HNO_3\,(aq) \rightarrow Ca(NO_3)_2\,(aq) + H_2CO_3\,(aq)$$

$$CaCO_3(s) + 2H^+(aq) + 2NO_3^-(aq) \rightarrow Ca^{2+} + 2NO_3^-(aq) + H_2O(l) + CO_2(g)$$

$$CaCO_3(s) + 2H^+(aq) \rightarrow Ca^{2+} + H_2O(l) + CO_2(g)$$