Chapter 5

Chemical Reactions and Equations

Introduction

- Chemical reactions occur all around us.
- How do we make sense of these changes? What patterns can we find?

Chapter 5 Topics

1. What happens in a chemical reaction?
2. How do we know a chemical reaction occurs?
3. Writing chemical equations
4. Predicting chemical reactions
5. Representing reactions in aqueous solution

5.1 What is a Chemical Reaction

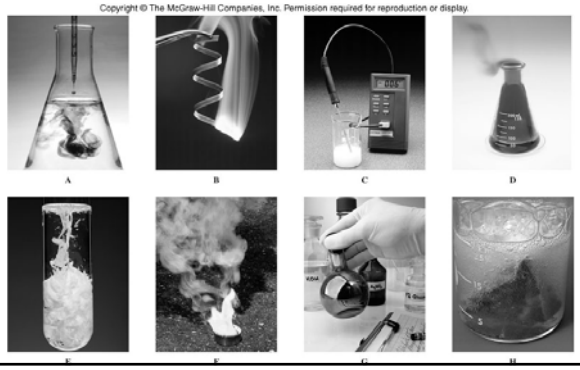
- A chemical reaction is a chemical change.
- A chemical reaction occurs when one or more substances is converted into one or more new substances.

- Reactant – A substance that we start with that undergoes a change
- Product – A new substance that forms during the reaction.

5.2 How do We Know a Chemical Reaction Occurs?

- What observations might indicate that a chemical reaction has taken place?

What <u>clues</u> tell you a reaction is likely occurring? (Fig. 5.8)

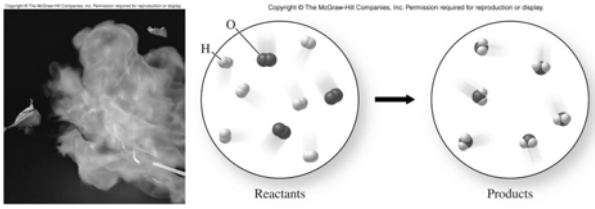


5.3 Writing Chemical Equations

- **A chemical equation is a symbolic representation of a chemical reaction.**
- **A chemical equation shows:**
  - **the formulas for reactants and products**
  - **the physical states of each substance (*s, l, g, aq*)**
  - **relative numbers of reactants that combine and products that form**
  - **special conditions required for the reaction, such as constant heating.**

Chemical Reactions

- **When hydrogen gas is ignited in the presence of oxygen, an explosive reaction occurs producing gaseous water molecules.**
- **Is mass conserved?**



Writing a Chemical Equation

- **When a powdered mixture of aluminum metal and iron(III) oxide is heated, it reacts to form liquid iron metal and aluminum(III) oxide.**

$Al(s) + Fe_2O_3(s) \rightarrow Al_2O_3(s) + Fe(l)$

The "thermite" reaction

Chemical Equations Must be Balanced

- $Al(s) + Fe_2O_3(s) \rightarrow Al_2O_3(s) + Fe(l)$

Atoms in Reactants $Al(s) + Fe_2O_3(s)$		Atoms in Products $Al_2O_3(s) + Fe(l)$	
1 Al		2 Al	
3 O		3 O	
2 Fe		1 Fe	

- **Is this equation balanced?**

Balance Equations with Coefficients

- $Al(s) + Fe_2O_3(s) \rightarrow Al_2O_3(s) + Fe(l)$
- **We balance the atoms in equations with coefficients.**
  - **The aluminum atoms are not balanced so we place a coefficient of 2 in front of the Al reactant:**

$$2Al(s) + Fe_2O_3(s) \rightarrow Al_2O_3(s) + Fe(l)$$

  - **The iron atoms are not balanced so we place a coefficient of 2 in front of the Fe product:**

$$2Al(s) + Fe_2O_3(s) \rightarrow Al_2O_3(s) + 2Fe(l)$$

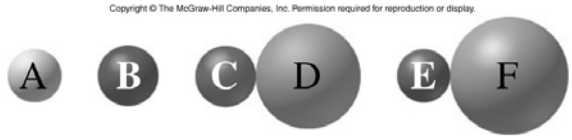
Atoms in Reactants $2Al(s) + Fe_2O_3(s)$		Atoms in Products $Al_2O_3(s) + 2Fe(l)$	
2 Al		2 Al	
3 O		3 O	
2 Fe		2 Fe	

Balance the Following Equations:

- $C_2H_4(g) + O_2(g) \rightarrow CO_2(g) + H_2O(g)$
- $CH_3OH(l) + O_2(g) \rightarrow CO_2(g) + H_2O(g)$
- **Practice: Examples 5.2, 5.3, 5.4**

5.4 Predicting Chemical Reactions

- **Since chemical reactions are rearrangements of atoms, let's look at the possible rearrangements for the following two elements and two compounds.**
  - **A and B are elements, either monatomic or diatomic.**
  - **C, D, E, and F might be atoms, monatomic ions, polyatomic ions**



Each compound could react to form its elements:

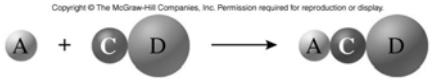
Example: $NH_4Cl(s) \longrightarrow NH_3(g) + HCl(g)$

Compound AB could react similarly.

The elements could combine to form a compound:

Example: $Zn(s) + Cl_2(g) \longrightarrow ZnCl_2(s)$

Similarly, an element could combine with a compound to form a more complex compound:



Example: $H_2(g) + CO(g) \longrightarrow H_2CO(g)$

An element could react with a compound to form a new element and a new compound:

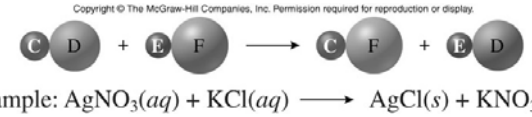
Example: $Zn(s) + CuCl_2(aq) \longrightarrow Cu(s) + ZnCl_2(aq)$

In the example, why did zinc displace copper instead of chlorine?

Two compounds can combine to form one new compound:

Example: $CaO(s) + SO_2(g) \longrightarrow CaSO_3(s)$

Two compounds can react to form two new compounds:



Example: $AgNO_3(aq) + KCl(aq) \longrightarrow AgCl(s) + KNO_3(aq)$

In the example, why did silver ion combine with chloride ion instead of potassium ion?

Summary of Reactions

- **All of the combinations we looked at fall into one of these four categories:**

Reactants	Products
1 compound	2 elements (or smaller compounds)
2 elements or compounds	1 compound
1 element and 1 compound	1 element and 1 compound
2 compounds	2 compounds

Summary of Reactions

- **These four <u>categories</u> have names:**

TABLE 5.1 Classes of Chemical Reactions

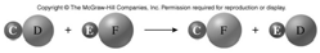
Class	Reactants	Products	Example
Decomposition	1 compound	2 elements (or smaller compounds)	$CD \longrightarrow C + D$
Combination	2 elements or compounds	1 compound	$A + B \longrightarrow AB$
Single-displacement	1 element and 1 compound	1 element and 1 compound	$A + CD \longrightarrow C + AD$
Double-displacement	2 compounds	2 compounds	$CD + EF \longrightarrow CF + ED$

Classify each of the following reactions:

Example: $NH_4Cl(s) \longrightarrow NH_3(g) + HCl(g)$

Example: $Zn(s) + Cl_2(g) \longrightarrow ZnCl_2(s)$

Example: $Zn(s) + CuCl_2(aq) \longrightarrow Cu(s) + ZnCl_2(aq)$



Example: $AgNO_3(aq) + KCl(aq) \longrightarrow AgCl(s) + KNO_3(aq)$

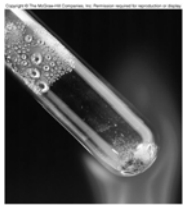
Classify the following reactions, based on the changes happening at an atomic/molecular level.

1. $AlF_3(aq) + 3H_2O(l) \rightarrow Al(OH)_3(s) + 3HF(aq)$
2. $BaCl_2(aq) + Na_2SO_4(aq) \rightarrow BaSO_4(s) + 2NaCl(aq)$
3. $Ca(OH)_2(s) \rightarrow CaO(s) + H_2O(g)$
4. $Ca(s) + 2H_2O(l) \rightarrow Ca(OH)_2(aq) + H_2(g)$
5. $CaO(s) + CO_2(g) \rightarrow CaCO_3(s)$
6. $Cl_2(aq) + 2NaI(aq) \rightarrow 2NaCl(aq) + I_2(aq)$
7. $Cu(s) + 2AgNO_3(aq) \rightarrow Cu(NO_3)_2(aq) + 2Ag(s)$
8. $Fe(s) + 2HCl(aq) \rightarrow FeCl_2(aq) + H_2(g)$
9. $H_2SO_3(aq) \rightarrow H_2O(l) + SO_2(g)$
10. $2HgO(s) \rightarrow 2Hg(l) + O_2(g)$
11. $KOH(aq) + HNO_3(aq) \rightarrow KNO_3(aq) + H_2O(l)$
12. $4Li(s) + O_2(g) \rightarrow 2Li_2O(s)$
13. $Na_2S(aq) + 2HCl(aq) \rightarrow 2NaCl(aq) + H_2S(g)$
14. $NH_3(g) + HCl(g) \rightarrow NH_4Cl(s)$
15. $NiCO_3(s) \rightarrow NiO(s) + CO_2(g)$
16. $P_4(s) + 10F_2(g) \rightarrow 4PF_5(g)$

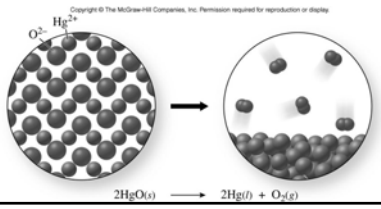
Decomposition Reactions ($CD \rightarrow C + D$)

- In a <u>decomposition</u> <u>reaction</u>, a single compound breaks down into elements and/or simpler compounds.

$2HgO(s) \rightarrow 2Hg(l) + O_2(g)$



<u>Rxn</u>

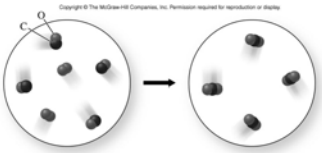


Predicting Products

- **Predict the products and balance the equation for the following decomposition reaction.**
  - **Platinum(IV) chloride decomposes to its elements:**
- **$PtCl_4(s) \rightarrow$**

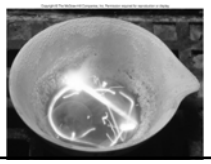
Combination Reactions (A + B → AB)

- **During a <u>combination</u> reaction, two substances combine to form a single compound.**
- **$2CO(g) + O_2(g) \rightarrow 2CO_2(g)$**



Predicting Products

- **We can often predict the products of combination reactions involving metal and nonmetal element reactants.**
- **Predict the product and balance the following equation:**
- **$Al(s) + Br_2(l) \rightarrow$**

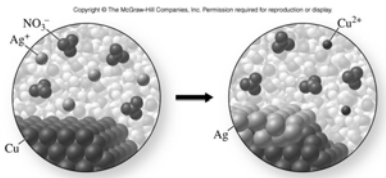


Rxn

Single-Displacement Reactions (A + CD → AD + C)

- In a <u>single</u>-<u>displacement</u>, a free element displaces another element from a compound to produce a different compound and another free element.

$Cu(s) + 2AgNO_3(aq) \rightarrow Cu(NO_3)_2(aq) + 2Ag(s)$



Single-Displacement Reactions

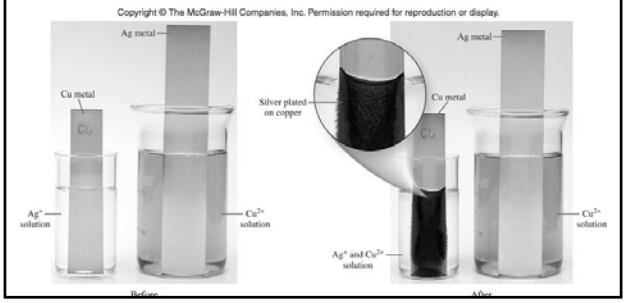
- **$2Al(s) + Fe_2O_3(s) \rightarrow Al_2O_3(s) + 2Fe(l)$**

- **$Fe(s) + CuO(s) \rightarrow FeO(s) + Cu(s)$**

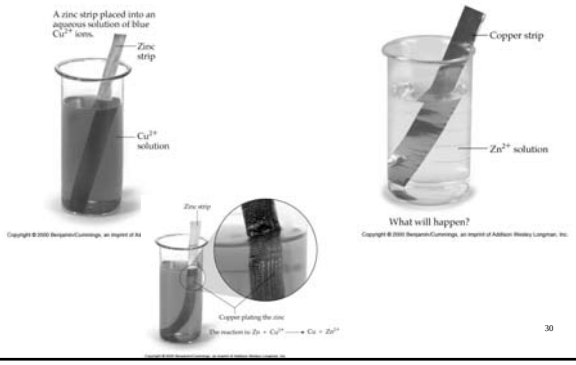
- **What happens to the charge on the metal doing the displacing?**

Predicting Single-Displacement Reactions

- **Does copper displace silver or does silver displace copper? Which is more active?** <u>rxn</u>

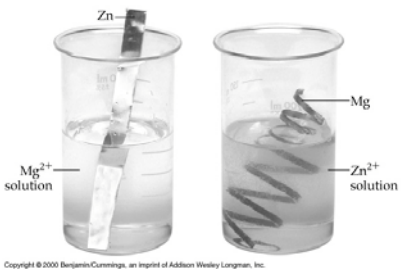


Which is more active, zinc or copper?



Which is more active, zinc or magnesium?

Test to find out which metal is more active Zn or Mg



Relative Activities

- **Cu > Ag**
- **Zn > Cu**
- **Mg > Zn**

The Activity Series

Will aluminum displace H^+?

$Mg(s) + 2HCl(aq) \rightarrow MgCl_2(aq) + H_2(g)$

Rxn

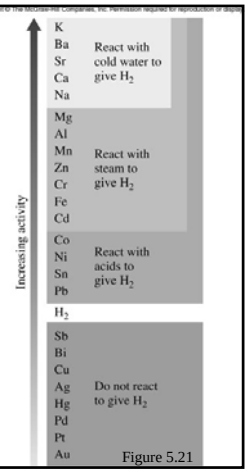
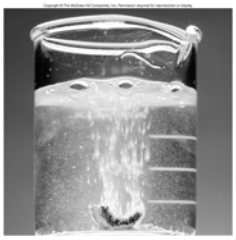


Figure 5.21

The Activity Series

- Write a balanced equation for the reaction of calcium metal with water.



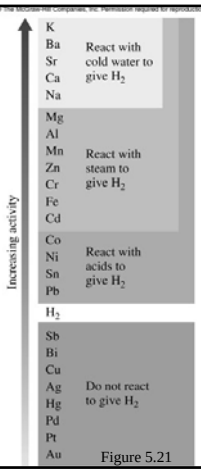


Figure 5.21

Double-Displacement Reactions (CD + EF → CF + ED)

- **In a double-displacement reaction, two compounds exchange ions to form two new compounds.**
- **There are three types:**
  - **Precipitation Reactions**
  - **Gas Formation Reactions**
  - **Acid-Base Neutralization Reactions**

Double-Displacement Reactions Precipitation Reactions

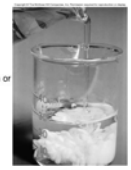
- In a precipitation reaction, an insoluble solid called a precipitate is formed.
- $BaCl_2(aq) + Na_2SO_4(aq) \rightarrow BaSO_4(s) + 2NaCl(aq)$

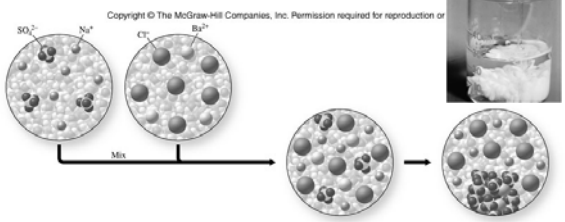
What is the white solid in the beaker?

Double-Displacement Reactions
<u>Precipitation Reactions</u>

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

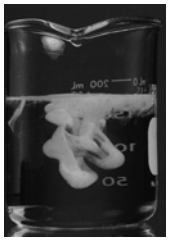
- Which ions undergo a chemical change?





Precipitation Reactions

$AgNO_3(aq) + NaCl(aq) \rightarrow AgCl(s) + NaNO_3(aq)$



<u>Molecular Scale</u>

Predicting Precipitation Reactions

- How do we know if a compound is insoluble?
- See solubility table in text or in back of lab manual.

TABLE 5.3 Rules Used to Predict the Solubility of Ionic Compounds

Ions	Rule
Na^+, K^+, NH_4^+ (and other alkali metal ions)	Most compounds of alkali metal and ammonium ions are soluble.
NO_3^-, $CH_3CO_2^-$	All nitrates and acetates are soluble.
SO_4^{2-}	Most sulfates are soluble. Exceptions are $BaSO_4$, $SrSO_4$, $PbSO_4$, $CaSO_4$, Hg_2SO_4, and Ag_2SO_4.
Cl^-, Br^-, I^-	Most chlorides, bromides, and iodides are soluble. Exceptions are AgX, Hg_2X_2, PbX_2, and HgI_2. (X = Cl, Br, or I.)
Ag^+	Silver compounds, except $AgNO_3$ and $AgClO_4$, are insoluble. $AgCH_3CO_2$ is slightly soluble.
O^{2-}, OH^-	Oxides and hydroxides are insoluble. Exceptions are alkali metal hydroxides, $Ba(OH)_2$, $Sr(OH)_2$, and $Ca(OH)_2$ (somewhat soluble).
S^{2-}	Sulfides are insoluble. Exceptions are compounds of Na^+, K^+, NH_4^+ and the alkaline earth metal ions.
CrO_4^{2-}	Most chromates are insoluble. Exceptions are compounds of Na^+, K^+, NH_4^+, Mg^{2+}, Ca^{2+}, Al^{3+}, and Ni^{2+}.
CO_3^{2-}, PO_4^{3-}, SO_3^{2-}, SiO_3^{2-}	Most carbonates, phosphates, sulfites, and silicates are insoluble. Exceptions are compounds of Na^+, K^+, and NH_4^+.

Predicting Precipitation Reactions

- Memorize the first four rules:

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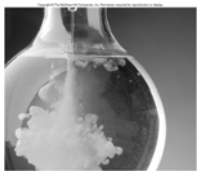
S^{2-}	Sulfides are insoluble. Exceptions are compounds of Na^+, K^+, NH_4^+ and the alkaline earth metal ions.
CrO_4^{2-}	Most chromates are insoluble. Exceptions are compounds of Na^+, K^+, NH_4^+, Mg^{2+}, Ca^{2+}, Al^{3+}, and Ni^{2+}.
CO_3^{2-}, PO_4^{3-}, SO_3^{2-}, SiO_3^{2-}	Most carbonates, phosphates, sulfites, and silicates are insoluble. Exceptions are compounds of Na^+, K^+, and NH_4^+.

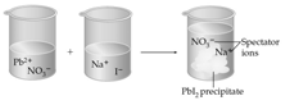
Predicting Precipitation Reactions

- Predict the products of the reaction, write phases, and then balance the equation:

$Pb(NO_3)_2(aq) + KI(aq) \rightarrow$



Predicting Precipitation Reactions



Group Work

Given that a precipitate forms in this reaction, predict the products and their phases, and balance the equation.

$BaCl_2(aq) + Na_2CrO_4(aq) \rightarrow$?

Rxn

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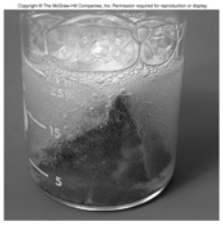
Double-Displacement Reactions
Gas-Formation Reactions

- In some double-displacement reactions, a gas is formed, which helps drive the reaction to completion.
- $CaCO_3(s) + 2HCl(aq) \rightarrow CaCl_2(aq) + H_2CO_3(aq)$
- $CaCO_3(s) + 2HCl(aq) \rightarrow CaCl_2(aq) + H_2O(l) + CO_2(g)$

Metal carbonates react with acids to form carbonic acid, which decomposes to carbon dioxide gas and water.



Acid Rain deteriorated this sculpture

Acid reacts with the calcium carbonate in the structure.

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Double-Displacement Reactions
Gas-Formation Reactions

- A similar reaction occurs when a metal sulfite reacts with an acid:

- $MgSO_3(s) + 2HCl(aq) \rightarrow MgCl_2(aq) + H_2SO_3(aq)$
- $MgSO_3(s) + 2HCl(aq) \rightarrow MgCl_2(aq) + H_2O(l) + SO_2(g)$

Metal sulfites react with acids to form sulfurous acid, which decomposes to sulfur dioxide gas and water.

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Double-Displacement Reactions
Acid-Base Neutralization Reactions

- **In an acid-base neutralization reaction, the driving force is the formation of H_2O, a molecular compound.**

- **$HCl(aq) + NaOH(aq) \rightarrow NaCl(aq) + H_2O(l)$**

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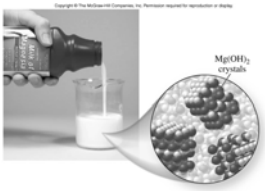
Double-Displacement Reactions
Acid-Base Neutralization Reactions

- **Complete the following reaction:**

$HCl(aq) + Mg(OH)_2(s) \rightarrow$



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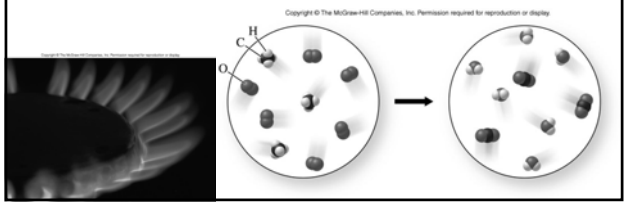
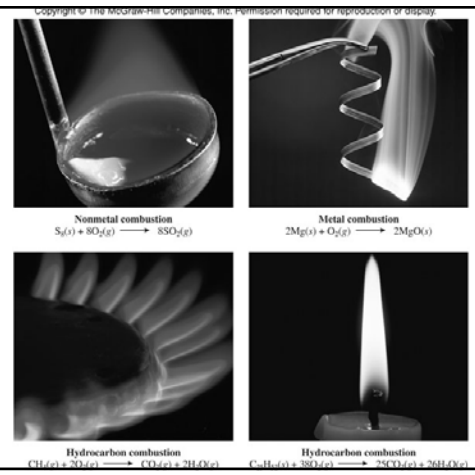
Combustion Reactions

- A <u>combustion</u> reaction is a 5th type of reaction that does not fall into one of the earlier categories.
- In a combustion reaction, a substance reacts with oxygen in a reaction that burns to produce a flame.

$$CH_4(g) + 2O_2(g) \rightarrow CO_2(g) + 2H_2O(g)$$





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Combustion of Hydrocarbons

- The most common <u>combustion</u> reactions involve the burning of a hydrocarbon, or a hydrocarbon containing oxygen. The products are always carbon dioxide and water.

$$2C_8H_{18}(g) + 25O_2(g) \rightarrow 16CO_2(g) + 18H_2O(g)$$

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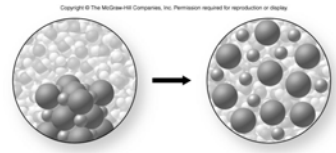
5.5 Representing Reactions in Aqueous Solution

- When reactions occur in water, soluble ionic compounds exist as separate ions, not grouped together with each other as might seem so from the equation, sometimes called a molecular equation:

$$AgNO_3(aq) + NaCl(aq) \rightarrow AgCl(s) + NaNO_3(aq)$$

NaCl(aq) exists in solution as separate ions



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5.5 Representing Reactions in Aqueous Solution

- When reactions occur in water, soluble ionic compounds exist as separate ions, not grouped together with each other as might seem so from the equation, sometimes called a molecular equation:

$$AgNO_3(aq) + NaCl(aq) \rightarrow AgCl(s) + NaNO_3(aq)$$

<u>Animation</u>

- An ionic equation shows soluble ionic compounds as separate ions:

$$Ag^+(aq) + NO_3^-(aq) + Na^+(aq) + Cl^-(aq) \rightarrow AgCl(s) + Na^+(aq) + NO_3^-(aq)$$

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Ionic Equations and Spectator Ions

- What are the spectator ions in the ionic equation?

$$Ag^+(aq) + NO_3^-(aq) + Na^+(aq) + Cl^-(aq) \rightarrow AgCl(s) + Na^+(aq) + NO_3^-(aq)$$

- Since the spectator ions do not change, we can leave them out of the net ionic equation:

$$Ag^+(aq) + Cl^-(aq) \rightarrow AgCl(s)$$

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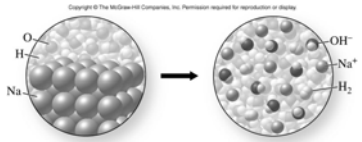
Spectator Ions and Net Ionic Equations

- **Identify the spectator ions and write the net ionic equations from the following molecular equations:**

a) $Cu(s) + 2AgNO_3(aq) \rightarrow Cu(NO_3)_2(aq) + 2Ag(s)$

b) $2Na(s) + 2H_2O(l) \rightarrow 2NaOH(aq) + H_2(g)$



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Net Ionic Equations

- **What is the net ionic equation for the reaction of KCl(aq) and $NaNO_3(aq)$?**

movie

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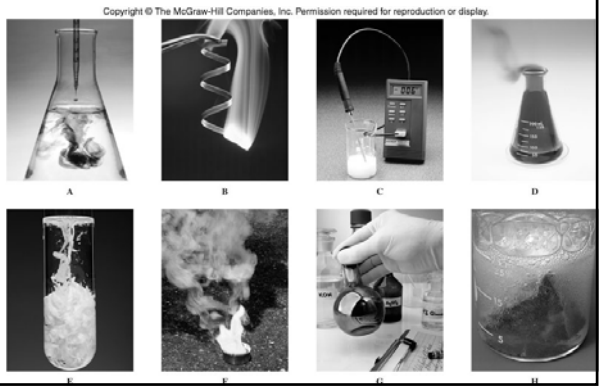
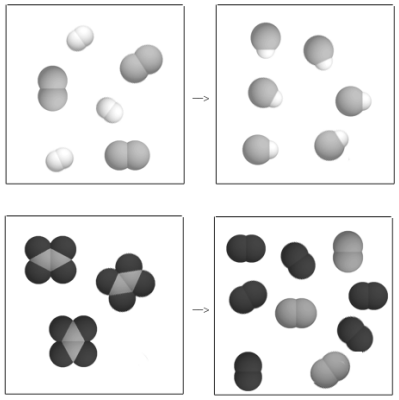
Can you classify any of these reactions?



Classify these reactions:



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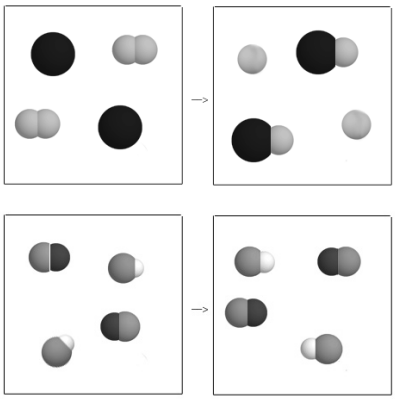
Classify these reactions:



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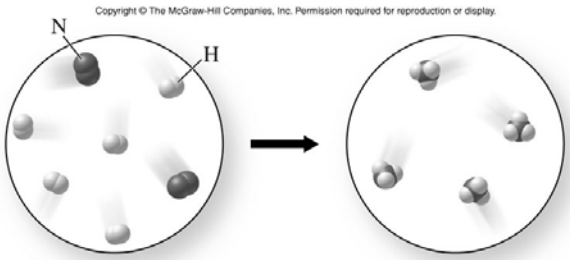
Classify this reaction

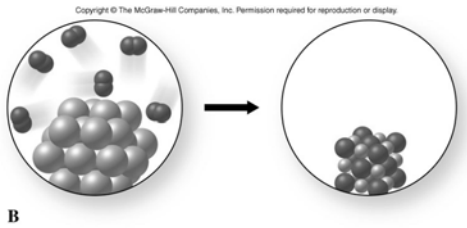
A



60

Classify this reaction

B

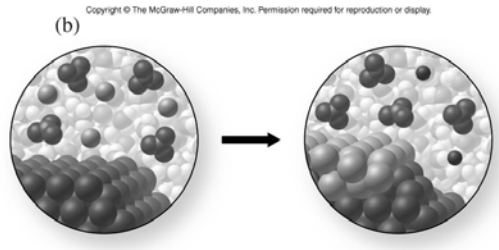


B

61

Classify this reaction

C.



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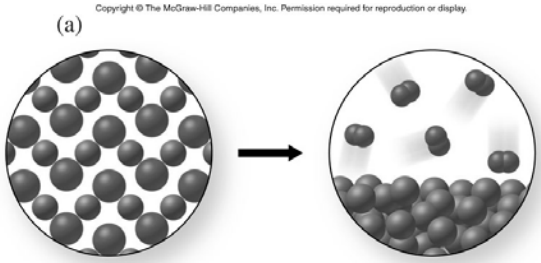
Classify this reaction

D.



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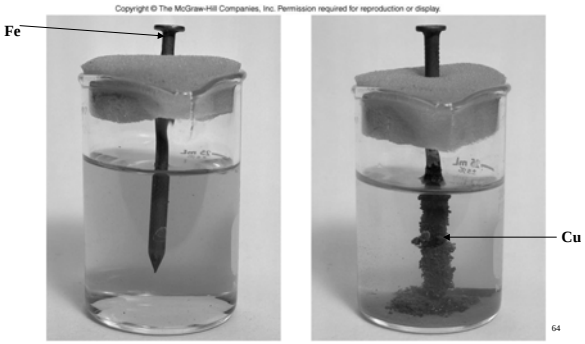
Classify this reaction

E.



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Other Types of Reactions:

Most, but not all reactions fall into these 5 categories.

An example that does not fit:

$$C_{12}H_{22}O_{11}(s) + 8KClO_3(l) \rightarrow 8KCl(s) + 12CO_2(g) + 11H_2O(g)$$

<u>Gummy bear</u>

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