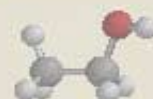
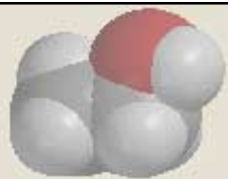
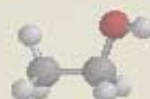
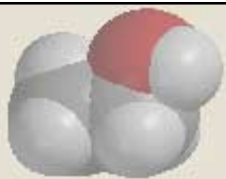


Chem101 - Lecture 5

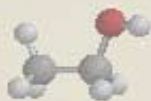
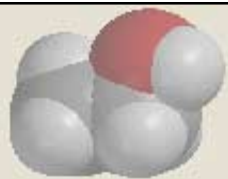
Chemical Reactions





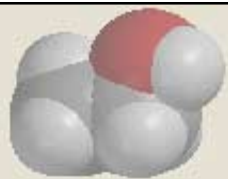
Introduction

- Chemical reactions are processes involving chemical change.
- In a chemical reaction, one or more pure substances are changed to one or more other pure substances.
 - The substances that are changed in the reaction are called **reactants**.
 - The substances that they are changed into are called **products**.



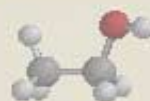
Introduction

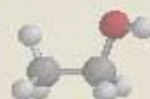
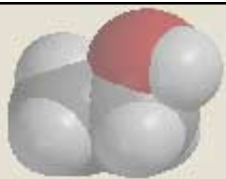
- In a chemical reaction, one or more pure substances are changed to one or more other pure substances.
 - 1. The substances that are changed in the reaction are called **reactants**.
 - 2. The substances that they are changed into are called **products**.



Chemical Equations

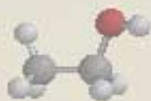
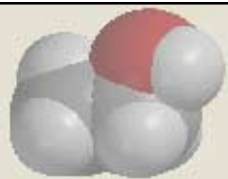
- Chemical equations are used to describe chemical reactions.





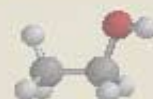
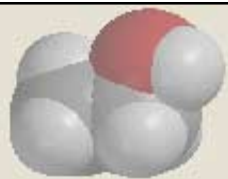
Chemical Equations

- A chemical equation has the following elements:
 - The chemical symbols for the reactants are placed on the left-hand side of the equation and the chemical symbols for the products are placed on the right-hand side.



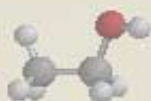
Chemical Equations

- A chemical equation has the following elements:
 - Either an arrow (\rightarrow) or an equal sign ($=$) are used to indicate the reactants converting to products.



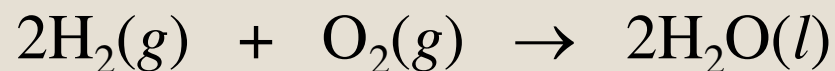
Chemical Equations

- A chemical equation has the following elements:
 - A plus sign (+) is used to separate individual reactants and products.



Chemical Equations

- For the reaction: “hydrogen and oxygen react to form water” the chemical equation is



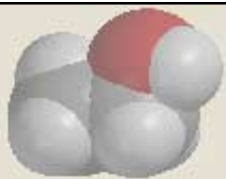
- The letters in parentheses are used to indicate that state of the reactant or the product

(*s*) for solid

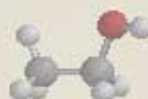
(*l*) for liquid

(*g*) for gas

(*aq*) for aqueous solution (dissolved in water)

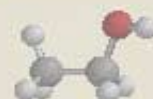
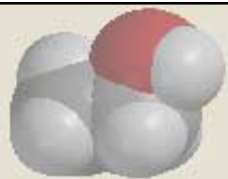


Chemical Equations



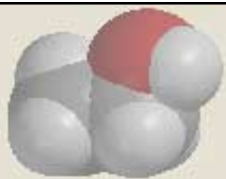
- Chemical equations embody a fundamental law of nature called the **law of conservation of matter**.

In a chemical reaction atoms are neither created or destroyed, only rearranged.



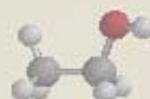
Chemical Equations

- All of the matter present in the reactants of the reaction is also present in the products of the reaction.
 - This allows us to treat chemical equation like mathematical equations
 - The coefficients are use to **balance** the equation.

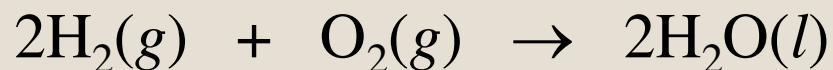


Chemical Equations

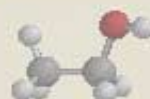
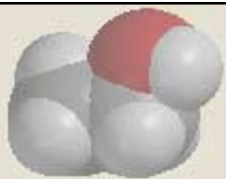
- For example



- In the chemical equation describing the formation of liquid water from hydrogen gas and oxygen gas:



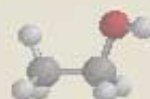
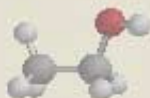
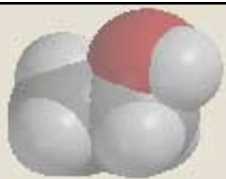
- There are 4 hydrogens on both the left and right-hand sides of the equation
- There are 2 oxygens on both the left and right-hand sides of the equation.



Exercise 5.3

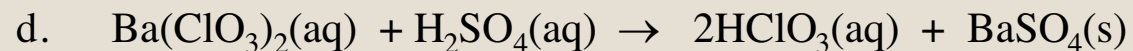
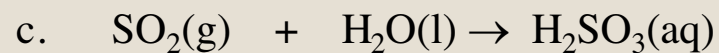
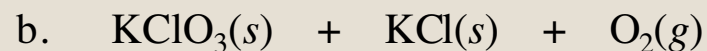
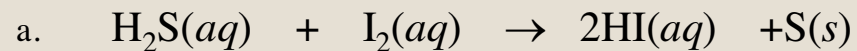
Identify which of the following are consistent with the law of conservation of matter. For those that are not, explain why they are not:

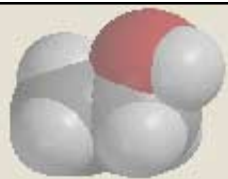
- $4 \text{ Al}(s) + 3 \text{ O}_2(g) \rightarrow 2 \text{ Al}_2\text{O}_3(s)$
- $\text{P}_4(s) + \text{O}_2(g) \rightarrow \text{P}_4\text{O}_{10}(s)$
- 3.2g oxygen + 3.21 g sulfur \rightarrow 6.41g sulfur dioxide
- $\text{CH}_4(g) + 2 \text{ O}_2(g) \rightarrow \text{CO}_2(g) + 2 \text{ H}_2\text{O}(g)$



Exercise 5.5

Determine the number of atoms of each element on each side of the following equations and decide which equations are balanced:





Types of Reactions



- There are many types of reactions



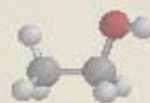
- We will focus on only a few.

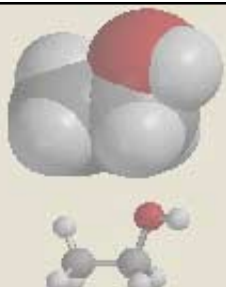


- There are different ways of classifying reactions

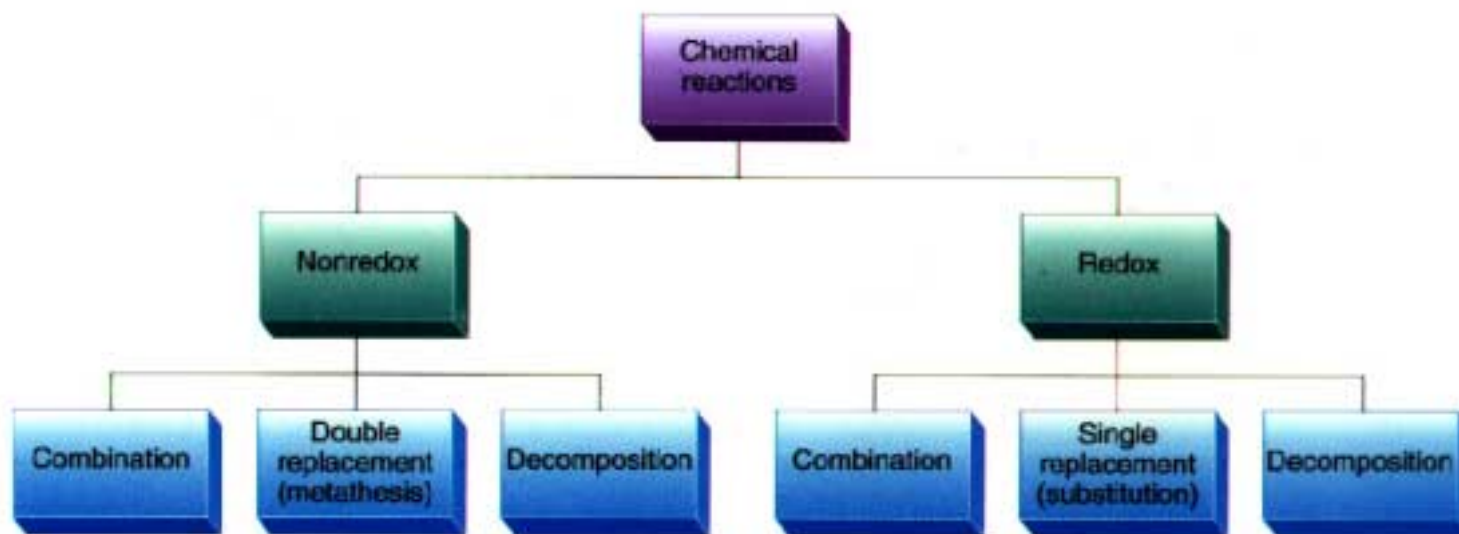


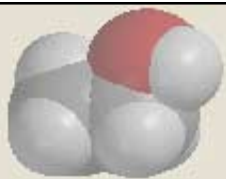
- Your text chooses to first classify all reactions as either redox or nonredox reactions.



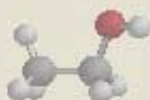


Types of Reactions





Types of Reactions



- There are many types of reactions



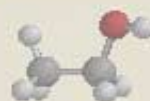
- We will focus on only a few.

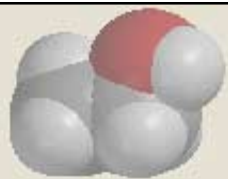


- There are different ways of classifying reactions



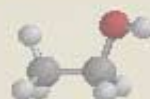
- Your text chooses to first classify all reactions as either **redox** or **nonredox** reactions.

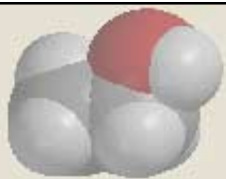




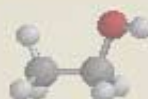
Types of Reactions

- The redox classification is made on the basis of whether the reactants and products exchange electrons during the reaction.

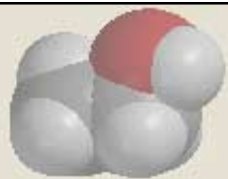




Types of Reactions

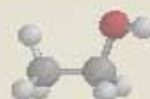
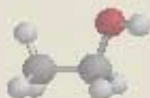


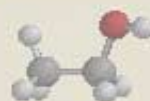
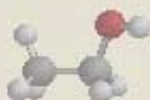
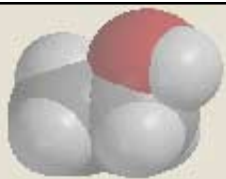
- Under both the redox and nonredox headings are the **combination** and the **decomposition** reactions.
 - Combination reactions involve the combining of two or more reactants to produce a single product.
 - Decomposition reactions involve the breakdown of a single reactant to produce two or more products.



Redox Reactions

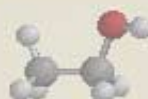
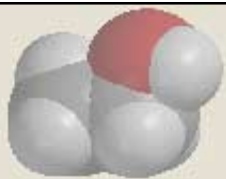
- *Redox* is an abbreviation for oxidation/reduction reactions.





Redox Reactions

- **Oxidation** reactions originally described reactions involving combining oxygen with the various elements to form oxides.
- Because oxygen is a very electronegative element, when it combines with other elements, the other elements lose electrons.

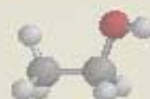
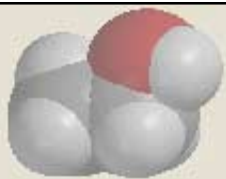


Redox Reactions

- This is strictly true only if an ionic compound is formed.

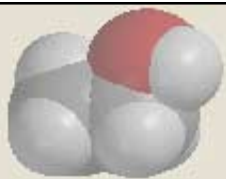


- In this reaction the oxygen is taking away 3 electrons from each iron atom to produce Fe^{3+} ions.
- Fe_2O_3 is an ionic compound comprising Fe^{3+} and O^{2-} ions

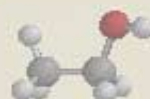


Redox Reactions

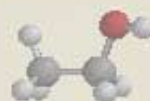
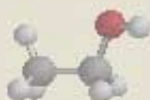
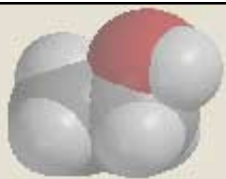
- However, even in covalent compounds, where the valence electrons are shared, the sharing is not equal when oxygen is involved.
 - Because of oxygen's high electronegativity, the shared electrons spend more time with the oxygen
 - It is useful to consider that the oxygen is taking the electrons away from the other element, even though technically they are being shared.



Redox Reactions

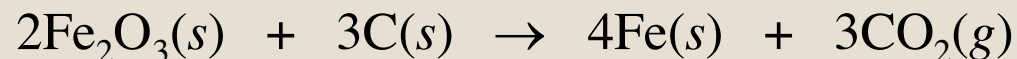


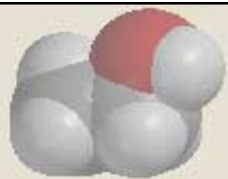
- The broader definition of *oxidation* is
 - A chemical process that results in the loss of electrons by a substance.
 - In this definition, oxygen does not necessarily need to be involved.
 - Other reactants can be responsible for the removal of the electrons.



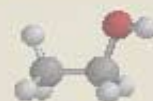
Redox Reactions

- The opposite of oxidation is **reduction**.
- **Reduction** reactions originally described reactions in which ionic forms of metals were converted to elemental forms by supplying them with electrons:

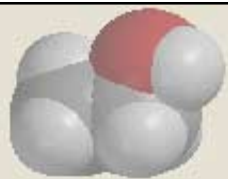




Redox Reactions

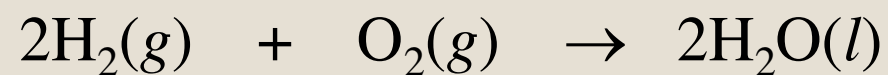


- As with oxidation, the electrons do not have to be completely gained by the element
 - If in the course of a chemical reaction an element becomes bonded to a less electronegative element, it is considered to be reduced.

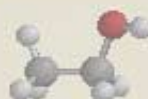


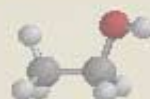
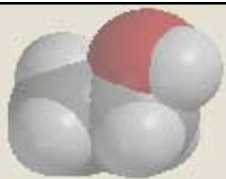
Redox Reactions

- For example, in the reaction



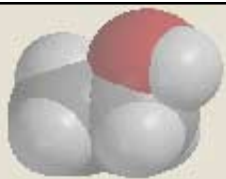
- the oxygen is reduced.





Redox Reactions

- There is a systematic set of rules that are used to determine if an element has been oxidized or reduced in a chemical reaction.
- These rules result in the assignment of an **oxidation number** for each element participating in a reaction.



Oxidations Numbers



1. Oxidation number (O.N.) for an uncombined element is 0.



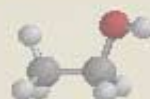
2. The O.N. of a simple ion is equal to its charge.



3. The O.N. of a group IA or IIA element is +1 and +2 respectively.



4. The O.N. of hydrogen is +1.



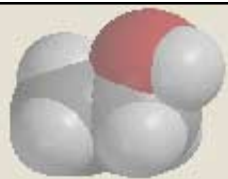
5. The O.N. of oxygen is -2 except in peroxides (-O-O-), where it is -1.



6. The algebraic sum of the O.N.'s of all atoms in a neutral compound is zero

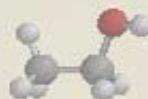


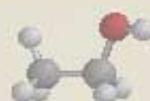
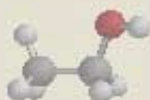
7. The algebraic sum of the O.N.'s of all atoms in a polyatomic ion is equal to the charge on the ion.



Redox Reactions

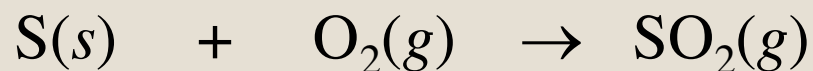
- If in a reaction the oxidation number for an element increases, it is *oxidized*
- Conversely, if its oxidation number decreases, it is *reduced*.



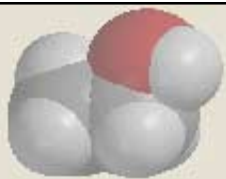


Redox Reactions

- Applying these rules to the reaction:



- As elements, both S and O₂ have oxidation numbers of 0 (Rule 1)
 - The oxidation number for the oxygen in SO₂ is -2 (Rule 5)
 - The oxidation number for the sulfur in SO₂ is +4 (Rule 6)
- In this reaction the sulfur is oxidized while the oxygen is reduced.



Redox Reactions



- Various definitions of oxidation and reduction:



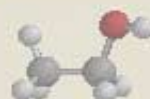
Oxidation

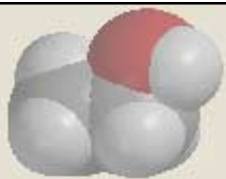
- To combine with oxygen
- To lose hydrogen
- To lose electrons
- To increase in oxidation number



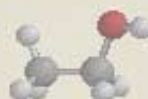
Reduction

- To lose oxygen
- To combine with hydrogen
- To gain electrons
- To decrease in oxidation number

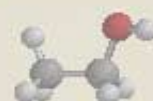
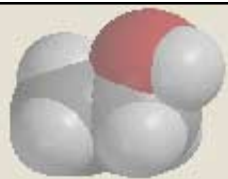




Redox Reactions



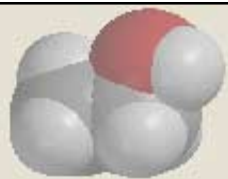
- Oxidizing and reducing agents:
 - A molecule that is capable of removing electrons from another molecule is called an **oxidizing agent**.
In the process the oxidizing agent becomes reduced because it gains electrons
 - A molecule that is capable of donating electrons to another molecule is called a **reducing agent**.
In the process the reducing agent becomes oxidized because it loses electrons.



Redox Reactions

- Oxidizing and reducing agents:

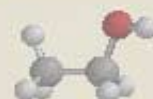
Oxidizing agent	Reducing agent
Gains electrons	Loses electrons
Oxidation number decreases	Oxidation number increases
Becomes reduced	Becomes oxidized

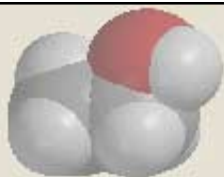


Redox Reactions

- Batteries:

- Batteries work by using redox reactions that require the electrons flowing from the oxidation reaction to the reduction reaction to flow through a wire.





Redox Reactions

- Batteries:

Carbon-zinc cell (dry cell)

Labels: Sealant, Carbon rod (cathode), MnO₂, NH₄Cl paste, Zinc container (anode)

Cathode reaction:
 $2\text{MnO}_2(\text{s}) + 2\text{NH}_4^+(\text{aq}) + 2\text{e}^- \rightarrow \text{Mn}_2\text{O}_3(\text{s}) + 2\text{NH}_3(\text{aq}) + \text{H}_2\text{O}(\text{l})$

Anode reaction:
 $\text{Zn}(\text{s}) \rightarrow \text{Zn}^{2+}(\text{aq}) + 2\text{e}^-$

Voltage: 1.5

Nickel-cadmium cell

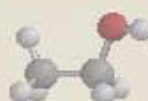
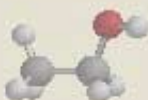
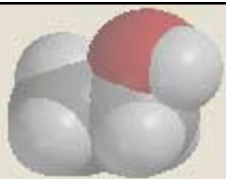
Labels: Sealant, Carbon rod, NiO₂ + KOH paste, Cadmium container

Cathode reaction:
 $\text{NiO}_2(\text{s}) + 2\text{H}_2\text{O}(\text{l}) + 2\text{e}^- \rightarrow \text{Ni}(\text{OH})_2(\text{s}) + 2\text{OH}^-(\text{aq})$

Anode reaction:
 $\text{Cd}(\text{s}) + 2\text{OH}^-(\text{aq}) \rightarrow \text{Cd}(\text{OH})_2(\text{s}) + 2\text{e}^-$

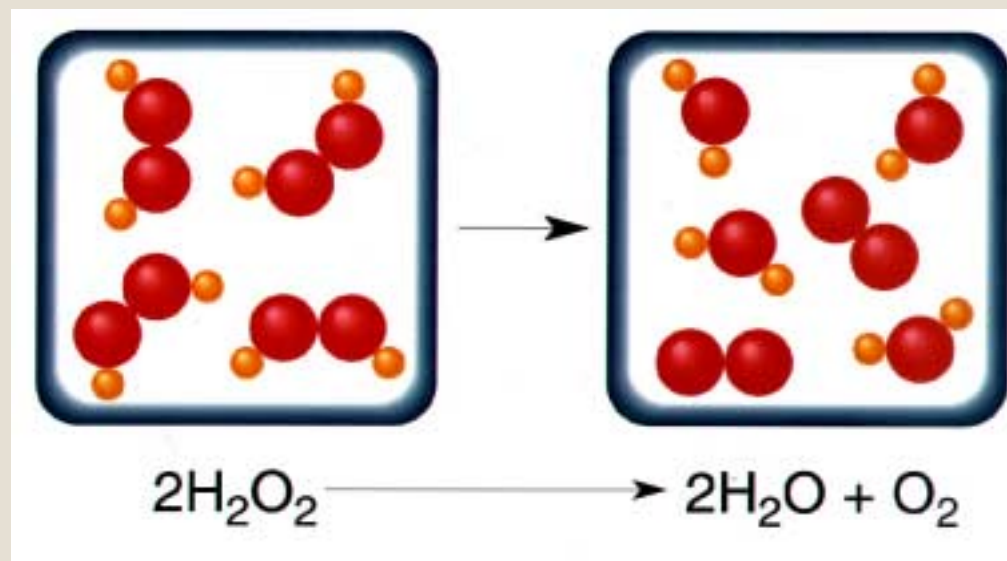
Voltage: 0.90

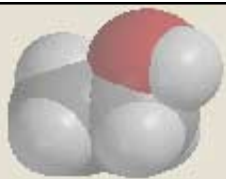
A carbon-zinc battery (left) cannot be recharged. A nickel-cadmium battery (right) can be recharged and used again and again.



Decomposition Reactions

- **Decomposition reactions** have the form $A \rightarrow B + C$
 - They can be recognized by having only one reactant, which breaks down



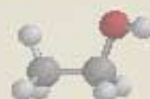


Decomposition Reactions

- Examples:



This reaction was used by Joseph Priestley in the discovery of oxygen in 1774.

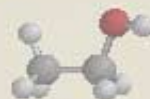


This reaction is called slaking, it is used to produce lime (CaO) from limestone (CaCO₃).

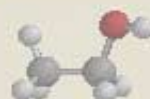
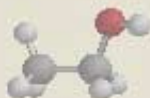
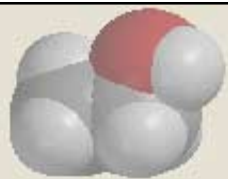




Decomposition Reactions



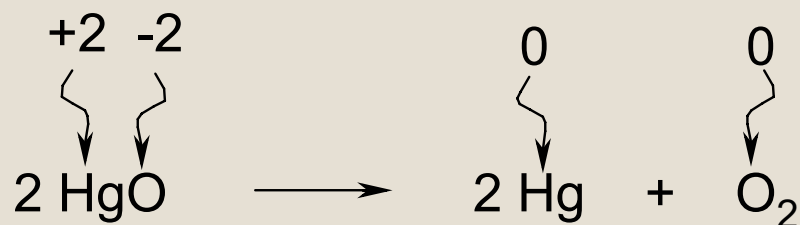
- Decomposition reactions can be either redox reactions or non redox reactions.
 - Which can be determined by determining the oxidation numbers of the each element in both the reactants and products of the reaction.

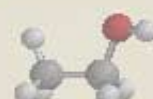
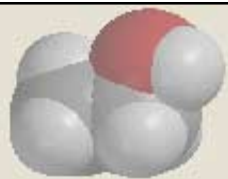


Decomposition Reactions

- Decomposition reactions can be either redox reactions or non redox reactions.

- The first reactions is a redox reaction because the mercury is reduced while the oxygen is oxidized.

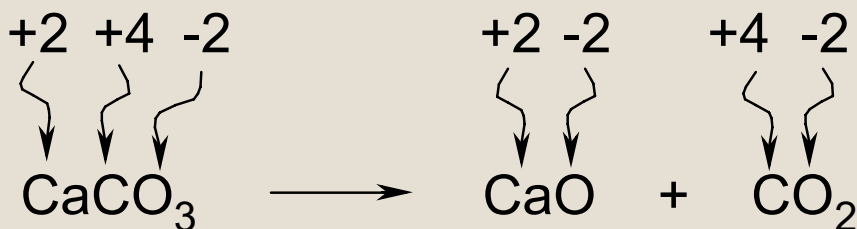


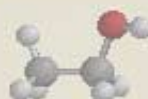
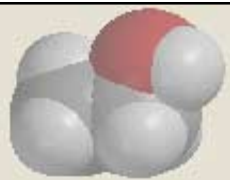


Decomposition Reactions

- Decomposition reactions can be either redox reactions or non redox reactions.

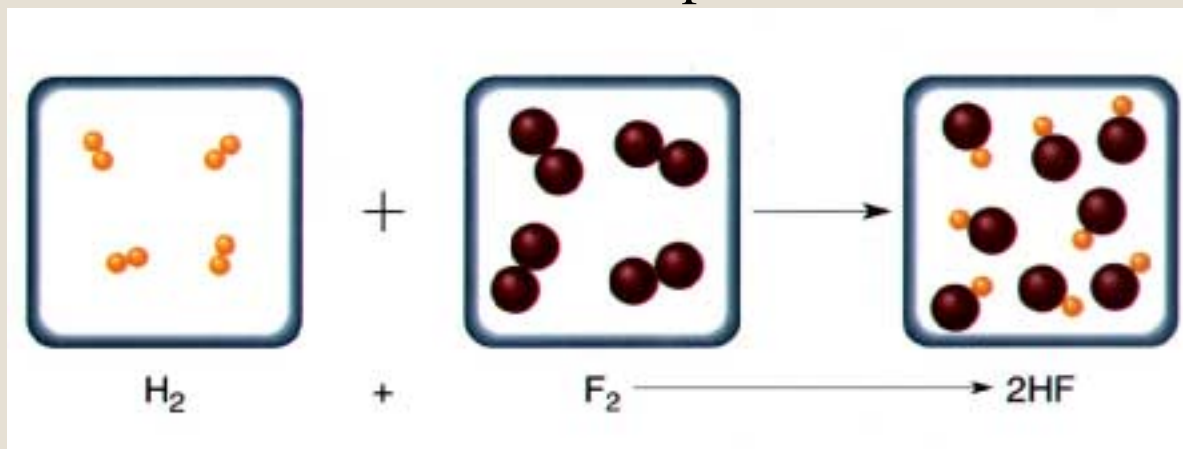
- The second reaction is a nonredox reaction because there is no change in the oxidation state of any of the elements in the reaction.

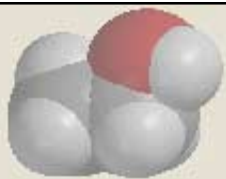




Combination Reactions

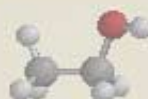
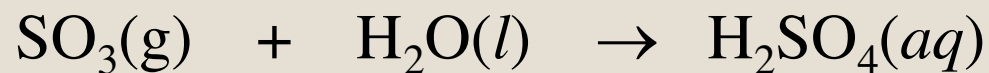
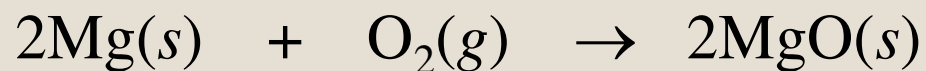
- **Combination reactions** have the form $A + B \rightarrow C$
 - They can be recognized by having only one product, which is formed from two or more products.



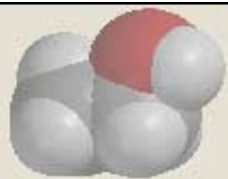


Combination Reactions

- Examples:



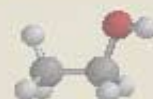
- Combination reactions can also be either redox or nonredox reactions.



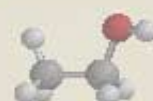
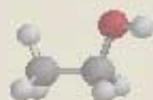
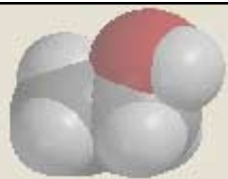
Replacement Reactions



- There are two types of replacement reactions

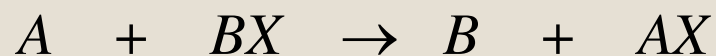


- **Single-replacement**, where one of the reactants and one of the products is an element
- **Double-replacement**, where all of the products and reactants are compounds.

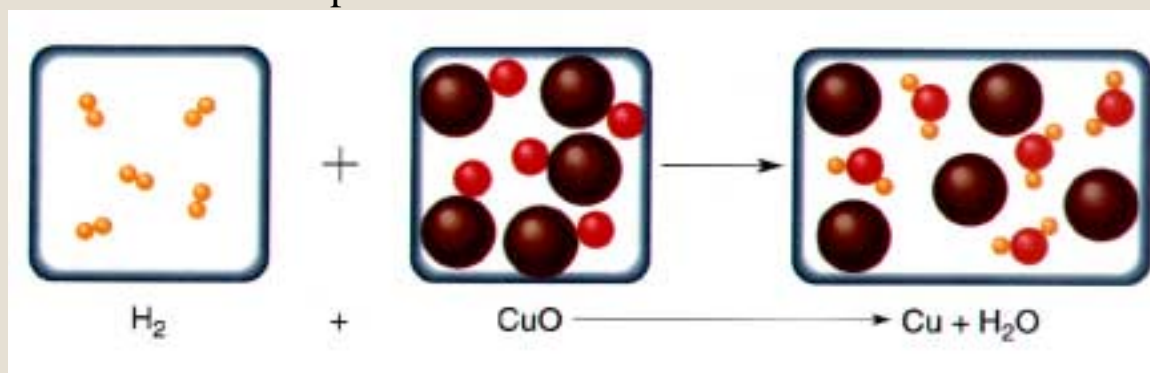


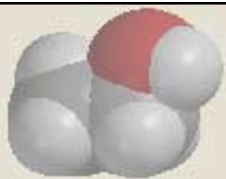
Replacement Reactions

- Single-replacement reactions
 - Are also called substitution reactions
 - They are always redox reactions
 - They have the form



where A and B are elements and BX and AX are compounds.





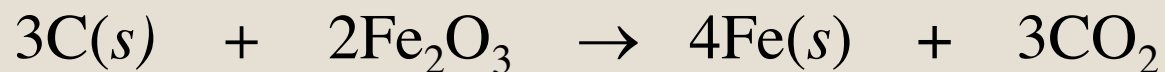
Replacement Reactions



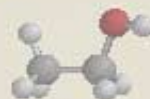
- Single-replacement reactions



- Example:

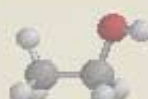
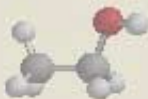
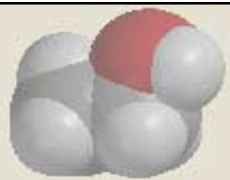


- Here, the iron in iron(III)oxide is reduced to elemental iron by carbon



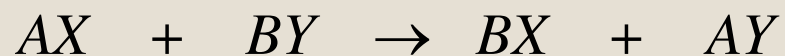
- Single replacement reactions are always redox reactions



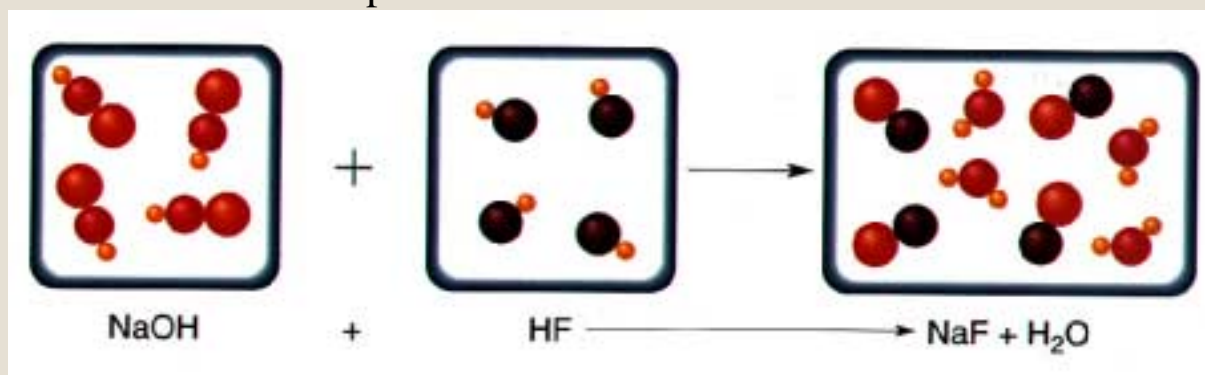


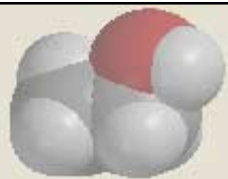
Replacement Reactions

- Double-replacement reactions
 - Are also called metathesis reactions
 - They are always nonredox reactions
 - They have the form



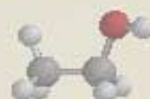
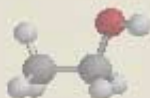
where *A* and *B* are elements and *BX* and *AX* are compounds.

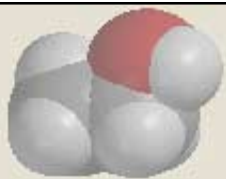




Replacement Reactions

- Double-replacement reactions
 - Often double replacement reactions take place in water.
 - Precipitation reactions
 - Acid-base reactions

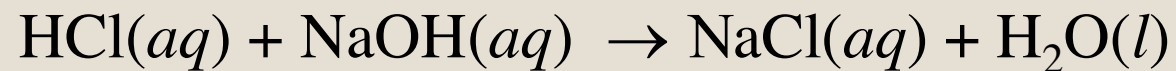




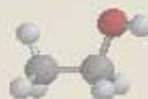
Replacement Reactions

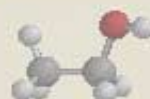
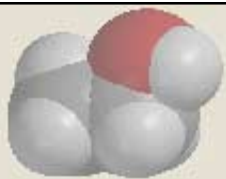
- Double-replacement reactions

- Example



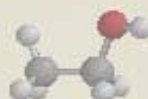
- This is an example of an acid-base reaction





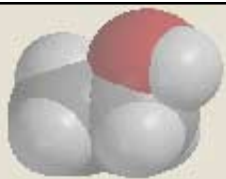
Ionic Equations

- Ionic compounds that dissolve in water and some highly polar molecular compounds, such as strong acids, dissociate into ions;
- When writing chemical equations it is useful to explicitly write the reactants and products that dissociate into ions as ions in the equation.
 - This is called a Total Ionic Equation



Ionic Equations

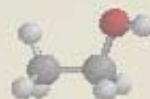
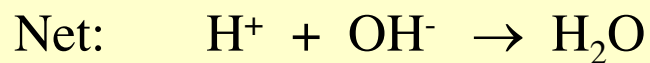
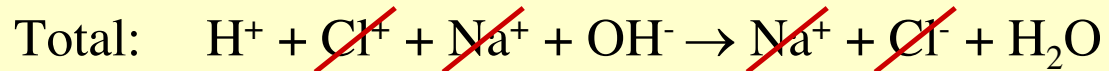
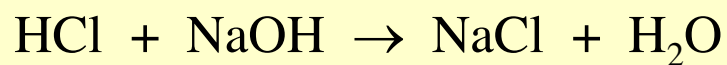
- As with algebraic equations, when an ionic component of a reaction appears on both sides of a chemical equation it can be canceled out.
 - These ions are called **Spectator Ions** because they are not participating in the reaction.
- After canceling out the spectator ions, the remaining reaction is called the **Net Ionic Equation**.

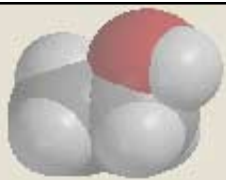


Ionic Equations



- Example

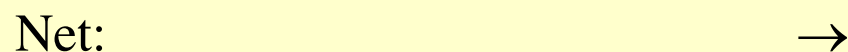
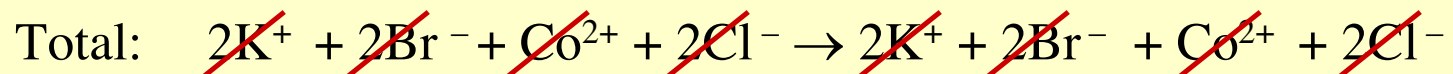
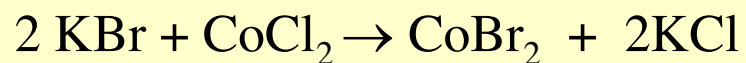




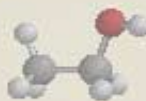
Ionic Equations

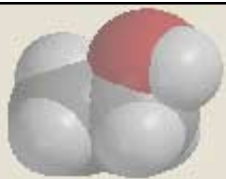


- Example



- If nothing remains, there is no reaction!





Energy and Reactions



- Energy changes accompany all reactions



- Can be in the form of

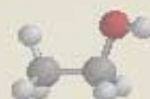


- Heat

- Light



- Sound



- High energy chemical bonds

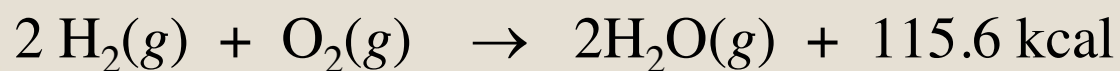




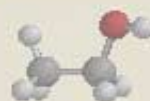
Energy and Reactions

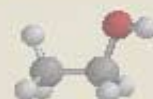
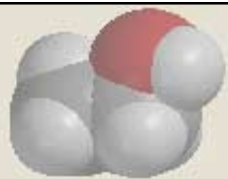


- Expressed in units of calories or Joules



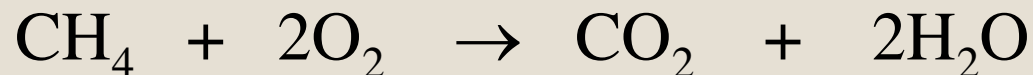
- When heat is given off the reaction is **exothermic**
- When heat is absorbed the reaction is **endothermic**.

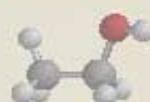
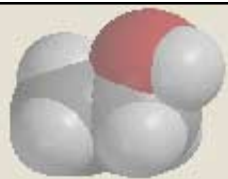




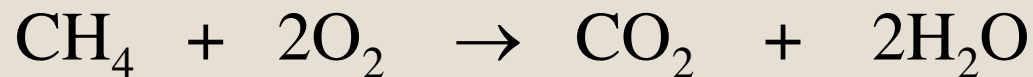
The Mole and Chemical Equations

- **Stoichiometry** - calculating the mass relationships in a chemical reactions
- Typically substances are quantitated by their mass
- However, chemical reactions relate numbers of reactants to numbers of products:

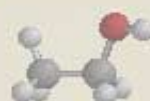
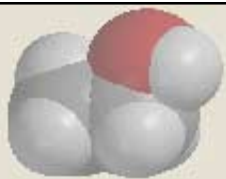




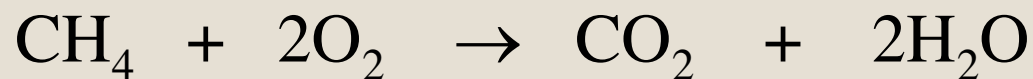
The Mole and Chemical Equations



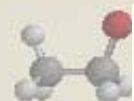
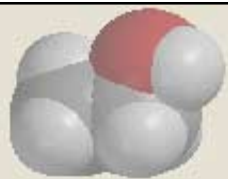
- Statements consistent with this equation include:
 - ♦ 1 CH₄ molecule + 2 O₂ molecules → 1 CO₂ molecule + 2 H₂O molecules.
 - ♦ 10 CH₄ molecules + 20 O₂ molecules → 10 CO₂ molecules + 20 H₂O molecules.
 - ♦ 100 CH₄ molecules + 200 O₂ molecules → 100 CO₂ molecules + 200 H₂O molecules.



The Mole and Chemical Equations

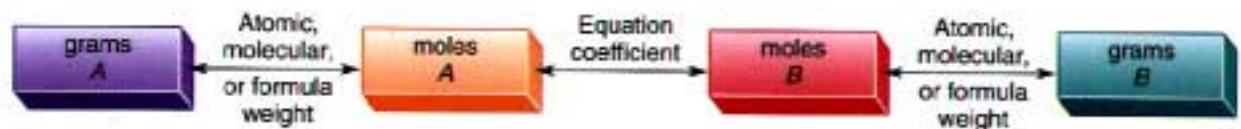


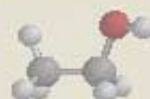
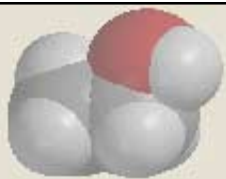
- Statements consistent with this equation include:
 - ◆ 6.02×10^{23} CH₄ molecules + 12.0×10^{23} O₂ molecules → 6.02×10^{23} CO₂ molecules + 12.0×10^{23} H₂O molecules.
 - ◆ 1 mol CH₄ + 2 mol O₂ → 1 mol CO₂ + 2 mol H₂O.
 - ◆ 16 g CH₄ + 64.0 g O₂ → 44.0 g CO₂ + 36.0 g H₂O



The Mole and Chemical Equations

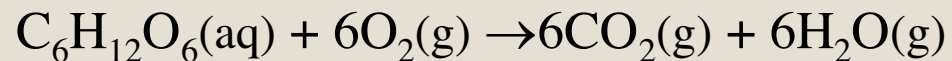
- To make use of the chemical equation we usually need to convert from mass to moles, then use the coefficients in the balanced chemical equation to relate the moles of one substance in the reaction with moles of another.
 - In the end we usually need to convert back to mass



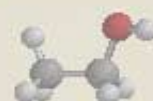
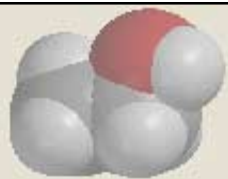


Exercise 5.49

An important metabolic process of the body is the oxidation of glucose to water and carbon dioxide. The equation for the reaction is

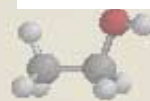
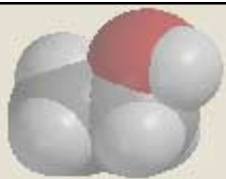


- What mass of water in grams is produced when the body oxidizes 1.00 mol of glucose?
- How many grams of oxygen are needed to oxidize 1.00 mol of glucose?



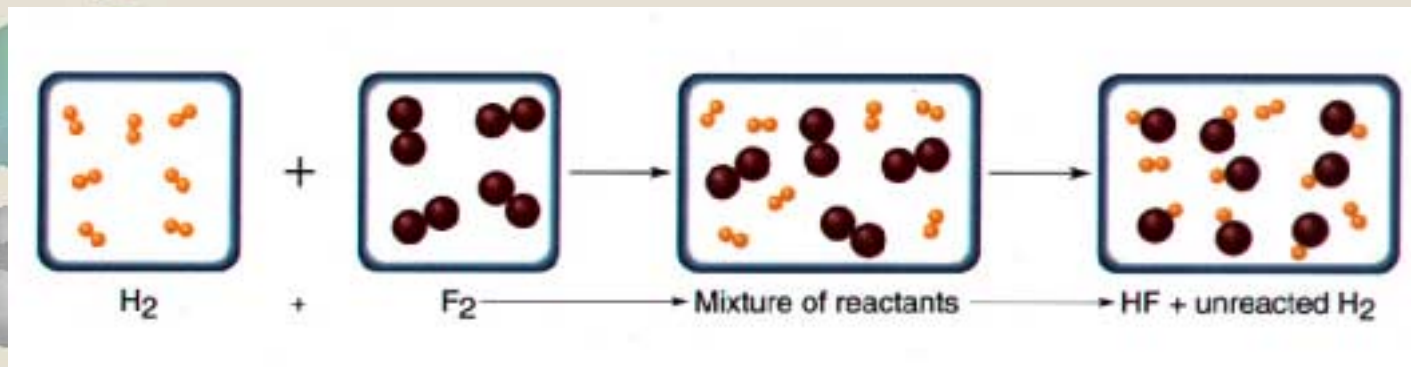
Limiting Reactant

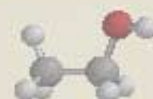
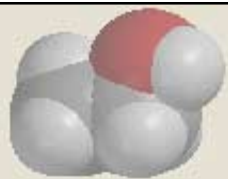
- Reactions can proceed only as long as all of the reactants are present.
 - In most cases one of the reactants will be used up before the others
 - This reactant is called the **limiting reactant** because it determines how much product can be made.
 - When the limiting reactant is used up the reaction comes to a stop.



Limiting Reactant

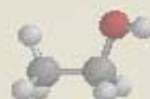
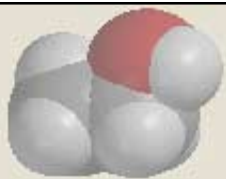
- Reactions can proceed only as long as all of the reactants are present.





Limiting Reactant

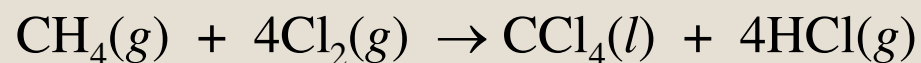
- The quantity of product that is produced when all of the limiting reactant is used up is called the **theoretical yield**.



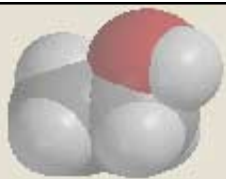
Exercise 5.49

A sample of 4.00 g of methane (CH_4) is mixed with 15.0 g of chlorine (Cl_2).

- a. Determine which is the limiting reactant according to the following equation:

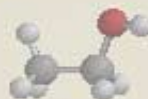


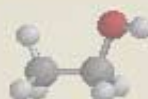
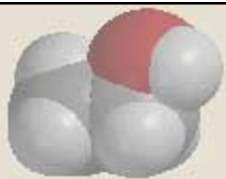
- b. What is the maximum mass (theoretical yield) of CCl_4 that can be formed?



Reaction Yields

- When carried out in the lab, a reaction rarely produces the theoretical yield
 - Loss of reactants and products, along with side reactions that produce different products reduce the yield of the desired product.
 - The experimental yield is called the **actual yield**.

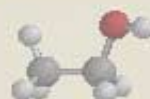
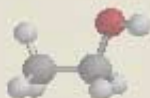
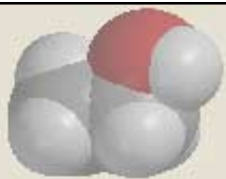




Reaction Yields

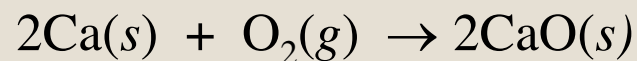
- The actual yield is compared to the theoretical yield by determining the **percent yield**:

$$\text{Percent Yield} = \frac{\text{Actual Yield}}{\text{Theoretical Yield}} \times 100\%$$



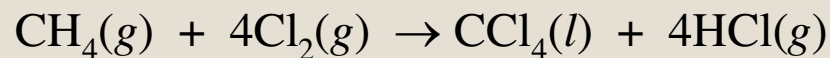
Exercise 5.59

A sample of calcium metal with a mass of 2.00 g was reacted with excess oxygen. The following equation represents the reaction that took place:



The isolated product (CaO) weighed 2.26 g. What is the percent yield of the reaction?

- a. Determine which is the limiting reactant according to the following equation:



- b. What is the maximum mass (theoretical yield) of CCl_4 that can be formed?