EC1 REDOX Lesson 1

A Simple Redox Experiment

When a copper wire is placed in an aqueous solution of silver nitrate, a spectacular reaction results. Within minutes a large number of shiny metallic crystals form on the wire, and the solution turns pale blue. When we shake off the crystals, we observe that much of the copper wire has disappeared. The crystals are silver crystals and the blue colour of the solution indicates the presence of hydrated copper ions. Copper metal has displaced silver from its salt.

$$Cu_{(s)} + 2\ AgNO_{3(aq)} \longrightarrow Cu(NO_3)_{2(aq)} + 2\ Ag_{(s)}$$

$$Cu_{(s)} + 2\ Ag^{+}_{(aq)} \longrightarrow Cu^{2+}_{(aq)} + 2\ Ag_{(s)}$$

Copper atoms in the wire each lose two electrons and go into solution as hydrated copper ions. The electrons are transferred to hydrated silver ions, which crystallize as metallic silver.

Any reaction in which electrons are lost is called an oxidation reaction. A reaction that involves the gain of electrons is called a reduction reaction. In the copper-silver nitrate reaction, the copper metal is oxidized to copper ions and the silver ions are reduced to silver metal. Because oxidation and reduction reactions always take place concurrently, we refer to these reactions as redox reactions.

RED-OX Reactions:

An oxidation-reduction (redox) reaction is a type of chemical reaction that involves a transfer of electrons between two species. An oxidation-reduction reaction is any chemical reaction in which the oxidation number of a molecule, atom, or ion changes by gaining or losing an electron. Redox reactions are common and vital to some of the basic functions of life, including photosynthesis, respiration, combustion, and corrosion or rusting.

Electronegativity and Oxidation Numbers

- The oxidation number tells us how many electrons an atom in a compound would gain or lose.
- In assigning oxidation numbers we assume that the electrons of each bond are transferred to the more electronegative atom in the bond.
- A positive oxidation number indicates a loss of electrons and a negative number indicates a gain of electrons.
- The oxidation number of an atom in its pure form, as an element, is zero.
- The oxidation number of a monatomic ion is equal to the charge on the ion, since the charge indicates the number of electrons lost or gained.

Example

What are the oxidation numbers of each element in calcium chloride?

Example

What are the oxidation numbers of iron in the two iron oxides, FeO and Fe_2O_3? Assume that oxygen has an oxidation number of −2 in each case.

The sum of the oxidation numbers in each compound will be zero.

Oxidation Number Rules

1. The oxidation number for an atom in its elemental form is always _____.
    - A substance is elemental if both of the following are true:
        - only one kind of atom is present
        - charge =_____
    - Examples:
        - S_8: The oxidation number of S =
        - Fe: The oxidation number of Fe =
2. The oxidation number of a monoatomic ion = _____ of the monatomic ion.
    - Examples:
        - Oxidation number of S^{2-} is _____.
        - Oxidation number of Al^{3+} is _____.
3. The oxidation number of all Group 1A metals = _____ (unless elemental).
4. The oxidation number of all Group 2A metals = _____ (unless elemental).
5. Hydrogen (H) has two possible oxidation numbers:
    - _____when bonded to a nonmetal
    - _____ when bonded to a metal
6. The oxidation number of fluorine (F) is always _____.
7. Oxygen (O) has two possible oxidation numbers:
    - _____ in most compounds...most common
    - _____ in peroxides (O_2^{2-})....pretty uncommon
8. The sum of the oxidation numbers of all atoms (or ions) in a neutral compound = _____.
9. The sum of the oxidation numbers of all atoms in a polyatomic ion = _____ on the polyatomic ion.

Example

What are the oxidation numbers of oxygen and fluorine in oxygen difluoride, OF_2?

The electronegativity values of oxygen and fluorine are _____ and _____respectively. The fluorine atoms attract electrons more strongly than oxygen; therefore it is assigned the _____ oxidation number, and the oxygen, the positive oxidation number.

H 2.01											**He** -
Li 0.98	**Be** 1.57			**B** 2.04	**C** 2.55	**N** 3.04	**O** 3.44	**F** 3.98	**Ne** -
Na 0.93	**Mg** 1.31			**Al** 1.61	**Si** 1.90	**P** 2.19	**S** 2.58	**Cl** 3.16	**Ar** -
K 0.82	**Ca** 1.00			**Ga** 1.81	**Ge** 2.01	**As** 2.18	**Se** 2.55	**Br** 2.96	**Kr** 3.0
Rb 0.82	**Sr** 0.95			**In** 1.78	**Sn** 1.96	**Sb** 2.05	**Te** 2.1	**I** 2.66	**Xe** 2.6
Cs 0.79	**Ba** 0.89			**Tl** 2.04	**Pb** 2.33	**Bi** 2.02	**Po** 2.0	**At** 2.2	**Rn** -

Example

What is the oxidation number of carbon in each of the following compounds:

a) ethane, C_2H_6 b) ethyne, C_2H_2

Oxidation Numbers of Atoms in Polyatomic Ions or Molecules

Example

What are the oxidation numbers of the elements in the fluorosulfate ion, FSO_3^-?

Example

What are the oxidation numbers of each of the elements in sodium perxenate, Na_4XeO_6?

Example

What are the oxidation numbers of each of the elements in ammonium carbonate, $(NH_4)_2CO_3$?

Redox Reactions

- An increase in the oxidation number of an atom indicates that it has lost electrons and has undergone oxidation.
- A decrease in the oxidation number of an atom means an increase in the number of electrons and indicates reduction.
- Since electrons are neither created nor destroyed in chemical reactions, the total number of electrons will always remain unchanged. This means that the loss of electrons must always be accompanied by the opposite process – the gain of electrons. In other words, oxidation and reduction are processes that always take place together.
- The element that undergoes oxidation is the reducing agent.
- The element that undergoes reduction is the oxidizing agent.

Example

Which of the following reactions is a redox reaction?

a. $2\ NaBr_{(aq)} + Cl_{2(aq)} \longrightarrow 2\ NaCl_{(aq)} + Br_{2(aq)}$

b. $2\ HCl_{(aq)} + Na_2S_{(aq)} \longrightarrow 2\ NaCl_{(aq)} + H_2S_{(g)}$

Oxidizing and Reducing Agents

- A good oxidizing agent must be a good electron acceptor and a good reducing agent must be a good electron donor.
- The cheapest and most widely-used oxidizing agent is atmospheric oxygen.
- Elemental chlorine is also a good oxidizing agent.
- The most commonly-used reducing agent is hydrogen gas.
- Reactive metals such as magnesium and aluminum are also good reducing agents.

Example

Consider the addition or removal of oxygen atoms, as well as the change in oxidation numbers, to determine which substance is oxidized and which is reduced in the following reaction:

$$CH_3OH_{(aq)} + 2\ HClO_{(aq)} \longrightarrow HCO_2H_{(aq)} + 2\ HCl_{(aq)} + H_2O_{(l)}$$

methanol hypochlorous acid formic acid

Types of Redox Reactions

Combination Reactions

Combination reactions are among the simplest redox reactions and, as the name suggests, involves "combining" elements to form a chemical compound. As usual, oxidation and reduction occur together. The general equation for a combination reaction is given below:

$$A+B \rightarrow AB$$

Example:

Consider the combination reaction of hydrogen and oxygen. Determine the oxidizing and reducing agents.

$$H_2 + O_2 \rightarrow H_2O$$

Decomposition Reactions

A decomposition reaction is the reverse of a combination reaction, the breakdown of a chemical compound into individual elements:

$$AB \rightarrow A+B$$

Example:

Consider the decomposition of water. Determine which element is being oxidized and which is being reduced.

$$H_2O \rightarrow H_2 + O_2$$

Single Replacement Reactions

A **single replacement** reaction involves the "replacing" of an element in the reactants with another element in the products:

$$A + BC \rightarrow AB + C$$

Example: Determine the oxidizing and reducing agents.

$$Cl_2 + NaBr \rightarrow NaCl + Br_2$$

Activity Series of Metals

A metal will displace any metal ion that appears below it in the series.

The Activity Series	
Lithium	These metals displace hydrogen in water
Potassium	
Barium	
Calcium	
Sodium	
Magnesium	These metals displace hydrogen in acids
Aluminium	
Zinc	
Chromium	
Iron	
Cadmium	
Nickel	
Tin	
Lead	
Hydrogen	
Copper	

Example

Mercury	These metals do not displace hydrogen from
Silver	
Gold	

Use the activity series to predict whether a reaction takes place when the following substances are mixed. If there is a reaction, complete and balance the equation, and then write the net ionic equation.

a) $Fe_{(s)} + ZnSO_{4(aq)} \longrightarrow$

b) $Al_{(s)} + H_2SO_{4(aq)} \longrightarrow$

c) $Sn_{(s)} + CuSO_{4(aq)} \longrightarrow$

Double Replacement Reactions

A **double replacement** reaction is similar to a double replacement reaction, but involves "replacing" two elements in the reactants, with two in the products:

$$AB + CD \rightarrow AD + CB$$

Example: Determine the oxidizing and reducing agents.

$$MgSO_4(aq) + Na_2C_2O_4(aq) \rightarrow MgC_2O_4(s) + Na_2SO_4(aq)$$

Combustion Reactions

Combustion reactions almost always involve oxygen in the form of O_2, and are almost always exothermic, meaning they produce heat. Chemical reactions that give off light and heat and light are colloquially referred to as "burning."

$$CxHy + O_2 \rightarrow CO_2 + H_2O$$

Example: Consider the combustion of propane.

$$2C_3H_8(g) + 7O_2(g) \rightarrow 6CO_2(g) + 8H_2O(g)$$

NOTE: Acid base reactions and precipitation reactions are almost always not redox.

Oxidation and Reduction Reaction Assignment

Name: _____

Determining Oxidation Numbers

1. What are the oxidation numbers for each element in the following ionic compounds:

   a) $SnCl_4$ b) Ca_3P_2 c) SnO d) Ag_2S

2. What are the formulas of the oxides of nitrogen in which nitrogen has oxidation numbers of +1, +2, +3, +4, and +5?

3. Determine the oxidation numbers for each element in the following substances or ions:

   a) $Cu_2 S$ d) $Mn O_4^{2-}$

   b) S_8 e) $Cr O_4^{2-}$

   c) $Li Al H_4$ f) $N H_4 Cl$

4. Assign oxidation numbers to all elements in the following compounds:
   a) nitrous acid

   b) potassium permanganate

   c) ammonium sulfate

   d) sodium aluminate

   e) hydronium ion

5. What is the oxidation number of carbon in each of the following compounds:

   a) methane, CH_4

   b) formaldehyde, CH_2O

   c) carbon monoxide

6. What are the oxidation numbers of the following:
   a) copper in $Cu_2 SO_4$ and in $Cu SO_4$

   b) lead in $Pb Br_2$ and in $Pb Br_4$

Name:_____

Oxidation and Reduction Reactions

1. Which of the following are redox reactions? For all reactions, state the reaction type.

   a) $Na_2S_{(aq)} + FeCl_{2(aq)} \longrightarrow 2\ NaCl_{(aq)} + FeS_{(s)}$

   b) $2\ Na_{(s)} + 2\ H_2O_{(l)} \longrightarrow 2\ NaOH_{(aq)} + H_{2(g)}$

   c) $2\ KClO3_{(s)} \longrightarrow 2\ KCl_{(s)} + 3\ O_{2(g)}$

   d) $H_2S + Na_2O \longrightarrow Na_2S + H_2O$

   e) $Ca + H_2O \longrightarrow Ca\ O + H_2$

   f) $C\ O + 2\ H_2 \longrightarrow C\ H_3\ O\ H$

   g) $S\ O_3 + H_2O \longrightarrow H_2S\ O_4$

   h) $Ca\ C\ O_3 + S\ O_2 \longrightarrow Ca\ S\ O_3 + C\ O_2$

2. Which reactant in each of the following is oxidized? Which reactant is the oxidizing agent?

   a) $H_{2(g)} + I_{2(g)} \longrightarrow 2\ HI_{(g)}$

   b) $O_{2(g)} + 2\ F_{2(g)} \longrightarrow 2\ F_2O_{(g)}$

   c) $3\ Mg_{(s)} + N_{2(g)} \longrightarrow Mg_3N_{2(s)}$

3. Identify the reducing agents in the following reactions. Which of the reactants are reduced?

   a) $CO_{(g)} + PbO_{(s)} \longrightarrow CO_{2(g)} + Pb_{(s)}$

   b) $Br_{2(aq)} + SO_{2(g)} + 2\ H_2O_{(l)} \longrightarrow 2\ HBr_{(aq)} + H_2SO_{4(aq)}$

   c) $2\ NaBr_{(aq)} + Cl_{2(aq)} \longrightarrow 2\ NaCl_{(aq)} + Br_{2(aq)}$

4. Show that in the following balanced redox reactions the increase in oxidation numbers equals the decrease.

   a) $N_2 + 3\ H_2 \longrightarrow 2\ NH_3$

   b) $2\ Fe^{3+} + 2\ I^- \longrightarrow 2\ Fe^{2+} + I_2$

   c) $2\ KClO_3 \longrightarrow 2\ KCl + 3\ O_2$