Chem 112L – M______ Name:_______________/Partner_________

GTA:_______________ Date: _____________

Lab #7 – Redox Reactions

1. Redox Reactions

1.1. Oxidation numbers

1.1.1. Flow chart and lecture will be available on D2L

1.2. Types of redox reactions

1.2.1. Combustion

1.2.2. Single Replacement

1.2.3. Double Replacement

1.2.4. Synthesis

1.2.5. Decomposition

1.3. Activity Series

1.3.1. Electroplating

2. Learning Objectives

2.1. Practice using oxidation numbers.

2.2. Observing oxidation number and metal solution color relationship.

2.3. Identifying different types of redox reactions.

2.4. Observing the Activity Series.

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3. **Equipment**
   3.1. Test Tubes
   3.2. Test tube rack
   3.3. Beakers
4. **Chemicals**
   4.1. HCl
   4.2. $Fe(NO_3)_3$
   4.3. $Ni(NO_3)_2$
   4.4. $Zn(NO_3)_2$
   4.5. $Cu(NO_3)_2$
   4.6. $NaNO_3$
5. **Additional Resources**
   5.1. https://chemistrytalk.org/understanding-oxidation-states/
   5.2. https://chem.libretexts.org/Bookshelves/Analytical_Chemistry/Supplemental_Modules_(Analytical_Chemistry)/Electrochemistry/Redox_Chemistry/Oxidation_States_(Oxidation_Numbers)
   5.3. https://www.youtube.com/watch?v=iSAwDJTLIKY
   5.4. https://www.youtube.com/watch?v=j0hl-a6EWWo
   5.5. https://www.chemistrylearner.com/chemical-reactions

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6. Introduction

6.1. Redox Reactions

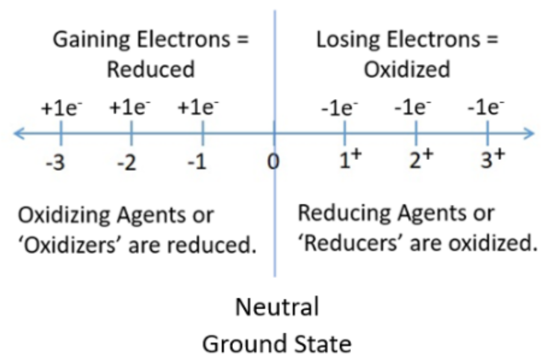
In chemistry we like to try to classify reactions into general categories. We have several different specific vocabulary words to help us better describe the similarities that allow us to categorize chemical properties. There are precipitation reactions, acid-base reactions, combustion reactions, decomposition reactions, and plenty more. This lab is about redox reactions. Redox reactions are reactions where electrons are transferred between species. The species can be just about anything, ions, atoms, or molecules. We call the reactions "Redox" reactions as a portmanteau word that combines the 'red' from reduced and the 'ox' from oxidized into one word. There are lots of different types of redox reactions. To be able to discuss the transfer of electrons, we need a system to keep track of which species is gaining or losing the electrons. This is where oxidation numbers come in.

6.2. Oxidation Numbers

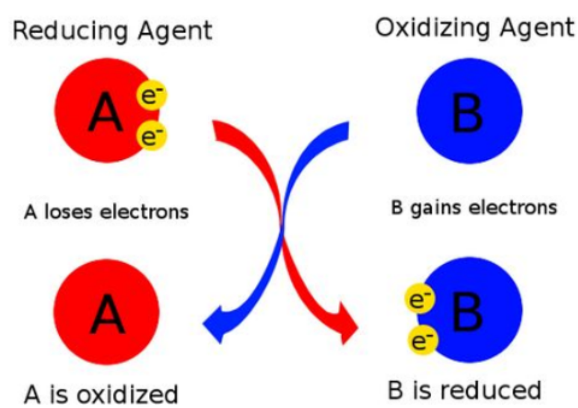
Oxidation states are a method of tracking the number of electrons an atom may be gaining or losing as a process of a chemical reaction. A neutral species or one in its elemental form has not gained nor lost any electrons is has an oxidation number of zero. Additional electrons reduce the oxidation number to a negative number equal to the additional electrons. We say the species has been reduced. Losing electrons shifts the oxidation number to a positive number equal to the number of electrons lost. Oxygen is a great electron acceptor (thief!) and so when the oxidation number is shifted to be more positive, we say the species is oxidized. Historically, oxygen is where many of these first reduction / oxidation reactions were first observed.

It is unfortunate that the terms are all so very similar. There are many mnemonics out there to help. LEO goes GER is one where LEO stands for loss of electrons is oxidation and GER stands for gain of electrons is reduction. Another mnemonic is OIL RIG: 'oxidation is loss' and 'reduction is gain' of electrons. There are many other mnemonics out there, find one and use it.

One key idea to remember is that oxidation and reduction are always paired together. There must be a means of transferring the electron, so one participant in the reaction will always be reduced and one will always be oxidized.



For this lab, we will be identifying oxidation states in the post-lab section and seeing how we can balance some simple redox equations step-by-step. The rules for how to identify an oxidation state are not hard.



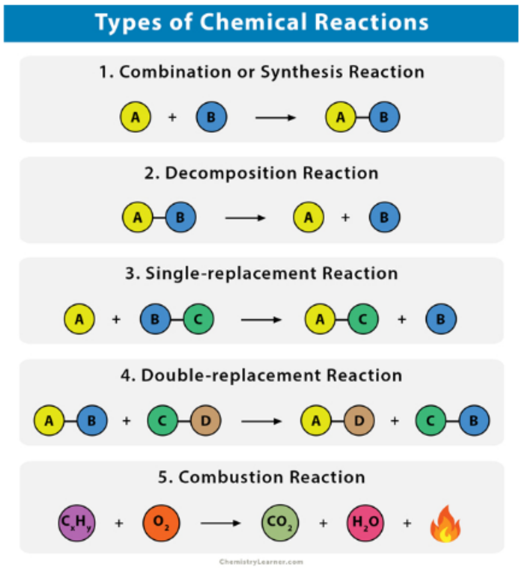
The sum of all the oxidation states must equal zero for all uncharged species. All elemental forms are neutral, that is the oxidation state is zero. Monoatomic ions have the same number for the oxidation state as the charge. Polyatomic ions will have the sum of the atomic oxidation numbers add up to the overall charge of the polyatomic ion. The periodic trends for ionic forms are very helpful for determining the oxidation states. Group 1, alkali metals will have an oxidation number of 1^+ just like they would as ions. Group 2, alkali earth metals, will have an oxidation number of 2^+ when not in elemental form. Halides will typically be 1^- just as they would typically have that anionic charge, but only fluorine must be 1^-. Hypervalency means that some halides will be capable of having other oxidation states. Hydrogen will nearly always be 1^+, but it is technically possible for it to be 1^- when bonded to a metal that is less electronegative than it is, such as in the case of NaH. Oxygen will always be 2^- provided it isn't bonded to another oxygen forming a peroxide, in which case it is 1^-.

Elemental form	**zero** (0). Only one kind of atom present, no charge
Atomic ions	**= the charge on the atom** (monatomic ion)
Group 1A Li, Na, K, Rb, Cs	**+1** unless in elemental form
Group 2A Be, Mg, Ca, Sr, Ba	**+2** unless in elemental form
Hydrogen (H)	**+1** when bonded to a nonmetal, **-1** when bonded to a metal
Oxygen (O)	**-1** in peroxides O_2^-, **-2** in all other compounds (most common)
Fluorine (F)	**-1**, always
Neutral compounds	The sum of all oxidation numbers of atoms or ions in a neutral compound is **zero**.
Ionic compounds	The sum of all oxidation numbers of atoms in an ionic compound is the **charge** on the polyatomic ion.

6.3. Types of Redox Reactions

There are many different types of redox reactions as the definition is just that at least one electron is moving from one atom to another. Combining two species into one is called synthesis. The reverse where one species becomes two or more species is called decomposition.

The precipitation reactions from the previous lab are double replacement reactions. The two salts broke into cations and anions and traded which cation went with which anion, some of which formed solids. For the experiments that did not form a precipitate, there was no reaction.



This lab features the single replacement reaction. The metal activity series features one metal replacing another in a single replacement reaction. The single replacement reaction is common in corrosion reactions. It is also commonly featured in various types of electroplating techniques.

Combustion reactions typically feature a carbohydrate (carbohydrate = carbon + hydrogen and maybe oxygen) and an oxidizer (usually oxygen gas) and yield carbon dioxide, water, and heat. This reaction will feature in a later lab class.

6.4. Metal Activity Series

Extensive studies with many metals have led to the development of a metal activity series. The activity series is a ranking of the relative reactivity of metals in displacement and other kinds of oxidation-reduction reactions. The most reactive metals (like Li, K, Ba) appear at the top of the series, and are

The activity series for metals

$Li \rightarrow Li^+ + e^-$	React with cold water to produce H_2
$K \rightarrow K^+ + e^-$	
$Ba \rightarrow Ba^{2+} + 2e^-$	
$Ca \rightarrow Ca^{2+} + 2e^-$	
$Na \rightarrow Na^+ + e^-$	
$Mg \rightarrow Mg^{2+} + 2e^-$	React with steam to produce H_2
$Al \rightarrow Al^{3+} + 3e^-$	
$Zn \rightarrow Zn^{2+} + 2e^-$	
$Cr \rightarrow Cr^{3+} + 3e^-$	
$Fe \rightarrow Fe^{2+} + 2e^-$	
$Cd \rightarrow Cd^{2+} + 2e^-$	
$Co \rightarrow Co^{2+} + 2e^-$	React with acids to produce H_2
$Ni \rightarrow Ni^{2+} + 2e^-$	
$Sn \rightarrow Sn^{2+} + 2e^-$	
$Pb \rightarrow Pb^{2+} + 2e^-$	
$H_2 \rightarrow 2H^+ + 2e^-$	
$Cu \rightarrow Cu^{2+} + 2e^-$	Do not react with water or acids to produce H_2
$Ag \rightarrow Ag^+ + e^-$	
$Hg \rightarrow Hg^{2+} + 2e^-$	
$Pt \rightarrow Pt^{2+} + 2e^-$	
$Au \rightarrow Au^{3+} + 3e^-$	

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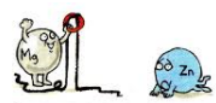
very powerful reducing agents that readily form cations. Metals near the bottom of the series (Au, Ag) are poor reducing agents that do not readily form cations. Their cations (Au^{+}, Ag^{+}), however, are powerful oxidizing agents that readily react to form the free metal. Two metals will have different strengths to pull on an electron or an oxidizer like oxygen and knowing the relative pull the metals can exert allows us to predict which reactions will occur and which will not. The cartoon below depicts magnesium and zinc both tugging on oxygen as an oxidizer, magnesium is much more easily oxidized so it wins the tug-of-war in the cartoon.

gnesium and zinc both want the oxygen



Magnesium wins the 'tug-of-war'

An element higher in the activity series will displace an element below it in the series from its components. For example, metallic zinc displaces copper from a Cu^{2+} solution and nickel form a Ni^{2+} solution.

$$Zn(s) + Cu^{2+}(aq) \rightarrow Cu(s) + Zn^{2+}(aq)$$

$$Zn(s) + Ni^{2+}(aq) \rightarrow Ni(s) + Zn^{2+}(aq)$$

This means that zinc metal must lie above copper metal and nickel metal in the activity series.

In today's laboratory experiment, you will construct a partial metal activity series by studying which cations a given metal is able to displace from solution. The series of half- reactions that will be studied are listed below:

$$H^{+}(aq) + e^{-} \rightarrow H_2(g)$$

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

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

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$$Fe^{3+}(aq) + 3e^- \rightarrow Fe(s)$$

$$Ni^{2+}(aq) + 2e^- \rightarrow Ni(s)$$

$$Cu^{2+}(aq) + 2e^- \rightarrow Cu(s)$$

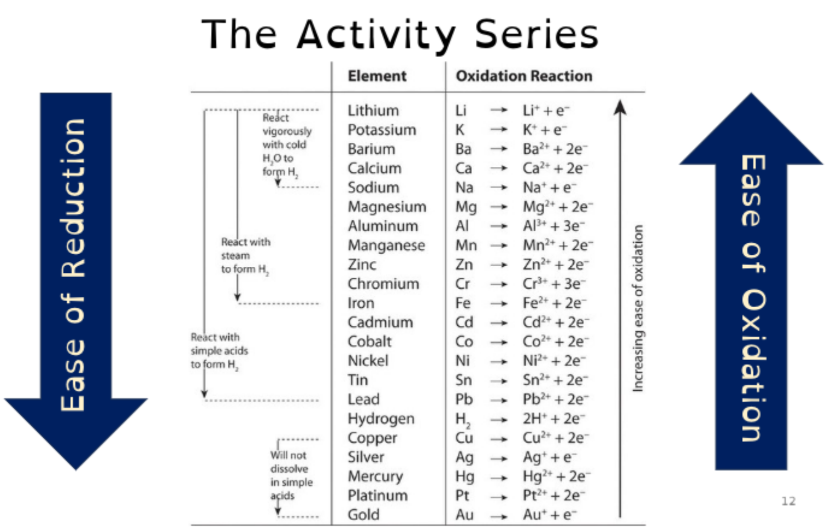
$$Zn^{2+}(aq) + 2e^- \rightarrow Zn(s)$$

The half-reactions are not listed in order of reactivity, but rather in terms of increasing atomic number. In deciding whether or not a reaction has occurred, look for color changes (both the solution and the metal), gas bubbles and the appearance of new substances.

7. Procedure

7.1. Precipitation experiment

It will take too long for you to perform all of the experiments necessary to establish the activity series. This experiment is to be done as a group experiment where each person (or group) is responsible for setting up and conducting one of the following set of experiments for class display. Sequentially each group should perform their task as the other students watch. Some of the reactions may be immediate, but others may take several minutes for some observable change to occur. Each display should be observed by each student a second time after a half-hour has past. That is, all students



will observe each demonstration as it is first performed, and then again, about a half-hour later. Each reaction should be carefully labeled with a piece of paper on the laboratory bench top so that all persons will be able to identify the respective reaction when they make their second tour around the laboratory room. The labels need to clearly indicate the reaction, for example, "Zn + $Cu(NO_3)_2$ " or "HCl + Fe".

7.1.1. Group 1:

Place about 2 ml of each of the following in different test tubes (all solutions should be at least I Molar):

$HCl{\cdot}Fe(NO_3)_3$ $Ni(NO_3)_2$ $Zn(NO_3)_2$ $Cu(NO_3)_2$ $NaNO_3$

Add a clean piece or strip of **copper** to each test tube, swirl and record your observations with the entire class watching.

7.1.2. Group 1:

Place about 2 ml of each of the following in different test tubes (all solutions should be at least I Molar):

$HCl{\cdot}Fe(NO_3)_3$ $Ni(NO_3)_2$ $Zn(NO_3)_2$ $Cu(NO_3)_2$ $NaNO_3$

Add a clean piece or strip of **iron** to each test tube, swirl and record your observations with the entire class watching.

7.1.3. Group 3:

Place about 2 ml of each of the following in different test tubes (all solutions should be at least I Molar):

$HCl{\cdot}Fe(NO_3)_3$ $Ni(NO_3)_2$ $Zn(NO_3)_2$ $Cu(NO_3)_2$ $NaNO_3$

Add a clean piece or strip of **nickel** to each test tube, swirl and record your observations with the entire class watching.

7.1.4. Group 5:

Place about 2 ml of each of the following in different test tubes (all solutions should be at least I Molar):

$HCl{\cdot}Fe(NO_3)_3$ $Ni(NO_3)_2$ $Zn(NO_3)_2$ $Cu(NO_3)_2$ $NaNO_3$

Add a clean piece or strip of **zinc** to each test tube, swirl and record your observations with the entire class watching.

7.1.5. Group 5:

Place about 2 ml of each of the following in different test tubes (all solutions should be at least I Molar):

$HCl{\cdot}Fe(NO_3)_3$ $Ni(NO_3)_2$ $Zn(NO_3)_2$ $Cu(NO_3)_2$ $NaNO_3$

Add a clean piece or strip of **aluminum** to each test tube, swirl and record your observations with the entire class watching. You will have to gently sand the aluminum with sandpaper or an emery board to remove any oxide coating that might have formed.

Additional Observation:

When sodium metal is added to water it reacts vigorously/violently. Water is a weak acid, having $[H_3O^+] = 1 \times 10^{-7}$. This piece of information combined with the observations that you made in regard to the sodium nitrate solutions should allow you to place correctly sodium metal on the metal activity scale.

8. Data Sheet

8.1. Group 1:

Describe the reaction of copper metal with:

HCl: ____

$Fe(NO_3)_3$: ____

$Ni(NO_3)_2$: ____

$Zn(NO_3)_2$: ____

$Cu(NO_3)_2$: ____

$NaNO_3$: ____

8.2. Group 2:

Describe the reaction of iron metal with:

HCl: ____

$Fe(NO_3)_3$: ____

$Ni(NO_3)_2$: ____

$Zn(NO_3)_2$: ____

$Cu(NO_3)_2$: ____

$NaNO_3$: ____

8.3. Group 3:

Describe the reaction of nickel metal with:

HCl: ____

$Fe(NO_3)_3$: ____

$Ni(NO_3)_2$: ____

$Zn(NO_3)_2$: ____

$Cu(NO_3)_2$: ____

$NaNO_3$: ____

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8.4. Group 4:

Describe the reaction of zinc metal with:

HCl: ______________________________

$Fe(NO_3)_3$: ______________________________

$Ni(NO_3)_2$: ______________________________

$Zn(NO_3)_2$: ______________________________

$Cu(NO_3)_2$: ______________________________

$NaNO_3$: ______________________________

8.5. Group 5:

Describe the reaction of aluminum metal with:

HCl: ______________________________

$Fe(NO_3)_3$: ______________________________

$Ni(NO_3)_2$: ______________________________

$Zn(NO_3)_2$: ______________________________

$Cu(NO_3)_2$: ______________________________

$NaNO_3$: ______________________________

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9. Post-Lab Questions

9.1. Label the 6 half-reactions below in order of decreasing tendency to proceed in the indicated direction. Place "l" besides the least reactive metal, and "6' besides the most reactive metal. The H+/H half-reaction is also included in the list.

___________$H^+(aq) + e^- \rightarrow H_2(g)$

___________$Na^+(aq) + e^- \rightarrow Na(s)$

___________$Al^{3+}(aq) + 3e^- \rightarrow Al(s)$

___________$Fe^{3+}(aq) + 3e^- \rightarrow Fe(s)$

___________$Ni^{2+}(aq) + 2e^- \rightarrow Ni(s)$

___________$Cu^{2+}(aq) + 2e^- \rightarrow Cu(s)$

___________$Zn^{2+}(aq) + 2e^- \rightarrow Zn(s)$

9.2. Show your work and determine the oxidation state of each atom in the following:

9.2.1. HNO_3 H:__________N:__________O:________________

9.2.2. NaH Na:_______________H:______________________

9.2.3. H_2SO_4 H:________________S:__________O:__________

9.2.4. $AlCl_3$ Al:_______________Cl:_____________________

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9.2.5. SO_3 S:________________ O:________________________

9.2.6. $Zn(OH)_2^{-4}$ Zn:________________ O:__________ H:__________

9.2.7. ClO^{-4} Cl:________________ O:________________________

9.2.8. K_2CrO_4 K:__________ Cr:________________ O:__________

9.2.9. $MgSO_4$ Mg:_________ S:__________ O:________________

9.2.10. $CaCr_2O_7$ Ca:_________ Cr:________________ O:__________

9.2.11. $(NH_4)_2MoO_4$ N:__________________ H:________________________

Mo:________________ O:________________________

9.2.12. $Na_3Co(NO_2)_6$ Na:________________ Co:______________________

N:________________ O:________________________

9.3. Consider the decomposition reaction:

$$I_2 + I^- \rightarrow I_3^-.$$

9.3.1. What are the oxidation states of each part of the equation?

I_2

I^-

I_3^-

9.4. Consider the double displacement reaction:

$$2Cu^{2+}(aq) + 4I^-(aq) \rightarrow 2CuI(s) + I_2(s).$$

9.4.1. How many electrons are being transferred for each half reaction?

$2Cu^{2+}(aq)$ + ______e^- → 2CuI(s)

$4I^-(aq)$ → 2CuI(s) + ____e^-

9.5. Thought experiment: How might separating a chemical equation into parts and deliberately writing out the electron transfer help to balance redox reactions?

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10. Summary and Conclusions

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