Experiment 6: Chemical Reactions and the Activity Series

(This experiment was adapted from two experiments from Santa Monica College: CH10 Chemical Reactivity and Types of Chemical Reactions.)

Purpose:

a) To perform and observe the results of a variety of single and double displacement reactions
b) To become familiar with some of the observable signs of these reactions
c) To identify the products formed in each of these reactions
d) To write balanced chemical equations for each single and double displacement reaction studied

Background

During a chemical reaction both the form and composition of matter are changed. Old substances are converted to new substances, which have unique physical and chemical properties of their own. Some of the observable signs that a chemical reaction has occurred include the following:

- A metallic deposit appears
- Bubbles appear
- A temperature change occurs
- A color change occurs
- A precipitate appears (cloudy, tiny particles)

Single Displacement Reactions

All single displacement reactions have the general form: **A + BC → B + AC**
Here, A is an element and BC is usually an aqueous ionic compound or an acid (consisting of B^+ and C^- aqueous ions). A displaces B in BC, resulting in the formation of a new element B and a new ionic compound or acid, AC. If the new element B is a metal, it will appear as a solid. If it is a gas, it will appear as bubbles.
An *Activity Series* of elements is often used to determine if A will displace B in a single displacement reaction. An *Activity Series* is provided on page 4. As a rule, if A has a higher activity that B, a single displacement reaction will occur. However, if A has lower activity than B, a single displacement reaction will <u>not</u> occur.

Double Displacement Reactions

All double displacement reactions have the general form: **AB + CD → AD + CB**
Reactions that can be classified as double displacements include precipitation reactions, neutralization reactions, and gas forming reactions.

Precipitation Reactions

Here AB and CD are usually aqueous ionic compounds (or acids) consisting of aqueous ions (A^+ and B^-, C^+ and D^-). When a double displacement reaction occurs, the cations and anions switch partners, resulting in the formation of two new ionic compounds AD and CB, one of which is in the solid state. This solid product is an insoluble ionic compound called a precipitate. To determine whether a product compound will be soluble (aq) or insoluble (s), consult the *Solubility Guidelines*. Note that if both of the predicted products are soluble, a precipitation reaction will not occur.

Neutralization Reactions

Here AB is an acid (consisting of H^+ and X^- aqueous ions) and BC is a base (consisting of M^+ and OH^- ions). When a double displacement reaction occurs, the cations and anions switch partners, resulting in the formation of water and a new ionic compound (a salt), which is usually soluble. Neutralization reactions are exothermic, and are generally accompanied by a noticeable release of heat.

Gas Forming Reactions

In these reactions one of the products after the double displacement is in the gaseous state (AD or CB). One such example is hydrogen sulfide (H_2S). However, one of the products could also be carbonic acid (H_2CO_3) or sulfurous acid (H_2SO_3). Both carbonic acid and sulfurous acid are unstable and will decompose to form carbon dioxide and sulfur dioxide gases, respectively:

Carbonic acid
H_2CO_3 (*aq*) → H_2O (*l*) + CO_2 (*g*)

Sulfurous Acid
H_2SO_3 (*aq*) → H_2O (*l*) + SO_2 (*g*)

Writing Equations for Reactions

- Write the correct formulas for each reactant and place a yield arrow (→) after the last reactant.
- Identify the reaction type (single or double displacement)
- If you determine that a reaction will occur, write the correct formula(s) of the products after the arrow. If you determine that a reaction will not occur, simply write “no reaction” after the arrow
- Balance the equation
- Be sure to include the physical states of all reactants and products in your final equation.

Safety

Be especially cautious when using the 6 M acid and base solutions as they can burn your skin. Also be aware that skin discoloration will result from contact with $AgNO_3$.

Chemicals
Metals: Aluminum, Copper, Zinc, Magnesium
Solutions: 6M sodium hydroxide 6M hydrochloric acid
All of the following solutions are 0.1 M: barium chloride, copper(II) sulfate, iron(III) chloride, silver nitrate, sodium carbonate, sodium hydroxide, sodium phosphate, sodium sulfate, zinc nitrate.

Equipment
10 small test tubes test tube rack Parafilm plastic dropper

Solubility Guidelines:

Ions that form soluble compounds (aq)…….. except when combined with …….	
Group I ions (Na^+, Li^+, K^+, etc)	no exceptions
Ammonium (NH_4^+)	no exceptions
Nitrate (NO_3^-)	no exceptions
Acetate (CH_3COO^-)	no exceptions
Hydrogen carbonate (HCO_3^-)	no exceptions
Chlorate (ClO_3^-)	no exceptions
Halides (F^-, Cl^-, Br^-)	Pb^{2+}, Ag^+ and Hg_2^{2+}
Sulfate (SO_4^{2-})	Ag^+, Ca^{2+}, Sr^{2+}, Ba^{2+}, Hg_2^{2+} and Pb^{2+}

Ions that form insoluble compounds (s)…….except when combined with….	
Carbonate (CO_3^{2-})	group I ions (Na^+, Li^+, etc) or (NH_4^+)
Chromate (CrO_4^{2-})	group I ions (Na^+, Li^+, etc) or Ca^{2+}, Mg^{2+} or (NH_4^+)
Phosphate (PO_4^{3-})	group I ions (Na^+, Li^+, etc) or (NH_4^+)
Sulfide (S^{2-})	group I ions (Na^+, Li^+, etc) or (NH_4^+)
Hydroxide (OH^-)	group I ions (Na^+, Li^+, etc) or Ca^{2+}, Mg^{2+}, Sr^{2+} or (NH_4^+)

Activity Series Table

$Li_{(s)} \rightarrow Li^{1+}_{(aq)} + 1e^-$ **Highest Activity (easily oxidized)**
$K_{(s)} \rightarrow K^{1+}_{(aq)} + 1e^-$
$Ba_{(s)} \rightarrow Ba^{2+}_{(aq)} + 2e^-$
$Ca_{(s)} \rightarrow Ca^{2+}_{(aq)} + 2e^-$
$Na_{(s)} \rightarrow Na^{1+}_{(aq)} + 1e^-$
$Mg_{(s)} \rightarrow Mg^{2+}_{(aq)} + 2e^-$
$Al_{(s)} \rightarrow Al^{3+}_{(aq)} + 3e^-$
$Mn_{(s)} \rightarrow Mn^{2+}_{(aq)} + 2e^-$
$Zn_{(s)} \rightarrow Zn^{2+}_{(aq)} + 2e^-$
$Cr_{(s)} \rightarrow Cr^{3+}_{(aq)} + 3e^-$
$Fe_{(s)} \rightarrow Fe^{2+}_{(aq)} + 2e^-$
$Cd_{(s)} \rightarrow Cd^{2+}_{(aq)} + 2e^-$
$Ni_{(s)} \rightarrow Ni^{2+}_{(aq)} + 2e^-$
$Sn_{(s)} \rightarrow Sn^{2+}_{(aq)} + 2e^-$
$Pb_{(s)} \rightarrow Pb^{2+}_{(aq)} + 2e^-$
$H_{2\,(s)} \rightarrow 2\,H^{1+}_{(aq)} + 2e^-$
$Cu_{(s)} \rightarrow Cu^{2+}_{(aq)} + 2e^-$
$Ag_{(s)} \rightarrow Ag^{1+}_{(aq)} + 1e^-$
$Hg_{(l)} \rightarrow Hg^{2+}_{(aq)} + 2e^-$
$Au_{(s)} \rightarrow Au^{3+}_{(aq)} + 3e^-$ **Lowest Activity (not easily oxidized)**

Procedure

- Always reuse clean test tubes that have been rinsed with ***distilled water***. The test tubes do not have to be dry. At the end of this experiment, do a final rinse of your test tubes and dispose of them in the broken glass container.
- Use approximately 2 mL quantities of all solutions (about the stem of a plastic dropper)
- For reactions involving metals, use just 1-2 pieces of each metal. Place the metal in the test tube first, and then add the solution. The metal should be completely immersed in the solution used.
- Perform the following reactions and record your observations in your notebook worksheet, in the order shown below. Note that some redox reactions take longer than others. If results are not obtained immediately, give the reaction some time. You may have to warm the test tube contents in the hot water bath in the hood.

All waste is to be disposed of in the waste container in the hood.

1. Aqueous barium chloride + aqueous sodium sulfate

2. Aqueous sodium phosphate + aqueous barium chloride
3. Aqueous sodium phosphate + aqueous copper(II) sulfate
4. Aqueous sodium phosphate + aqueous iron(III) chloride
5. Aqueous sodium phosphate + aqueous zinc nitrate

6. Aqueous sodium hydroxide + aqueous barium chloride
7. Aqueous sodium hydroxide + aqueous copper(II) sulfate
8. Aqueous sodium hydroxide + aqueous iron(III) chloride
9. Aqueous sodium hydroxide + aqueous zinc nitrate

10. Hydrochloric acid (6 M) + aqueous sodium hydroxide (6 M)

11. Aqueous sodium carbonate + aqueous barium chloride
12. Aqueous sodium carbonate + aqueous copper(II) sulfate
13. Aqueous sodium carbonate + aqueous iron(III) chloride
14. Aqueous sodium carbonate + aqueous zinc nitrate
15. Aqueous sodium carbonate + aqueous sodium sulfate

16. Aluminum metal + hydrochloric acid
17. Copper metal + hydrochloric acid
18. Magnesium metal + hydrochloric acid
19. Zinc metal + hydrochloric acid

20. Aluminum metal + iron(III) chloride
21. Copper metal + iron(III) chloride
22. Magnesium metal + iron(III) chloride
23. Zinc metal + iron(III) chloride

24. Aluminum metal + zinc nitrate
25. Copper metal + zinc nitrate
26. Magnesium metal + zinc nitrate

27. Aluminum metal + copper(II) sulfate
28. Magnesium metal + copper(II) sulfate
29. Zinc metal + copper(II) sulfate

30. Copper metal + aqueous silver nitrate