Experiment 11
Single Displacement Reactions

Jay C. McLaughlin
Colorado Northwestern Community College

Name:

Date:

Key Objectives

1. Understand Activity Series and use it to predict if a reaction occurs.
2. Write complete Single Displacement chemical reactions
   (a) Balance charges.
   (b) Balance atoms.
   (c) Include states when known.
3. Recognize when no reaction (NR) occurs.
4. Use a solubility table to determine the state of compounds.

Discussion

The chemical reactivity of elements varies over an immense range. Some, like sodium and chlorine are so reactive that they are never found in a pure state, and instead always form compounds. Others like xenon and platinum are nearly inert and can be made to form compounds with other elements only under special conditions. In this experiment we will explore the relative reactivity of the elements, and establish a reactivity order.

The reactivity of an element is related to its tendency to gain and lose electrons. An element which loses electrons in a reaction is said to be **oxidized**, and an element that gains electrons in a reaction is said to be **reduced**. In a chemical reaction, oxidation and reduction of elements is always paired, resulting in an exchange of electrons. It is this exchange of electrons which is the primary driving force for the reaction to occur. Oxidation and reductions reactions are very important industrially for the electroplating of metals, production of batteries and cathodic protection.

It is possible to arrange nearly all of the elements into a single series in order of their reactivities (ability to be oxidized or reduced). A series of this kind is commonly called an **activity series**.

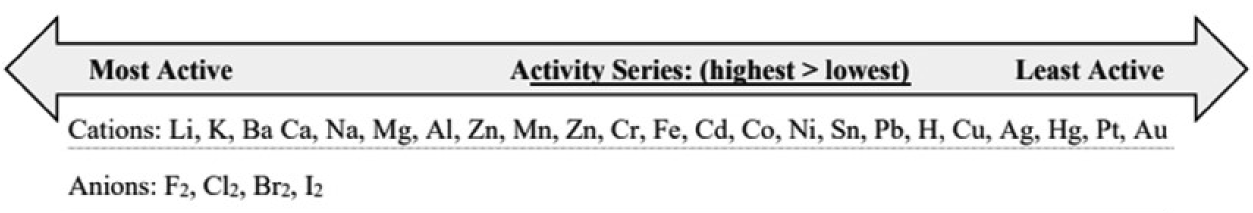

Figure 11.1: The reactivity of elements decreases going from left (most active) to right (least active). credit: author

One key to successfully completing single displacement reactions is to know which elements are metals and form cations (+) and which elements are nonmetals and form anions (-). Metals are to the left of the **metalloids** (B, Si, Ge, As, Sb, Te and Po/At) except for Hydrogen which is considered a nonmetal. The nonmetals are to the right of the metalloids as shown in Figure 11.2.

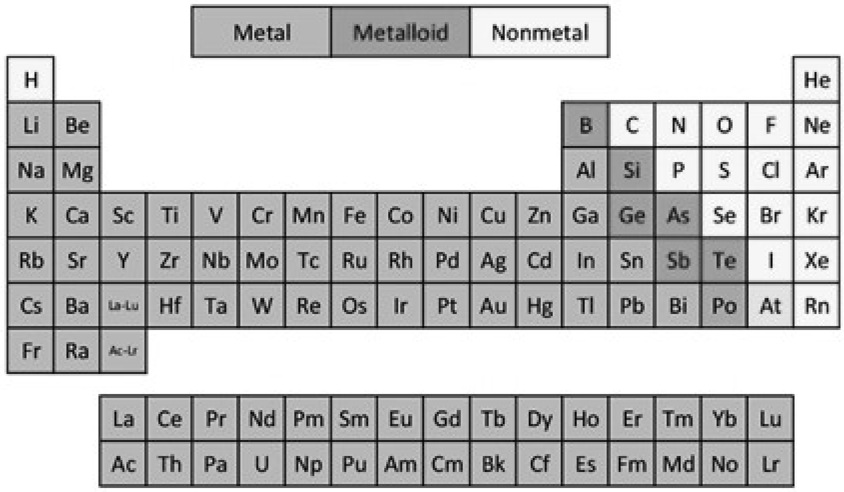

Figure 11.2: Periodic table illustrating the metalloids, metals and nonmetals. credit: unknown

A generalized single displacement reaction is given below. If the element A is more reactive then it will displace the less reactive element and form a new compound. If element A is less active then no reaction will occur. Which reaction occurs depends on if element A is a metal or nonmetal and thus more likely to form a cation or anion. If element A is a metal it will displace the metal/cation (B) in the compound or if element A is a nonmetal it will displace the nonmetal/anion (C) in the compound,

$$\mathrm{A + BC(aq) \longrightarrow B + AC(aq)} \qquad \text{or} \qquad \mathrm{A + BC(aq) \longrightarrow C + BA(aq)} \tag{21}$$

A more visual representation of what occurs is shown in Figure 11.3, the Element (E) swaps with either the cation (if E is a metal) or the anion (if E is a nonmetal) as long as the Element (E) is more reactive than the cation or anion in the compound. If it is not no reaction will occur.

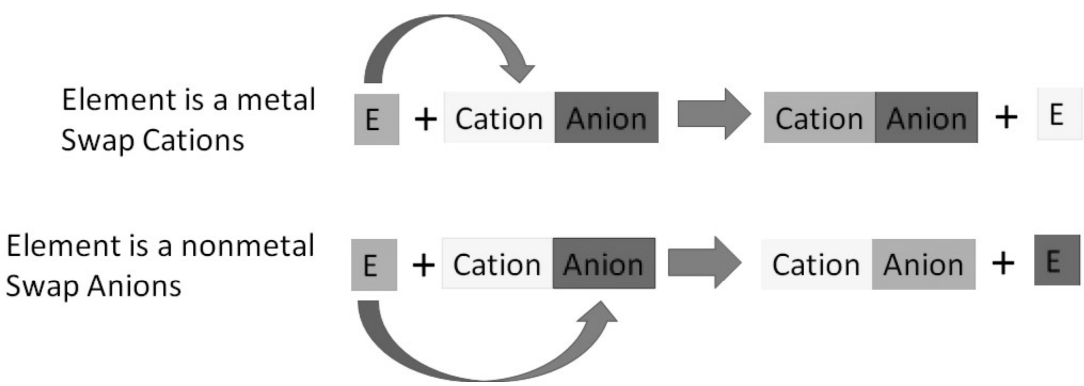

Figure 11.3: Another way of visualizing single displacement reactions. The nature of the element (metal or nonmetal) determine what elements swap (cations or anions). credit: author

One last way of thinking about single displacement reactions is illustrated in the cartoon in Figure 11.4.

A couple of examples will help to clarify what will occur in this experiment.

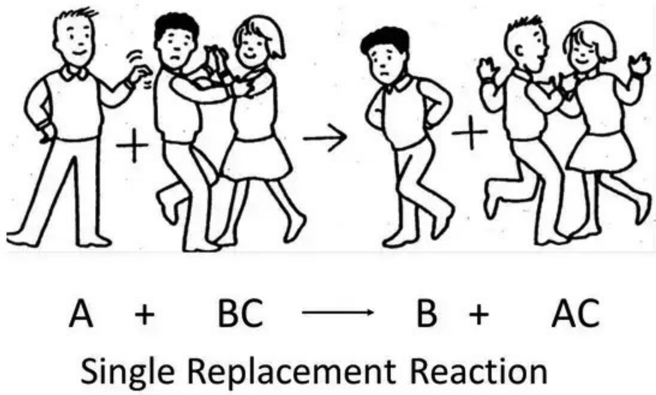

Figure 11.4: Cartoon illustrating the concept of single displacement reactions, the better dancer (A) displaces the bad dancer (B) and gets to dance with the girl (C). credit: unknown

Example 1

A few drops of mercury metal is reacted with a solution of copper (II) chloride. No reaction is observed. We can write the complete chemical equation as:

$$\mathrm{Hg(l) + CuCl_2(aq) \longrightarrow NR} \tag{22}$$

We conclude then that mercury is less reactive than copper (Hg $<$ Cu) because it will not displace copper from the compound. Similarly we could say that Cu is more reactive than Hg and thus desires to be in the compound more than Hg. (Cu $>$ Hg)

Example 2

A strip of metallic copper is immersed in a solution of mercury (II) chloride. After several minutes, the solution becomes pale green and the copper strip is coated with a metallic color. We can write the complete chemical reaction as:

$$\mathrm{Cu(s) + HgCl_2(aq) \longrightarrow Hg(s) + CuCl_2(aq)} \tag{23}$$

We conclude then that copper is more reactive than mercury and will displace mercury from compounds. (Cu $>$ Hg)

From the second example we can see that the oxidation number (relative charge on the atoms) that the copper lost two electrons and went from an oxidation number of 0 $\longrightarrow$ $+2$, thus it was oxidized. Mercury gained two electrons and went from an oxidation number of $+2$ $\longrightarrow$ 0, thus it was reduced. The chlorine remained unchanged in the reaction with an oxidation state of -1. We can summarize this by stating:

$$Cu^0(s) + Hg^{+2}(aq) \longrightarrow Hg^0(s) + Cu^{+2}(aq) \tag{24}$$

Procedure

An exciting new discovery has been made! Six new elements (5 metals and 1 gas) have been discovered. It is your job to create an activity series for these new elements. In this experiment you will be observing the reactions of various solid metals and aqueous solutions of a second metal. From this data we will be able to generate an activity series for the new elements.

The new metals are being named after their discoverer and have the temporary symbols of J1, J2, J3, J4, J5, J6. The charges of each metal have been determined to be: $J1^{+2}$, $J2^{+2}$, $J3^{+1}$, $J4^{+3}$, $J5^{+2}$, $J6^{+1}$.

Read the entire procedure before beginning the experiment.

1. The reactions may be done in any order desired.
2. Label 6 clean test tubes 1-6. To each test tube add about 3 mL of the aqueous solution.
3. Add the appropriate thin strip of the solid metal to the test tube indicated.
   (a) Tube 1: J3 (I) Nitrate + J4 strip.
   (b) Tube 2: J4 (III) Nitrate + J1 strip.
   (c) Tube 3: J1 (II) Nitrate + J2 strip.
   (d) Tube 4: J5 (II) Sulfate + J2 strip.
   (e) Tube 5: J6 (I) Sulfate + J2 strip.
   (f) Tube 6: J6 (I) Sulfate + J4 strip.
4. Observe the contents of each tube carefully and record any evidence of a chemical reaction. Some reactions may be slow to occur or difficult to detect. If no immediate evidence of a reaction occurs, set the tube aside for 10 minutes and then reexamine it.
5. After the reactions are complete:
   (a) Remove the metal strips from each test tube and place them in the labeled beaker.
   (b) Pour the solutions in each test tube into the “Experiment SD - Heavy Metals” waste container.
6. Write the complete chemical reaction (balanced, and include the states where known) for each test tube in the data table. If NO REACTION occurs write the reactants $\longrightarrow$ NR. Answer all of the questions before leaving. Ex: $J3_2SO_4(aq) + J_1(s) \longrightarrow$

Results

TT #	Observations	Complete Chemical Equation
1.		
2.		
3.		
4.		
5.		
6.		

Table 11.1: Results

Post Lab Questions

1. Complete the following table by writing the symbols of the two elements whose reactivities are being compared in each test. Explain how you determined which element was the most active in the space below the table.

TT #	**1**	**2**	**3**	**4**	**5**	**6**
More Active Metal:						
Less Active Metal:						

Table 11.2: Relative Activity of Tested Metals

Explanation:

2. Arrange J1, J2, and J4 in order from highest activity to lowest activity (Ex: A $>$ B $>$ C).

3. Arrange J5, J6, and J3 in order from highest activity to lowest activity (Ex: A $>$ B $>$ C).

4. Arrange J3, J4, and J5 in order from highest activity to lowest activity (Ex: A $>$ B $>$ C).

5. Arrange all 5 metals (excluding J6) in order from highest activity to lowest activity (Ex: A $>$ B $>$ C). Explain your ordering based on the observations made in test tubes 1-6 or on the previous 3 questions.

6. On the basis of the reactions observed in test tubes 1-6 explain why it is not possible to place J6 in the activity series in the previous question?

7. Write a chemical reaction(s) (using chemicals available in the experiment) that would allow you to place J6 in the activity series. Only write the Reactants side of the reaction.

8. If the reaction written in the previous question results in NO REACTION, write the complete activity series for all 6 elements in order from highest activity to lowest activity.

9. Using the activity series in your book/cheat sheet complete the following reactions. If the reaction will occur complete and balance each compound, and equation, properly indicate the state of all products where known. If no reaction will occur write "No reaction" or "NR" as the products.

   (a) ___ H_2(g) + ___ $AgNO_3$(aq) $\longrightarrow$

   (b) ___ $Pb(C_2H_3O_2)_2$(aq) + ___ Na(s) $\longrightarrow$

   (c) ___ H_2SO_4(aq) + ___ Mg(s) $\longrightarrow$

   (d) ___ Pb(s) + ___ $Cu(NO_3)_2$(aq) $\longrightarrow$

   (e) ___ $AlBr_3$(aq) + ___ Cl_2(g) $\longrightarrow$

   (f) ___ $ZnSO_4$(aq) + ___ Mg(s) $\longrightarrow$

   (g) ___ Cl_2(g) + ___ NaI(aq) $\longrightarrow$

   (h) ___ $Al_2(SO_4)_3$(aq) + ___ Na(s) $\longrightarrow$

   (i) ___MgF_2(aq) + ___I_2(s) $\longrightarrow$

   (j) ___ Zn(s) + ___ H_3PO_4(aq) $\longrightarrow$

I thought of adding a bunch of extra questions to fill up the blank space, but was in a good/lazy mood when I wrote this so didn't add any!