Experiment 10 - Single Replacement Reactions

A single replacement reaction is a type of oxidation-reduction reaction. In a single replacement reaction (also called a single displacement reaction), an element reacts with an ionic compound to give a different free element and a different ionic compound. The general form of a single replacement reaction looks like this:

$$A + BC \rightarrow B + AC$$

Where A is an element, BC is an ionic compound consisting of positively charged B ions and negatively charged C ions, B is an element, and AC consists of positively charged A ions and negatively charged C ions. It is called a "single replacement" reaction because it appears as though the element A is replacing B in its compound. (In actuality, BC is usually a soluble compound, so it consists of separated B^{x+} ions and C^{x-} ions. Since they are already separated, it isn't really accurate to say that any replacement is occurring.) If this reaction occurs as written, it is said that A is more active than B. If it does not occur, B must be more active than A. (We are assuming, of course, that A and B do not have the same exact activity.)

Recall that oxidation-reduction reactions involve a transfer of electrons. The substance that gets oxidized loses electrons and its oxidation number increases. On the other hand, the substance that is getting reduced is gaining electrons and its oxidation number is therefore decreasing. In a reaction of this type, the element A is going from a zero oxidation number to a positive oxidation number. Its oxidation number is therefore increasing, so it is being oxidized. The substance B, however, is going from a positive to a zero oxidation number, and is therefore being reduced.

Therefore, the more active element is the one that is oxidized the most easily.

To use a specific example, if a strip of copper metal is immersed in a solution of mercury (II) chloride, a reaction occurs:

$Cu_{(s)}$	+	$HgCl_{2\,(aq)}$	$\rightarrow$	$CuCl_{2\,(aq)}$	+	$Hg_{(l)}$
Orange		colorless		pale blue		silvery or black

Two electrons are taken from each copper atom, and transferred to a mercury (II) ion, converting it to a neutral mercury atom. The process simultaneously converts Cu to Cu^{2+}, the copper (II) ion. Copper is thus more active than mercury.

The reverse is not the case. That is, Cu^{2+} cannot oxidize Hg (it cannot take electrons from Hg). This can be proven by adding $Hg_{(l)}$ to a solution of $CuCl_{2\,(aq)}$:

nothing happens. If a certain reaction occurs spontaneously – in our example, the transfer of 2 electrons from Hg^{2+} to Cu – the reverse process will NOT be spontaneous.

The purpose of this experiment is to determine relative activities of different elements by combining elements with aqueous solutions of ionic compounds. By looking at the surface of the metal during the next few minutes, we can decide whether or not the oxidation-reduction reaction has occurred. We will look for a coating of the metal that gains electrons forming on the surface of the metal that loses the electrons. (Just as a coating of mercury formed on the surface of the copper in the previous example.) In cases where reaction does occur, it will mean that the metal of the strip is undergoing oxidation and that the other metal's ions are gaining electrons (being reduced), forming a coating of that element on the surface of the original metal. Whether or not the reactions occur, each combination will tell you which of the two elements is more active. When all of the data is obtained, you will rank the substances in order of activity.

Safety Precautions:

- Wear safety goggles.
- Lead metal and solutions containing lead ions are poisonous. Make sure to wash your hands after handling any lead or lead compounds.
- Silver nitrate ($AgNO_3$) solutions will stain skin and clothes. If you suspect you may have spilled $AgNO_3$ on yourself, rinse it off immediately. The stains are dark brown and they don't show up right away. You'll know the next day whether or not you spilled $AgNO_3$ on yourself.

Waste Disposal:

- While you are doing the experiment, pour your waste into a beaker. (Separate the solid metal pieces from the waste solution. Solids should go in the waste basket after being rinsed with water.)
- When you are finished with the experiment, pour the contents of the waste beaker (liquid waste only) into the **INORGANIC WASTE** container (with a blue label) in the fume hood.

Procedure

With some of the combinations used in these experiments the reactions may be slow or difficult to detect. If you see no immediate evidence of reaction, set the tube aside and allow it to stand for about 10 minutes, then reexamine it.

Evidence of reaction will be either evolution of a gas or appearance of a metallic deposit on the surface of the metal strip. Metals deposited from a solution are often black or gray (in the case of copper, very dark reddish brown) and do not resemble commercially prepared metals.

1. Wash, rinse (with deionized water), and label six test tubes. Shake out the excess water, but do not bother to dry the tubes completely on the inside. Set them up in your test tube rack.
2. Obtain three pieces of zinc, two of copper, and one of lead. Clean the metal pieces with fine sandpaper or steel wool until their surfaces are clean and shiny. This is important, because coatings on their surfaces can inhibit chemical reactions.
3. Set up the metal samples and test solutions in the test tubes as follows:

Tube 1:	copper strip and about 2 mL of silver nitrate solution
Tube 2:	lead strip and about 2 mL of copper (II) nitrate solution
Tube 3:	zinc strip and about 2 mL of lead (II) nitrate solution
Tube 4:	zinc strip and about 2 mL of magnesium sulfate solution
Tube 5:	copper strip and about 2 mL of sulfuric acid solution
Tube 6:	zinc strip and about 2 mL of sulfuric acid solution

   Note that it is not necessary to measure the volumes of the solutions. Find out in the beginning of the experiment what 2 mL looks like in a test tube, and fill all of the tubes to about the same depth.
4. Remember to wait 10 minutes before deciding that no reaction has occurred.
5. In the cases where reaction does occur, figure out what the products are, basing your decisions on your knowledge of ions that commonly exist. (See your text if necessary.)

Questions and Problems

1. Complete the following table by writing the symbols of the two elements whose reactivities are being compared in each test:

	Tube 1	Tube 2	Tube 3	Tube 4	Tube 5	Tube 6
Greater activity						
Lesser activity						

2. Arrange Pb, Mg and Zn in order of their activities, listing the most active first.
3. Arrange Cu, Ag and Zn in order of their activities, listing the most active first.
4. Arrange Mg, H and Ag in order of their activities, listing the most active first.
5. Arrange all five of the metals (excluding hydrogen) in an activity series, listing the most active first.
6. On the basis of the reactions observed in the six test tubes, explain why the position of hydrogen cannot be fixed exactly with respect to all of the other elements listed in the activity series in Question 5.
7. What additional test(s) would be needed to establish the exact position of hydrogen in the activity series of the elements listed in Question 5?
8. On the basis of the evidence developed in this experiment:
   (a) Would silver react with dilute sulfuric acid? Why or why not?
   (b) Would magnesium react with dilute sulfuric acid? Why or why not?