EXPERIMENT 6

Redox Reactions – The Activity Series

Objective

In this experiment you will perform several reactions between various metals and solutions of ionic compounds. The goal is to determine the relative reactivity of the elements. By observing the reactions that occur (or do not occur), an activity series will be created.

Introduction

Redox reactions are defined as reactions in which electrons are transferred from one element to another. The element that gains one or more electrons is said to be reduced and the element that loses one or more electrons is said to be oxidized. There are many types of redox reactions but in this experiment, we will limit our examination to **single displacement reactions**. These are reactions in which an ion in solution gets replaced by some other ion. The ion originally in solution gets reduced or oxidized to the elemental form. The ion that ends up in the final solution is formed by oxidation of a metal atom, oxidation of a metal cation or reduction of a nonmetal.

EXAMPLE 6.1

1. $Cu_{(s)} + 2\,AgNO_{3\,(aq)} \rightarrow 2\,Ag_{(s)} + Cu(NO_3)_{2\,(aq)}$
In this reaction, copper metal is oxidized to the Cu^{2+} ion and replaces the silver ion, which is reduced to silver metal.

2. $Fe(NO_3)_{2\,(aq)} + 3\,AgNO_{3\,(aq)} \rightarrow 3\,Ag_{(s)} + Fe(NO_3)_{3\,(aq)}$
In this example, the Fe^{2+} ion is oxidized to the Fe^{3+} ion. Here the Fe^{3+} ion replaces the Fe^{2+} ion in solution while silver ion gets reduced to the metal.

3. $Zn_{(s)} + 2\,HBr_{(aq)} \rightarrow ZnBr_{2\,(aq)} + H_{2\,(g)}$
Acids can also oxidize metals: notice that zinc metal gets oxidized by the hydrogen ion. Hydrogen ion gets reduced to form H_2

4. $2\,KI_{(aq)} + F_{2\,(g)} \rightarrow I_{2\,(s)} + 2\,KF_{(aq)}$
In this reaction, the nonmetal anion, iodide ion, is being oxidized to elemental iodine while fluorine gets reduced to the fluoride anion.

In each case in Example 6.1 the overall process is the same: one species gets oxidized while another species gets reduced. Or to say this another way: one species replaces another in solution.

Referring to Example 6.1, determine which species in each pair is more active:

1. copper or silver?

Answer: copper

2. silver ion or iron(II) ion?

Answer: iron(II) ion

3. iodide or fluorine?

Answer: fluorine

In this experiment, the student will perform several redox reactions and determine the relative ease of oxidation for each element. An activity table will be constructed based upon the results. For example:

EXAMPLE 6.2

If a strip of copper metal is placed into a solution of mercury(II) chloride, the solution will become blue over time and a small pool of liquid mercury will collect at the bottom of the container. The reaction written below is occurring.

$$Cu_{(s)} + HgCl_{2\,(aq)} \rightarrow Hg_{(s)} + CuCl_{2\,(aq)}$$

Copper is more easily oxidized than mercury because we observe that the copper replaces the mercury as the more oxidized substance. If we were to try the reverse reaction, that is to pour some liquid mercury into a solution of copper chloride, there would be no reaction. Again we would conclude that copper is more easily oxidized because mercury is not able to replace copper as the more oxidized substance. We state that copper is more active than mercury because it is the most easily oxidized. The actual reaction that occurs is called the net ionic reaction:

$$Cu_{(s)} + Hg^{2+}_{(aq)} \rightarrow Hg_{(s)} + Cu^{2+}_{(aq)}$$

If the reaction proceeds to the right, copper is more active than mercury. If the reaction proceeds to the left, mercury is more active than copper. Because the reaction proceeds to the right, copper is the more active metal.

EXAMPLE 6.3

A strip of copper metal is dropped into a solution of lead(II) chloride. There is no visible reaction.

Which is more active, copper or lead?

Answer: lead

Combining the results of this experiment with the results from the reaction between copper and mercury ion (Example 6.2), can you determine whether lead is more or less active than mercury?

Answer: lead is more active than mercury.

Therefore, the activity series for Pb, Cu, and Hg from most active to least is Pb > Hg > Cu.

Procedure

You will mix the following sets of substances and determine the more easily oxidized species in each case. From the relative oxidizability of each set, you will develop a comprehensive activity series. Be sure the data is clearly organized, and that clear and complete observations are made for each reaction. Observations should include color changes, temperature changes, gas formation, and precipitate formation.

In this procedure, there are various combinations of reactants to observe:

Reactions between a metal and a salt solution. The student must determine whether the metal or the salt cation is more active. *The actual comparison is to determine which metal is more easily oxidized (more active).*

Reactions between a metal and an acid solution. The student must determine whether the metal or the hydrogen ion is more active. *The actual comparison is between a metal and hydrogen.*

Reactions between a halogen (I_2 and Br_2) and a halide ion. The student must determine which halide ion is more active. *The actual comparison is that between halogens*.

Reactions between a halide ion and a metal ion. "The student must determine whether the halide ion or metal ion is more active. *The actual comparison is between a metal and a nonmetal.*

As you perform each reaction, keep in mind the following:

1. Be sure to sand all of the metal pieces to provide a clean metal surface.
2. Watch the reactions for at least 15 minutes before deciding whether or not a reaction has occurred. Some of the reactions are slow.
3. Describe the reactions that occur in such a manner that you could identify it from your lab notebook. Describe texture, color, location of precipitate (i.e., bottom of test tube or a deposit on the metal strip), etc. Be detailed in these descriptions, they are you observations and therefore your data.
4. Note that some of the metals are reacted with acids. Here, the cation is H^+, which will be reduced to $H_{2\,(g)}$ if a reaction occurs.

EXAMPLE 6.4 Sample Data Log

$Au^{3+}_{(aq)} + I^-_{(aq)}$

Log: Mixed with 1 mL of KI with about 1 mL of gold(III) nitrate.

Observations: The solution became darker and it was difficult to determine what was happening. After the reaction had progressed for about 10 minutes, I poured some of the supernatant into another tube and added hexane. A pink color was extracted into the hexane layer.

The net ionic reaction would be:

$2\,Au^{3+}_{(aq)} + 6\,I^-_{(aq)} \rightarrow 2\,Au_{(s)} + 3\,I_{2\,(s)}$

Analysis: Stronger oxidizing agent is Au. More active element is I.

Reactions:

Metal + salt solution.

1. Place a strip of copper metal into a 3 mL sample of 0.1 *M* $ZnSO_4$.

2. Place a strip of copper metal into a 3 mL sample of 0.1 *M* $FeSO_4$.
3. Place a strip of zinc metal into a 3 mL sample of 0.1 *M* $CuSO_4$.
4. Place a strip of zinc metal into a 3 mL sample of 0.1 *M* $FeSO_4$.
5. Place a piece of steel wool (iron) into a 3 mL sample of 0.1 *M* $CuSO_4$.
6. Place a piece of steel wool (iron) into a 3 mL sample of 0.1 *M* $ZnSO_4$.

Metal + acid solution.

1. Place a strip of copper metal into a 3 mL sample of 1.0 *M* H_2SO_4 (or what the stockroom has available for this experiment).
2. Place a strip of zinc metal into a 3 mL sample of 1.0 *M* H_2SO_4 (or what the stockroom has available for this experiment).
3. Place a piece of steel wool (iron) into a 3 mL sample of 3.0 *M* H_2SO_4 (or what the stockroom has available for this experiment).

Halogen + halide solution. For reactions involving the halogens, a two-phase system will be used. The halide ion is soluble in water and the halogen will be partitioned between an aqueous layer and an organic (hexane) layer. The student must first be able to recognize what happens when a halide ion is oxidized to the halogen: When a halide gets oxidized, the resulting halogen dissolves into the organic layer and the hexane becomes colored. Hexane is a colorless liquid. The appearance of a colored hexane layer is evidence for oxidation of a halide ion to the halogen.

NOTE: This simple procedure must be done before the halogen reactions are performed so that the student easily recognizes what happens when the halides are oxidized.

1. Add a few drops of I_2 (in methanol) to a mixture of 3 mL of water and 1 mL of hexane.
2. Shake well and record the color of the organic, hexane, layer and the color of the aqueous layer. The halogen will dissolve into the organic layer.
3. Repeat with the Br_2 (in water). Now you know how to detect the presence of a halogen.

CAUTION: When you are finished working with the halogen solutions, dispose of them in the appropriate container in the hood.

1. Mix 3 mL of 0.1 *M* KBr with 1 mL of hexane (this may be already prepared for you by the stockroom). Add a few drops of I_2.
2. Mix 3 mL of 0.1 *M* KI with 1 mL of hexane (this may be already prepared for you by the stockroom). Add a few drops of Br_2.

Halogen/Halide + metal/metal ion. You will examine the redox chemistry of iron(III) ions and copper metal with the halogen/halides. Use the information gained in these experiments to get a complete activity series.

All balanced equations should be redox equations. Do not include the reactions of copper with ammonia or the reactions to detect halides with silver nitrate. Note that the Fe^{3+} ion will be reduced to Fe^{2+} ion if a reaction occurs. Also remember that the hexane is used only to detect the presence of either I_2 or Br_2.

1. Mix 1 ml of 0.1 *M* $FeCl_3$ with 2 mL of 0.1 *M* KBr.
2. Mix 1 ml of 0.1 *M* $FeCl_3$ with 2 mL of 0.1 *M* KI.
3. Add some copper turnings to 10 mL of Br_2 water. Shake well for several minutes. Allow any precipitate that forms to settle and pour off some of the liquid phase into each of two new test tubes.

   To the first tube add a few drops of 0.1*M* $AgNO_3$, does a AgBr precipitate form?

   To the second tube add 1 mL of 6 *M* NH_3, does a blue $Cu(NH_3)_4^{2+}$ (tetraamminecopper(II) ion) complex form?
4. Add some copper turnings to 15 mL of 0.05 *M* I_2 methanol. Shake well for several minutes. Allow any precipitate that forms to settle and pour off some of the liquid phase into each of two new test tubes.

   To the first tube add a few drops of 0.1M $AgNO_3$, does a AgI precipitate form?

> **NOTE:** You may see a precipitate of CuI_2 here, do the test for Cu^{2+} to be sure that the expected reaction occurred.

5. To the second tube add 1 mL of 6 *M* NH_3, does a blue $Cu(NH_3)_4^{2+}$ (tetraamminecopper(II) ion) complex form?

Results and Calculations

In your lab book create a table like Table 6.5 on page 56. Be sure to write balanced equations for each reaction that occurred. If no reaction occurs state that by writing NO RXN. Do not write out reactions that will not occur. Remember that you can determine relative activity from a null result as well as a positive result. For each experiment note which of the two elements is more active.

Be careful when you start working with the halogens. All of the balanced equations should be redox equations. Do not include the reactions of copper with ammonia or the reactions to detect halides with silver nitrate in your report.

Note that Fe^{3+} will be reduced to Fe^{2+} if a reaction occurs. Also remember that hexane is used only to detect the presence of either I_2 or Br_2.

From the data you have gathered in this experiment, develop an activity series for Br, Cu, Fe, Fe^{3+}, H, I and Zn, as was done for Pb, Cu, and Hg in the introduction.

- Did you have any difficulties determining the activity series?
- If so, what species are you unsure of the relative activities?
- What additional experiments might help you to make a better assessment of the relative activities?

TABLE 6.5

	Reactants		Observation	Net Ionic Reaction	Element Oxidized	Element Reduced	Stronger Oxidizing Agent	More Active
1	Cu	Zn^{2+}						
2	Cu	Fe^{2+}						
3	Zn	Cu^{2+}						
4	Zn	Fe^{2+}						
5	Fe	Cu^{2+}						
6	Fe	Zn^{2+}						
7	Cu	H^+						
8	Zn	H^+						
9	Fe	H^+						
10	I_2	Br^-						
11	Br_2	I^-						
12	Fe^{3+}	Br^-						
13	Fe^{3+}	I^-						
14	Cu	I_2						
15	Cu	Br_2						