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An Activity Series

AP Chemistry Laboratory #20

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Introduction

In this experiment, a series of metals and a series of nonmetal halogens are studied to find their relative reactivities. The reactivity of the metals is determined by combining the metals with a complementary series of metal ions in solution. The reactivity of three halogens is found by mixing each with a halide ion solution. Using the observed reactions, an activity series, from most reactive to least reactive, is developed for the metals and for the halogens.

Concepts

- Activity series
- Oxidation–reduction
- Half-cell reaction

Background

A ranking of elements according to their reactivity is called an *activity series*. For example, an activity series containing the elements calcium, gold, and iron would put the reactive calcium at the top, iron in the middle, and the unreactive gold at the bottom. If a piece of iron metal is placed in a solution of gold nitrate, the iron dissolves forming positive ions in solution while solid gold metal appears. The more reactive metal (iron) displaces ions of the less reactive metal [gold(III)] from solution. The less reactive element appears as the solid element.

Reactions such as these are examples of *oxidation–reduction reactions*. Oxidation is defined as the process of losing electrons and substances that lose electrons during chemical reactions are said to be oxidized. Substances that gain electrons during chemical reactions undergo reduction and are said to be reduced. If one reactant gains electrons, another must lose electrons. Oxidation and reduction reactions occur simultaneously, and there must be an equal number of electrons lost and gained during the two reactions. In the reaction of iron metal with gold ions, the iron metal is oxidized and the gold ions are reduced. The more reactive metal is the one that is more easily oxidized.

$3Fe(s) \rightarrow 3Fe^{2+}(aq) + 6e^-$	Iron loses electrons.	*Oxidation*
$2Au^{3+}(aq) + 6e^- \rightarrow 2Au(s)$	Gold gains electrons.	*Reduction*
$3Fe(s) + 2Au^{3+}(aq) \rightarrow 3Fe^{2+}(aq) + Au(s)$		*Oxidation–reduction*

Figure 1. Reduction of gold ions by iron metal.

When writing oxidation–reduction reactions, it is customary to break the reaction into the two parts or *half-cell reactions*. These half-cell reactions represent the separate oxidation and reduction processes that occur simultaneously. The electrons within the two half-cell reactions must be equal so there is no net gain or loss of electrons for the overall reaction.

When a substance readily loses electrons (and is oxidized), it acts as a good reducing agent. When a substance has a strong tendency to gain electrons (and be reduced), it acts as a good oxidizing agent. Gold ions, Au^{3+}(aq), have a strong tendency to acquire electrons to form neutral gold atoms, Au(s). Gold ions are thus easily reduced and act as good oxidizing agents.

Experiment Overview

The purpose of this experiment is to determine the activity series for five metals and for three halogens. The first part of this experiment derives an activity series for metals and uses a microscale technique. The second part derives an activity series for halogens. It makes use of a solvent extraction technique.

The series of metals to be studied are copper, zinc, magnesium, lead, and silver. Solutions of metal nitrates for each of these metals are placed in reaction wells. A piece of each metal is then placed in the other metals' nitrate solutions and observed to see if any reaction occurs. If a metal reacts with another metal nitrate, then the solid metal has reduced the other metal ion and is, therefore, the more reactive metal of the two. By comparing the results of 16 different reactions, the five metals are ranked from most reactive to least reactive.

In Part 2, tests are performed to determine the activity series of the halogens. Chlorine (Cl_2), bromine (Br_2), and iodine (I_2) are placed in solutions containing chloride (Cl^-), bromide (Br^-), or iodide (I^-). An activity series of the nonmetallic halogens places the most reactive halogen at the top. In the reaction of a free halogen (X_2) with a different halide ions (Y^-), the free halogen gains electrons and is then reduced to its corresponding halide ions (X^-). The original halide ions lose electrons and therefore are oxidized to their corresponding free halogen (Y_2). The more reactive halogens displaces ions of the less reactive halides from solution. In an activity series of halogens, the most reactive halogen is the one most easily reduced.

$$X_2(aq) + 2e^-(aq) \rightarrow 2X^-(aq) \qquad \textit{Reduction}$$

$$2Y^-(aq) \rightarrow Y_2(aq) + 2e^- \qquad \textit{Oxidation}$$

$$X_2(aq) + 2Y^-(aq) \rightarrow 2X^-(aq) + Y_2(aq) \qquad \textit{Oxidation–reduction}$$

Figure 2. Reduction of a free halogen X_2 by halide ions Y^-.

To determine if a reaction occurs, a method is needed to identify which halogen is present. Halogens dissolve in the nonpolar solvent mineral oil forming different colored solutions. Mineral oil does not dissolve in water, but when shaken with an aqueous halogen solution, the halogen is extracted from the water into the mineral oil. The color of the mineral oil layer indicates which halogen is present.

Materials

Part 1

Copper foil, 6 × 6 mm pieces, 4
Zinc foil, Zn, 6 × 6 mm pieces,4
Magnesium ribbon, Mg, 6-mm pieces, 4
Lead foil,Pb, 6 × 6 mm pieces, 4
Silver nitrate solution, $AgNO_3$,0.1 M, 4 mL
Cupric nitrate solution, $Cu(NO_3)_2$,0.1 M,4 mL
Zinc nitrate solution, $Zn(NO_3)_2$,0.1 M,4 mL
Magnesium nitrate solution, $Mg(NO_3)_2$,0.1 M,4 mL
Lead nitrate solution, $Pb(NO_3)_2$,0.1 M,4 mL
24-well reaction plate
Beral-type pipets, 5
Forceps
Stirring rod

Part 2

Chlorine water, Cl_2 in H_2O,3 mL
Bromine water, Br_2 in H_2O,3 mL
Iodine water, I_2 in H_2O, 3 mL
Mineral oil, 12 mL
Sodium chloride solution, NaCl, 0.1 M,3 mL
Sodium bromide solution, NaBr,0.1 M, 3 mL
Potassium iodide solution, KI, 0.1 M,3 mL
Beral-type pipets, 7
Test tubes, 13 × 100 mm, 12
Cork stoppers for test tubes, 12
Test tube rack

Safety Precautions

The silver nitrate solution is moderately toxic by ingestion and is a body tissue irritant. Silver nitrate stains skin and clothing; however, the stains may not appear for several hours. The cupric nitrate solution is slightly toxic by ingestion and is irritating to skin, eyes, and mucous membranes. Zinc nitrate solution is slightly toxic by ingestion and is corrosive to body tissue. Magnesium nitrate solution is a body tissue irritant. The lead nitrate solution is moderately toxic by ingestion and inhalation; it is a possible carcinogen and is irritating to skin, eyes, and mucous membranes. The magnesium ribbon is a flammable solid. The chlorine, bromine, and iodine water solutions have strong odors and are highly toxic by ingestion and inhalation. All are very irritating to eyes, skin, and mucous membranes. Mineral oil is a combustible liquid. Wear chemical splash goggles, chemical-resistant gloves, and a chemical-resistant apron. Wash hands thoroughly with soap and water before leaving the laboratory.

Procedure

Part 1. Determine an Activity Series for Metals.

1. Place the 24-well plate on top of a piece of white paper so that there are 6 wells across (columns) and 4 wells down (rows). Refer to Figure 3 to see how the wells are arranged. Note that each well is identified by an unique combination of a letter and a number, where the letter refers to a horizontal row and the number to a vertical column.

2. Put one dropper-full (about 15 drops or 1 mL) of cupric nitrate solution in wells B1, C1, and D1 in the first column.

3. Put one dropper-full of magnesium nitrate solution in wells A2, C2, and D2 of the second column.

4. Put one dropper-full of lead nitrate solution in wells A3, B3, and D3 of the third column.

5. Put one dropper-full of zinc nitrate solution in wells A4, B4, and C4 of the fourth column.

6. Put one dropper-full of silver nitrate solution in each of the wells A5 through D5 in the fifth column.

7. Put a small piece of copper metal in each of the wells containing a solution in the first row.

8. Add magnesium metal to the solutions in the second row, add lead metal to the solutions in the third row, and add zinc metal to the solutions in the fourth row. Use a stirring rod to submerge each metal in the solutions. Allow to stand at least 5 minutes.

9. Determine if a reaction has occurred in each well by observing if a new metal has deposited or if the surface of the metal has become coated.

10. Record each observation as either *coating forms* or *no reaction* in the Part 1 Data Table.

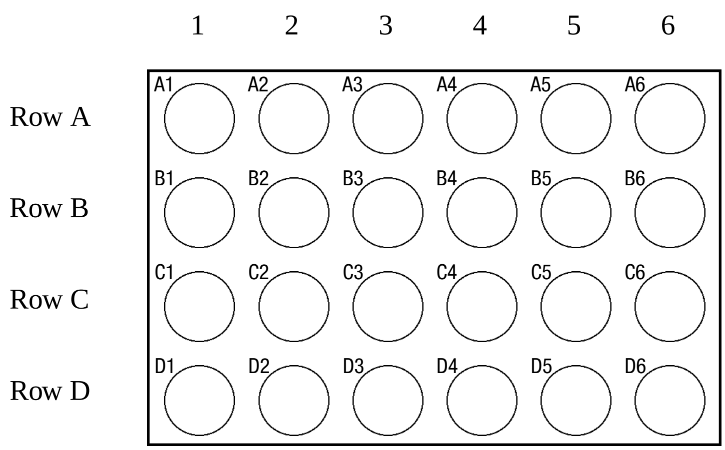

Figure 3.

Part 2. Determine an Activity Series for Some Halogens.

All work in Part 2 should be done in a fume hood.

1. As a reference, test to see what color develops when each halogen is dissolved in mineral oil. Place one dropper-full of chlorine water, one dropper-full of bromine water, and one dropper-full of iodine water into three separate 10 mm test tubes.

2. Add one dropper-full of mineral oil to each test tube, cork the tube, and shake it for ten seconds.

3. Let the mineral oil layer rise to the top and record the color that each halogen shows when dissolved in mineral oil. Record your observations in the Part 2 Data Table.

4. Test to see if the halide ions give a color to mineral oil. Place one dropper-full of sodium chloride, sodium bromide, and potassium iodide solutions into three separate test tubes.

5. Add a dropper-full of mineral oil to each test tube, cork the tubes, and shake for ten seconds to determine if the halide ions impart a color to the mineral oil layer.

6. Record your observations in the Part 2 Data Table.

7. Set up six test tubes in a test tube holder as in Figure 4. Label the test tubes 1 through 6 with a marker.

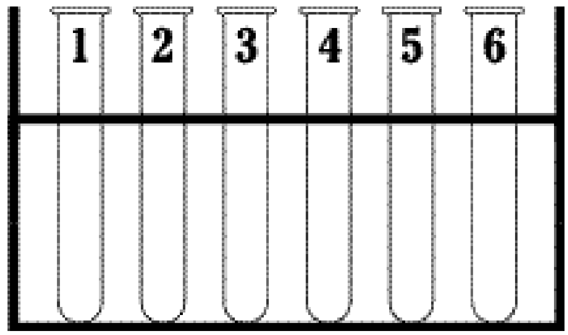

Figure 4.

8. React each halogen with the other two halide ion solutions to determine if the ions reduce the halogens. Place one dropper-full of sodium bromide solution into test tube #1 and one dropper-full of potassium iodide solution into test tube #2.
9. Add one dropper-full of chlorine water to each of test tubes #1 and #2, cork each, and shake to mix.
10. Add one dropper-full of mineral oil to each of test tubes #1 and #2, cork each, and shake again.
11. When the mineral oil layer has separated, determine its color and whether a reaction has occurred. If the color of the chlorine appears in the mineral oil layer then no reaction has occurred. If either the bromine or iodine color appears in the mineral layer, then there was a reaction.
12. Record both the color and the reaction results (*reaction* or *no reaction*) for $Cl_2(aq)$ in the Part 2 Reaction Data Table.
13. Repeat the test using bromine water. Add one dropper-full of sodium chloride solution to test tube #3 and one dropper-full of potassium iodide to test tube #4.
14. Add one dropper-full of bromine water to each of test tubes #3 and #4, cork each, and shake to mix.
15. Add one dropper-full of mineral oil to each of test tubes #3 and #4, cork each, and shake again.
16. When the mineral oil layer has separated, determine its color and whether a reaction has occurred. If the color of the bromine appears in the mineral layer, then *no reaction* has occurred. if either the chlorine or iodine color appears in the mineral layer, then there was a *reaction*.
17. Record both the color and reaction results (*reaction* or *no reaction*) for $Br_2(aq)$ in the Part 2 Reaction Data Table.
18. Repeat the test for iodine water. Add one dropper-full of sodium chloride solution to test tube #5 and one dropper-full of sodium bromide solution to test tube #6.
19. Add one dropper-full of iodine water to each of test tubes #5 and #6, cork each, and shake to mix.
20. Add one dropper-full of mineral oil to each of test tubes #5 and #6, cork each, and shake again.
21. Record both the color of the mineral oil layer and the reaction results (*reaction* or *no reaction*) for $I_2(aq)$ in the Part 2 Data Table.

Data Tables

Name ______________________________

Part 1. An Activity Series for Some Metals.

Record your observations in the data table below:

	Cu^{2+}(aq)	Mg^{2+}(aq)	Pb^{2+}(aq)	Zn^{2+}(aq)	Ag^{+}(aq)
Cu(s)	×				
Mg(s)		×			
Pb(s)			×		
Zn(s)				×	

Part 2. An Activity Series for Some Halogens.

Record your observations in the data tables below:

Halogen	Color in Mineral Oil	Halide Ion	Color in Mineral Oil

Reaction Data Table

Reactants	Cl_2(aq)	Br_2(aq)	I_2(aq)
Cl^-(aq)	×		
Br^-(aq)		×	
I^-(aq)			×

Disposal

Part 1

Discard all solutions into the container provided by your instructor. Clean the 24-well plate with soap and water using cotton swabs if needed.

Part 2

Empty the test tubes in the container provided for disposal by your instructor. A different container than the one used in Part 1 will be used in Part 2.

Post-Lab Questions

1. Write balanced net ionic equations for all the reactions that occurred with the metals.
2. List the metals in order of decreasing ease of oxidation. Compare this list with an activity series found in a textbook. How do the two lists correlate?
3. Write reduction half-reactions for each of the metal ions. Arrange the reaction list in order of decreasing ease of reduction. Compare the order with a listing found in a table of standard reduction potentials. How do the two lists correlate?
4. Explain how to determine if a reaction occurs in the halogen experiment.
5. Why should the halide ions not dissolve in mineral oil?
6. Explain what is meant by solvent extraction. How is it used in Part 2?
7. Write balanced net ionic equations for the reactions which occurred with the halogens.
8. List the halogens in decreasing order of reactivity. Compare this list with an activity series found in a textbook. How do the two lists correlate? Predict the location of fluorine in this activity series.
9. Write reduction half-reactions for each of the halogens. Arrange in order of decreasing ease of reduction. Compare the listing with the order found in a table of standard reduction potentials. How do the lists correlate?
10. Why was it necessary to test the halide ions for their color in mineral oil?
11. Would it make a difference if calcium bromide solution, $CaBr_2$, is used rather than sodium bromide solution? Explain.