EXPERIMENT 10
The Activity Series

PURPOSE:

- To study some typical single replacement (redox) reactions
- To identify oxidizing and reducing agents and write half-reactions.
- To develop an activity series for a limited number of elements.

PRINCIPLES:

The chemical reactivity of elements varies over a wide range. Some elements, like sodium and fluorine, are so reactive that they are never found in the free, uncombined state in nature. Other elements, like xenon and platinum, are nearly inert and can be made to react with other elements only under special conditions.

The **reactivity of an element** is related to its tendency to **lose or gain electrons**, which is to be oxidized or reduced.

In principle, it is possible to arrange nearly all the elements into a single series in order of their reactivities. A series of this kind indicates which free elements are capable of replacing other elements from their compounds. Such a list is known as an **activity or electromotive series**.

To illustrate the preparation of an activity series we will experiment with a small group of selected elements and their compounds. A generalized single replacement reaction is represented in the form:

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

Element A is the more active element and replaces element B from the compound BC. But if element B is more active than element A, no reaction will occur.

Let us consider two specific examples, using copper and mercury:

Example 1:

A few drops of mercury metal are added to a solution of copper (II) chloride. In this example no change is observed even after the solution has been standing for a prolonged time, hence, we conclude that there is no reaction.

$$Hg_{(l)} + CuCl_{2(aq)} \rightarrow No\ reaction$$

From this evidence we conclude that mercury will not replace copper in copper compounds, and therefore mercury is a less active metal than copper.

Example 2:

A strip of metallic copper is immersed in a solution of mercury (II) chloride. In this example the copper strip is soon coated with metallic mercury and the solution becomes pale blue-green (the color of Cu^{2+} ions in aqueous solution).

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

From this evidence we conclude that copper will replace mercury in mercury compounds. Therefore copper is more reactive than mercury and is before mercury in the activity series.

The single replacement equation given above shows that in terms of oxidation numbers, the chloride ion remains unchanged, but the oxidation number of mercury has changed from 2+ to 0, and the oxidation number of copper has changed from 0 to 2+.

Expressed another way, the actual reaction that occurred was the replacement of a mercury ion (Hg^{2+}) by a copper atom (Cu^0).

This can be expresses more simply in the form of a **total ionic equation**:

$$Cu^0{}_{(s)} + Hg^{2+}{}_{(aq)} + 2Cl^-{}_{(aq)} \rightarrow Hg^0{}_{(l)} + Cu^{2+}{}_{(aq)} + 2Cl^-{}_{(aq)}$$

Since the chloride ions do not experience chemical change, they are called **spectator ions** and can be removed from the total ionic equation. This results in a **net ionic equation**:

$$Cu^0{}_{(s)} + Hg^{2+}{}_{(aq)} \rightarrow Hg^0{}_{(l)} + Cu^{2+}{}_{(aq)}$$

The net ionic equation shows only those reactants that are actually consumed and those products that are actually formed in the reaction. Total ionic equations are an intermediate step in writing net ionic equations, and for this reason they are often omitted. Since single replacement reactions Involve changes in oxidation number, they are also classified as oxidation-reduction reactions.

PROCEDURE:

NOTES:

1. 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 spot plate aside and allow it to stand for about 10 minutes, and then reexamine it.
2. Evidence of reaction will be either the evolution of a gas or the appearance of a metallic deposit on the surface of the metal strip. Metals deposited from a solution are often black or grayish (in the case of copper-very dark reddish-brown) and bear little resemblance to commercially prepared metals.

Place a small strip of metal (reactant 1) in a depression in the spot plate. Add enough drops of reactant 2 to cover the metal strip.

Trial	Reactant 1	Reactant 2
1	Copper strip	5 mL 0.2 M $AgNO_3$
2	Lead Strip	5 mL 0.1 M $Cu(NO_3)_2$
3	Zinc Strip	5 mL 0.1 M $Pb(NO_3)_2$
4	Zinc Strip	5 mL 0.1 M $MgSO_4$
5	Copper Strip	5 mL 0.1 M H_2SO_4
6	Zinc Strip	5 mL 0.1 M H_2SO_4

Observe the contents of each depression carefully and record any evidence of chemical reaction (gas evolved, metal deposited. change in color of solution).

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REPORT FORM

No.	Evidence of Reaction	Equations I. Overall Equation II. Oxidation half-reaction III. Reduction half-reaction IV. Net Ionic Equation (sum of oxid. & red.)
1.		I. $Cu\ (s) + \quad AgNO_3\ (aq) \rightarrow$ II. III. IV.
2.		I. $Pb\ (s) + \quad Cu(NO_3)_2\ (aq) \rightarrow$ II. III. IV.
3.		I. $Zn\ (s) + \quad Pb(NO_3)_2\ (aq) \rightarrow$ II. III. IV.

No.	Evidence of Reaction	Equations I. Overall Equation II. Oxidation half-reaction III. Reduction half-reaction IV. Net Ionic Equation (sum of oxid. & red.)
4.		I. $Zn (s) + \quad MgSO_4 (aq) \rightarrow$ II. III. IV.
5.		I. $Cu (s) + \quad H_2SO_4 (aq) \rightarrow$ II. III. IV.
6.		I. $Zn (s) + \quad H_2SO_4 (aq) \rightarrow$ II. III. IV.

QUESTIONS:

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

REACTION NUMBER

	1	2	3	4	5	6
GREATER ACTIVITY						
LESSER ACTIVITY						
ELEMENT OXIDIZED						
ELEMENT REDUCED						
# OF ELECTRONS INVOLVED						
OXIDIZING AGENT						
REDUCING AGENT						

2. Arrange Pb, Mg, and Zn in order of their activities, listing the most active first:

   (1) __________ (2) ___________ (3) ___________

3. Arrange Cu, Ag, and Zn in order of their activities, listing the most active first:

   (1) __________ (2) __________ (3) ___________

4. Arrange Mg, H, and Ag in order of their activities, listing the most active first:

   (1) __________ (2) __________ (3) ___________

5. Arrange all five of the metals (exclude hydrogen) in an activity series, list the most active first:

   (1) __________ (2) __________ (3) ___________ (4) __________ (5) __________

6. On the basis of the reactions observed in the six trials, explain why the position of hydrogen cannot be fixed exactly with respect to all of the other elements listed in Question 5?

7. What additional test, or test, would be needed to establish the exact position of hydrogen among the metals listed in Question 5? Explain how you would interpret the results of the suggested test(s)?

8. On the basis of the evidence developed in this experiment:
   (a) Would metallic silver react with dilute sulfuric acid?___________
   Why or why not?

   (b) Would metallic magnesium react with dilute sulfuric acid?___________
   Why or why not?

9. Three hypothetical metals all form 2+ cations and will be designated as X, Y, and Z. A series of experiments are carried out on these metals and solutions of ions. The results are summarized by the equations given below:

$$\mathbf{X\,(s) + Y^{2+}\,(aq) \longrightarrow X^{2+}\,(aq) + Y\,(s)}$$

$$\mathbf{X\,(s) + Z^{2+}\,(aq) \longrightarrow \text{No reaction}}$$

Arrange X, Y, and Z in order of activities, listing the most active first:

(1) __________ (2) ___________ (3) ____________