Redox on Filter Paper

Activity Series of Metals

Introduction

The usefulness of metals in structural and other applications depends on their physical and chemical properties. Although iron is the most common metal used in manufacturing, it must be protected against corrosion because iron rusts easily. Copper is used in electrical wiring because it conducts electricity extremely well and resists corrosion better than many metals. Gold is a highly valuable jewelry metal because it is essentially unreactive. How can we determine the relative reactivity of different metals?

Concepts

- Activity series
- Single replacement reactions
- Oxidation–reduction
- Net ionic equations

Background

A ranking of metals in order of their tendency to react with acids and water is called an activity series. Comparing the reactions of sodium, magnesium, and aluminum reveals that sodium reacts violently with acids and water, magnesium reacts with acids and hot water, and aluminum reacts only with acids. Based on this trend in reactivity, sodium is more active than magnesium, which is more active than aluminum. The activity series for these metals would be written as Na > Mg > Al. Another way to determine the activity of metals is to compare the reactions of metals with different metal ions. Consider, for example, what happens when a piece of aluminum foil is placed in a solution of copper(II) chloride. A vigorous reaction is observed—heat is released, the blue color due to copper(II) ions fades, the aluminum foil disintegrates, and a new, reddish brown solid appears in the reaction mixture. The reaction is summarized in Equation 1. Copper(II) ions from copper(II) chloride are converted to copper metal, and aluminum metal is converted to aluminum cations in aluminum chloride, which is soluble in water. In contrast, when a piece of copper metal is placed in a solution of aluminum chloride, no reaction takes place (Equation 2).

$$2Al(s) + 3CuCl_2(aq) \rightarrow 2AlCl_3(aq) + 3Cu(s) \qquad \textit{Equation 1}$$

$$Cu(s) + AlCl_3(aq) \rightarrow \text{No Reaction} \qquad \textit{Equation 2}$$

The reaction of aluminum with copper(II) chloride is classified as a single replacement reaction—aluminum reacts with and "replaces" copper ions in copper(II) chloride. Single replacement reactions will occur spontaneously in one direction only (compare Equations 1 and 2). A more active metal always replaces the ion of a less active metal in a compound. In general, the activity of a metal may be defined as follows: An active metal will react with a compound of a less active metal, which is converted to its "free element" form. The more active metal forms a new compound containing metal cations. Based on Equation 1, aluminum is more active than copper.

Single replacement reactions are examples of oxidation–reduction reactions. Oxidation is defined as the process of losing electrons, and a substance that loses electrons during a chemical reaction is said to be oxidized. If a substance loses electrons during the course of a chemical reaction, then another substance must gain electrons. The process of gaining electrons is called reduction, and a substance that gains electrons during a chemical reaction is said to be reduced. Oxidation and reduction occur together so that the total number of electrons lost by the substance that is oxidized will be equal to the number of electrons gained by the substance that is reduced. The number of moles of each reactant in the balanced chemical equation for an oxidation–reduction reaction reflects "electron balance" as well as "atom balance."

The loss and gain of electrons by the reactants in Equation 1 will be more apparent if the overall reaction is broken down into two separate half-reactions. Equations 3 and 4 on the next page show the oxidation and reduction half-reactions, respectively, for the reaction of aluminum metal with copper(II) ions. In the oxidation half-reaction (Equation 3), each aluminum atom loses three electrons and is oxidized to an Al^{3+} ion. In the reduction half-reaction (Equation 4), each Cu^{2+} ion gains two electrons and is reduced to a copper atom. Notice that the total charge on both sides of a half-reaction must be the same (charge is conserved).

$$Al(s) \rightarrow Al^{3+}(aq) + 3e^- \qquad \textit{Equation 3}$$

$$Cu^{2+}(aq) + 2e^- \rightarrow Cu(s) \qquad \textit{Equation 4}$$

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The number of electrons involved in the overall oxidation–reduction reaction will be balanced if Equation 3 is multiplied by a factor of two (Equation 5a) and Equation 4 is multiplied by a factor of three (Equation 5b). When the resulting half-reactions are added together, the number of electrons lost by the aluminum atoms is equal to the number of electrons gained by the copper ions and the electrons "cancel out" of the overall equation. Equation 5c is the balanced, net ionic equation for the reaction of aluminum with copper(II) chloride—the chloride ions are "spectator ions" and are not shown.

$$2Al(s) \rightarrow 2Al^{3+}(aq) + 6e^- \qquad \textit{Equation 5a}$$

$$3Cu^{2+}(aq) + 6e^- \rightarrow 3Cu(s) \qquad \textit{Equation 5b}$$

$$2Al(s) + 3Cu^{2+}(aq) \rightarrow 2Al^{3+}(aq) + 3Cu(s) \qquad \textit{Equation 5c}$$

Materials

Copper nitrate solution, $Cu(NO_3)_2$, 1.0 M, 5 drops

Copper strip, Cu, 1 × 15 cm

Lead nitrate solution, $Pb(NO_3)_2$, 1.0 M, 5 drops

Lead strip, Pb, 1 × 15 cm

Magnesium nitrate solution, $Mg(NO_3)_2$, 1.0 M, 5 drops

Magnesium ribbon, Mg, 0.15 × 3.2 mm

Silver nitrate solution, $AgNO_3$, 1.0 M, 5 drops

Silver strip, Ag, 1 × 15 cm

Zinc nitrate solution, $Zn(NO_3)_2$, 1.0 M, 5 drops

Zinc strip, Zn, 1 × 15 cm

Foam board, 8" × 8" or larger

Safety Precautions

Silver nitrate solution is toxic by ingestion and irritating to body tissue. It also stains skin and clothing. Lead nitrate solution is toxic by ingestion and inhalation, and is irritating to eyes, skin, and mucous membranes. Zinc nitrate solution is slightly toxic by ingestion and corrosive to body tissue. Copper nitrate solution is slightly toxic by ingestion; it is irritating to skin, eyes, and mucous membranes. Magnesium nitrate solution is a body tissue irritant. Metal pieces may have sharp edges—handle with care. Avoid contact of all chemicals with eyes and skin. Wear chemical splash goggles, chemical resistant gloves, and a chemical resistant apron. Please review current Material Safety Data Sheet for additional safety, handling, and disposal information. Wash hands thoroughly with soap and water before leaving the lab.

Preparation

Obtain the foam board, and use a permanent marker or computer paper to create Table 1.

	Cu^{2+}	Zn^{2+}	Mg^{2+}	Pb^{2+}	Ag^{+}
Cu					
Zn					
Mg					
Pb					
Ag					

Table 1.

Procedure

1. Arrange the metal strips on the foam board in their rows.
2. Obtain the copper(II) nitrate solution. Using a dropper bottle or Beral-type pipet, dispense one drop on each of the metal strips in the Cu^{2+} column.
3. Repeat step 2 for each of the nitrate solutions, keeping the drops in their columns.
4. Based on observations (presence of a precipitate or evidence of a reaction), rank the metals from the most active to the least active.

Disposal

Please consult your current *Flinn Scientific Catalog/Reference Manual* for general guidelines and specific procedures governing the disposal of laboratory wastes. The metal strips may be stored and reused. The lead nitrate may be disposed of according to Flinn Suggested Disposal Method #27f. The copper nitrate, magnesium nitrate, and zinc nitrate solutions may be poured down the drain with an excess of water according to Flinn Suggested Disposal Method #26b. The silver nitrate solution may be disposed of according to Flinn Suggested Disposal Method #11.

Connecting to the National Standards

This laboratory activity relates to the following National Science Education Standards (1996):

Unifying Concepts and Processes: Grades K–12
Evidence, models, and explanation
Constancy, change, and measurement
Content Standards: Grades 5–8
Content Standard A: Science as Inquiry
Content Standard B: Physical Science, properties and changes of properties in matter, transfer of energy
Content Standards: Grades 9–12
Content Standard A: Science as Inquiry
Content Standard B: Physical Science, structure and properties of matter, chemical reactions

Flinn Scientific—Teaching Chemistry™ eLearning Video Series

A video of the *Redox on Filter Paper* activity, presented by Michael Heinz, is available in *Activity Series of Metals*, part of the Flinn Scientific—Teaching Chemistry eLearning Video Series.

Materials for *Redox on Filter Paper* are available from Flinn Scientific, Inc.

Materials to perform this activity are available in *Single Replacement Reactions and Metal Activity—Student Laboratory Kit*, available from Flinn Scientific. Materials may also be purchased separately.

Catalog No.	Description
AP7177	Single Replacement Reactions and Metal Activity— Student Laboratory Kit
C0182	Copper, Strips, 1.2 × 15 cm, Pkg/6
Z0024	Zinc, Strips, 5" × ½", Pkg/10
M0139	Magnesium, Ribbon, 0.15 × 3.2 mm, 12.5 g
L0065	Lead, Strips, 15 × 1 cm, Pkg/6
S0270	Silver, Foil, 0.005" × 2", 5 g
C0213	Copper (II) Nitrate, Reagent, 25 g
Z0030	Zinc Nitrate Solution, 1.0 M, 500 mL
M0114	Magnesium Nitrate, Reagent, 100 g
L0067	Lead Nitrate Solution, 1.0 M, 500 mL
S0304	Silver Nitrate Solution, 1.0 M, 25 mL

Consult your *Flinn Scientific Catalog/Reference Manual* for current prices.