Using Single-Replacement Reactions to Compare Reactivities

Background Information

In nature, elements can occur either free (uncombined with other elements) or chemically combined in a compound. The tendency of an element to combine with other substances is called the reactivity of that element. The more reactive an element is, the more likely it is to combine with other substances. In a **single-replacement reaction,** one element takes the place of another element in a compound. In general, more reactive elements replace less reactive elements. As a result of the reaction, the less reactive element is freed from the compound. Consider the following reaction.

$$Zn + CuSO_4 \rightarrow Cu + ZnSO_4$$

The more reactive zinc replaces copper and combines with the sulfate ion. The less reactive copper is released from the compound and becomes a free element.

When a metal is placed in hydrochloric acid (HCl), a single-replacement reaction can occur. If the metal is more reactive than the hydrogen in the acid, the metal will replace the hydrogen, and bubbles of hydrogen gas (H_2) will be produced. The more reactive a metal is, the more vigorously it will react with hydrochloric acid.

The alkali metals and alkaline earth metals have only one or two electrons in their highest energy level. By losing those electrons, these elements can easily acquire a stable electron configuration with a completely filled highest energy level. As a result, the alkali metals and alkaline earth metals tend to be highly reactive.

In this investigation, you will determine whether various metals undergo single-replacement reactions when placed in hydrochloric acid. Based on your observations of these reactions, you will then rank the metals by reactivity.

Problem

Which metals are most reactive?

Pre-Lab Discussion

Read the entire investigation. Then, work with a partner to answer the following questions.

1. **Predicting** If any of the metals react with hydrochloric acid, what kind of compound will be formed?

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2. **Inferring** How will your observations help you determine which metals are the most reactive? Explain your answer.

3. **Controlling Variables** Identify the manipulated, responding, and controlled variables in this investigation.

   a. Manipulated variable

   b. Responding variable

   c. Controlled variables

4. **Formulating Hypotheses** State a hypothesis about which metals are the most reactive.

5. **Predicting** Based on your hypothesis, predict which metal will react most vigorously with hydrochloric acid. Explain the reason for your prediction.

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Materials *(per group)*

glass-marking pencil
5 test tubes
test-tube rack
10-mL graduated cylinder
1 *M* hydrochloric acid
zinc (Zn)
copper (Cu)
aluminum (Al)
iron (Fe)
magnesium (Mg)

Safety

Put on safety goggles and a lab apron. Be careful to avoid breakage when working with glassware. Wear plastic disposable gloves when handling chemicals, as they may irritate the skin or stain skin or clothing. Never touch or taste any chemical unless instructed to do so. Follow your teacher's instructions for disposing of the used hydrochloric acid. Wash your hands with warm water and soap or detergent before leaving the laboratory. Note all safety alert symbols next to the steps in the Procedure and review the meaning of each symbol by referring to the Safety Symbols on page xiii.

Procedure

1. Use the glass-marking pencil to label each test tube with the symbol for each metal listed in Materials. Place the test tubes in a test-tube rack.
2. One at a time, place the appropriate metal in each test tube. Carefully pour 5 mL of hydrochloric acid into each of the five test tubes, using the graduated cylinder. **CAUTION:** *Put on gloves when working with hydrochloric acid. Handle hydrochloric acid with care. It is corrosive. If it spills on your skin, rinse it off with plenty of cold water and notify your teacher immediately.*
3. Observe what happens to the metal in each test tube and feel each test tube as the reaction proceeds. Record your observations in the data table.
4. When you have completed the investigation, follow your teacher's instructions for disposing of the used acid. Rinse the pieces of metal several times with water and put them into a container provided by your teacher. Do not put any metal in the sink.

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Observations

DATA TABLE

Metal	Observations
Magnesium (Mg)	
Aluminum (Al)	
Iron (Fe)	
Copper (Cu)	
Zinc (Zn)	

Analysis and Conclusions

1. **Analyzing Data** Which of the metals that you tested in this investigation are more reactive than hydrogen? Explain your answer.

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2. **Analyzing Data** Which of the metals that you tested in this investigation are less reactive than hydrogen? Explain your answer.

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Name _____ Class _____ Date _____

3. **Drawing Conclusions** The rate at which hydrogen gas is produced as a result of these single-replacement reactions is an indication of the relative reactivity of the metals. List the metals in order of their reactivity from the most reactive to the least reactive.

4. **Inferring** Were these reactions endothermic or exothermic? Explain your answer.

5. **Evaluating and Revising** Did the results of the lab support or contradict your hypothesis?

6. **Calculating** Write a balanced chemical equation for the single-replacement reaction, if any, that occurred between the acid and each metal. Refer to Figure 1 for the charges of the ions involved.

   a. Magnesium

   b. Aluminum

   c. Iron

   d. Copper

   e. Zinc

Element	Charge of Ion
H	1+
Cl	1–
Mg	2+
Al	3+
Fe	3+
Cu	2+
Zn	2+

Figure 1

7. **Inferring** What could you do to determine whether the gas produced as a result of these reactions is hydrogen?

8. **Applying Concepts** Nonmetals can also be involved in single-replacement reactions. If chlorine is more reactive than bromine, write a balanced chemical equation for the reaction between chlorine gas (Cl_2) and potassium bromide (KBr).

Go Further

Balance each of the following chemical equations. Then, classify each reaction as a synthesis, decomposition, or single-replacement reaction.

1. $Cu + AgNO_3 \rightarrow Ag + Cu(NO_3)_2$

2. $H_2 + O_2 \rightarrow H_2O$

3. $Al + ZnCl_2 \rightarrow Zn + AlCl_3$

4. $Al(OH)_3 \rightarrow Al_2O_3 + H_2O$