Periodic Properties of Some Elements

Objective: Investigate the trends in reactivity of the elements based on their relative position in the periodic table

Materials: Samples of metals (magnesium, Mg; aluminum, Al; calcium, Ca; silicon, Si); 4 M hydrochloric acid, HCl; water-phenolphthalein mixture

Equipment: Watch glass; Bunsen burner; crucible tongs; four 50-mL beakers; 25-mL graduated cylinder; stirring rod

Safety: HCl solutions are toxic and corrosive, and should be handled with care. If contact is made with skin, wash affected areas with lots of water. When burning Mg ribbon, do not stare at the flame--the bright light that is produced can cause eye damage. Phenolphthalein solutions are flammable and toxic.

Waste Disposal: Dispose of all solutions in the individual waste beakers provided in the lab.

INTRODUCTION

The development of the periodic table by Mendeleev in 1869 is arguably the most significant advancement in chemistry of the last 150 years. Mendeleev ordered the known elements by increasing atomic mass, and then grouped them in columns based on similarities in chemical behavior. The resulting table effectively organized the current knowledge of chemistry, and also provided a framework for future work on electronic structure of the elements. As we now know, the chemical behavior of all elements is related to their electronic structure. What is most remarkable about Mendeleev's table is that it was created nearly 50 years before the discovery of the electron and the development of theories regarding electronic structure.

The elements in the periodic table are arranged into horizontal rows, known as **periods**, and into vertical columns called **groups** or **families**. The electronic structure of an atom is like an onion--it has layers. The outermost layer is called the **valence** shell, and the electrons in this layer are called **valence electrons**. When we get to the end of a row, that valence shell is filled and cannot hold any additional electrons. As we move down in the table to a new period we add a new layer of electrons. A completely filled valence shell represents a very stable condition, and atoms of different elements will react in different ways to achieve that stable, filled shell configuration.

Members of a biological family share similarities, but maintain their individuality. By analogy, elements in a chemical family exhibit similarities in chemical reactivity, but differ in the vigor of the observed reactions. For example, the alkali metals (Li, Na, K…) tend to lose electrons to form cations having a +1 charge, and react with water to form basic solutions, as shown in Equations (1), (2), and (3).

$$2\ Li(s) + H_2O(l) \rightarrow H_2(g) + LiOH(aq) \qquad (1)$$

$$2\ Na(s) + H_2O(l) \rightarrow H_2(g) + NaOH(aq) \qquad (2)$$

$$2\ K(s) + H_2O(l) \rightarrow H_2(g) + KOH(aq) \qquad (3)$$

This reaction is relatively mild for Li, but very vigorous for K. The reaction in Eq. (3) releases enough heat that the $H_2(g)$ that is produced ignites and burns. The fact that all three metals produce basic solutions can be verified by adding an acid-base indicator, such as phenolphthalein, to the reaction mixture.

The progressive changes in reactivity as we move across a period or down in a group are called **periodic trends**. The arrangement of the periodic table also makes it easier to explain these trends. For example, metals (on the left side of the table) tend to lose electrons, while non-metals (on the right) tend to gain electrons. The **ionization energy** of a metal is a measure of how easily the metal will lose an electron, and can be used as a gauge of reactivity. In general, ionization energy decreases as you move <u>down</u> in a family, and increases as you move across a period. Other trends that are related to chemical reactivity are atomic size and electron affinity.

All elements in a given family exhibit similar chemical behavior because they have the same number of valence electrons. For example, the alkali metals shown in Eqs. (1)--(3) all have one electron in their valence shell. As we move down the family, that valence electron is located in a shell or layer of higher energy. As a result, it is easier to remove (i.e., it has a lower ionization energy). This trend in ionization energy, therefore, explains the trend of increasingly vigorous reaction with water noted previously.

In this lab you will observe the chemical reactivity of calcium (Ca), magnesium (Mg), aluminum (Al), and silicon (Si) when exposed to oxygen (O_2) and water. If a given element does not react vigorously with water, it will be tested in reaction with hydrochloric acid (HCl). Based on your observations you will determine the trends in reactivity within a group (Mg and Ca), and across a period (Mg, Al, and Si).

Pre-Lab Questions

1. Discuss the safety precautions associated with this lab exercise, and why these precautions are necessary.

2. Ionization energy is one of the periodic trends discussed in the Introduction section. Before lab, use your textbook or other reference to find the ionization energies of the alkali metals discussed in the Introduction and the elements studied in this lab exercise. Record your findings in the space below.

3. When Mendeleev developed his periodic table he left gaps for certain elements that had not yet been discovered. One example is gallium (Ga, element number 31), which was discovered in 1875. Explain why Mendeleev left a gap for this element.

4. In general, atomic masses increase as you move across a row or down a column. This was one of the fundamental principles of Mendeleev's table. Yet, there are two elements in the fourth period that contradict this principle. Identify these elements, and explain why Mendeleev kept them in their current order rather than arranging them by atomic mass.

PROCEDURE

Part 1. Reaction with Atmospheric Oxygen (O_2)

1. Obtain a 0.02 g piece of Mg ribbon (~ 2 cm long). Place the Mg sample on a clean, dry watch glass. Record the appearance of the Mg ribbon on your Data Sheet, including color and surface characteristics.
2. Scratch the surface and immediately note the appearance of the exposed surface. Record your observations. After 5 minutes, note any changes in the appearance of the scratched surface.
3. Light your Bunsen burner and adjust the flame so that it is a clear blue. Grasp the Mg ribbon sample with crucible tongs, and hold the Mg ribbon in the hottest portion of the flame. If the Mg ribbon does not react immediately, continue to heat in the hot portion of the flame for 1–2 minutes. **DO NOT STARE AT THE Mg RIBBON ONCE IT STARTS TO BURN.** Record your observations during the heating process, as well as the appearance of the reaction product.
4. Obtain a small sample (0.05 g) of Al metal, and repeat Steps 1--3 for your Al sample.
5. Obtain a small sample (0.03 g) of Ca metal, and repeat Steps 1--3 for your Ca sample.
6. Obtain a small sample (0.05 g piece of Si, and repeat Steps 1--3 for your Si sample.

Part 2. Reaction with Water

7. Label four 50-mL beakers with the symbols for your samples (Mg, Al, Ca, Si).
8. Add 20 mL of de-ionized water and 3--5 drops of phenolphthalein solution to a 25 mL graduated cylinder. Stir the solution with a stirring rod, and save for use in Steps 9–12.
9. Transfer a 2-cm piece of mg ribbon to the Mg beaker, and pour 5 mL of the water-phenolphthalein mixture into the beaker. Cover the beaker with the watch glass. Observe the Mg and solution immediately after mixing, and again after about 5 minutes. Record all your observations on your Data Sheet.
10. Dispose of the beaker contents as directed, and rinse and dry your beaker.
11. Repeat Step 9 with a 0.05 g sample of Al in the Al beaker.
12. Repeat Step 9 with a 0.03 g sample of Ca in the Ca beaker.
13. Repeat Step 9 with a 0.05 g sample of Si in the Si beaker.

Part 3. Reaction with 4 M HCl

14. Obtain 25 mL of 4 M HCl in your 35-mL graduated cylinder.
15. Transfer 5 mL of the HCl solution to your Mg beaker. Add a 2-cm piece of Mg ribbon to the HCl in the beaker, and cover the beaker with the watch glass.
16. Record your observations on your Data Sheet. Dispose of the solution in the beaker as directed.
17. Repeat Steps 15 and 16 with a 0.05 g piece of Al in your Al beaker.
18. Repeat Steps 15 and 16 with a 0.03 g piece of Ca in your Ca beaker.
19. Repeat Steps 15 and 16 with a 0.05 g piece of Si in your Si beaker
20. Wash and rinse all glassware with de-ionized water.

Data Sheet

Part 1. Reaction with Atmospheric Oxygen (O_2)

Element	Initial Appearance	Appearance of scratched surface (initial)	Appearance of scratched surface (after 5 min.)
Mg			
Al			
Ca			
Si			

Element	Observations during heating	Appearance of product (or after heating)
Mg		
Al		
Ca		
Si		

Part 2. Reaction with Water

Element	Observations after mixing with water-phenolphthalein mixture
Mg	
Al	
Ca	
Si	

Part 3. Reaction with 4 M HCl

Element	Observations after mixing with 4 M HCl
Mg	
Al	
Ca	
Si	

Conclusions

1. Some substances react with atmospheric oxygen at ambient temperature; heating can produce significantly increased reaction with atmospheric O_2. Based on your observations in Part 1, describe the trends in chemical behavior of the elements in reaction with O_2:

   a) Across a period.

   b) Within a group.

2. Based on your observations in Part 2, describe the trends in chemical behavior of the elements in reaction with H_2O:

   a) Across a period.

   b) Within a group.

3. Based on your observations in Part 3, describe the trend in how reactivity of the elements with 4 M HCl changes:

   c) Across a period.

   d) Within a group.

4. Are your conclusions consistent with one another? Explain.

Post-Lab Questions

Answer questions 1--4 based on the chemical behaviors observed in this lab exercise and the data presented in the Introduction.

1. How would you expect the reactivity of Li and Na with atmospheric O_2 to compare with the reactivity of Mg? Explain.

2. How would you expect the reactivity of Li and Na with water to compare with the reactivity of Mg? Explain.

3. How would you expect the reactivity of cesium (Cs) and barium (Ba) in water to compare with the behavior of Na and Mg? Explain.

4. For the reactions in question 3, do you think safety precautions might be required? Explain why or why not.

5. Explain the trends in reactivity in terms of <u>other</u> periodic trends, (i.e., atomic size, ionization energy, etc.).