Activity 3

Chemical Behavior of Metals

What Do You Think?

Various metals have been used since ancient times for works of art. The properties of metals determine their uses.

- How might the properties of metals be related to the atomic structure of the metal’s atoms?

Record your ideas about this question in your Active Chemistry log. Be prepared to discuss your responses with your group and the class.

Investigate

Part A: Losing Electrons

In this activity you will investigate the chemical reactivity of metals.

1. Your teacher will provide you with a voltmeter, connecting wires, samples of several metals, and a salt-water solution. Among the metals you may find copper, aluminum, tin, iron, zinc, magnesium, and silver. If two different metals are connected by a wire and the metals are placed in the salt-water solution, electrons may flow through the wire from one metal to the other, creating an electric current in the wire. The potential difference (voltage) creating this current can be measured with the voltmeter.
Attach a wire to each of two metals. Attach the wire from one of the metals to the voltmeter terminal marked positive “+”. Attach the wire from the other to the terminal marked negative “−”.

2. Place the metals in the salt-water solution (be sure to place only the metals in the solution, not the ends of the wire clips). Decide which metal will be metal 1.

a) What happens to the reading on the voltmeter? If the reading is positive, the metal connected to the negative side is losing electrons more easily than the other metal. The electrons are flowing through the voltmeter to the plus side. If the reading is negative, the metal connected to the plus side is losing its electrons more easily and electrons are flowing in the opposite direction to the metal connected to the minus side. In either case, it is the same metal that is losing electrons more easily.

Switch the wires to the opposite terminals.

b) What happens to the reading on the voltmeter now?

3. Make a table in your Active Chemistry log for the data you will be collecting. You can use one similar to the one shown.

<table>
<thead>
<tr>
<th>Negative terminal</th>
<th>Positive terminal</th>
<th>Reading</th>
</tr>
</thead>
<tbody>
<tr>
<td>metal 1</td>
<td>metal 2</td>
<td></td>
</tr>
<tr>
<td>metal 1</td>
<td>metal 3</td>
<td></td>
</tr>
<tr>
<td>metal 1</td>
<td>metal 4</td>
<td></td>
</tr>
<tr>
<td>metal 1</td>
<td>metal 5</td>
<td></td>
</tr>
<tr>
<td>metal 1</td>
<td>metal 6</td>
<td></td>
</tr>
</tbody>
</table>

a) Record the reading for each combination of metals when placed in the salt-water solution. Be sure to identify whether the reading is positive or negative.

4. Repeat Step 2, using a different metal on the negative terminal each time. Continue this until you have tested all possible combinations.

a) Record all your readings.

5. Dispose of the salt-water solution and rinse and dry all metal samples when the investigation is completed. Clean up your workstation.

6. Answer the following questions in your Active Chemistry log.

a) Which metal lost its electrons most easily?

b) Which one had the most difficulty losing its electrons?

c) Rank the rest of the metals in between. Begin with the ones that lose their electrons most easily.

Part B: Reactivity with Acids

1. Use the information you gained in Part A and in Activity 2 (Part D) to predict which metals are more reactive with acids.
a) Record your predictions in your Active Chemistry log.

2. Place a small piece of each polished metal provided in a separate well in a spot plate. Add 10–15 drops of 3 M hydrochloric acid to each well.
   a) Record your observations. Discuss the results in small groups.
   b) Rank the metals in order of increasing reactivity with acid.
   c) How does this ranking compare with the ranking of the metals in Part A?

3. Dispose of the materials as directed by your teacher. Clean up your workstation.

Part C: Electroplating

1. You can electroplate copper onto a nickel strip by using a 27-V battery (made up of three 9-V batteries in series), wires, a solution of copper (II) sulfate, a piece of copper, and a nickel strip. Electroplating is the deposition of a thin layer of a metal on an object by electrolysis.

   a) Make a sketch in your Active Chemistry log of the nickel strip after electroplating.
   b) What has been deposited on the nickel? Where did it come from?
   c) What was the purpose of the three 9-V batteries?
   d) How might an artist use this process?

2. Dispose of the materials as directed by your teacher. Clean up your workstation.
REACTIVITY OF METALS

Valence Electrons and the Octet Rule

In this activity you looked at the chemical reactivity of metals. This reactivity depends on the valence electrons. (Recall that you first learned about valence electrons in the Fun with the Periodic Table chapter.) In the modern model of atomic structure, protons and neutrons are located in the nucleus. The electrons are in some predictable cloudlike energy level (called an orbital) outside of the nucleus. The electrons in the outermost electron shell that are furthest from the nucleus are the valence electrons. These electrons are responsible for the reactivity of an element.

Metals tend to lose these electrons in chemical reactions with other substances. When a metal atom loses electrons, it becomes a positively charged particle, or an ion. Ion is the name for a charged atom or charged group of atoms. Cation is the name for a positively charged ion. Some metals are better than others at losing their valence electrons. In this activity, you determined which metals tend to lose electrons easily and which ones do not. This property relates to the reactivity of the metal and therefore to its usefulness as material for works of art.

You can determine the number of valence electrons an element has by examining its location on the periodic table. The metals that belong to group 1A all have one valence electron. Those metals in group 2A all have two valence electrons. Elements in groups 3A, 4A, 5A, 6A, 7A, and 8A similarly have 3, 4, 5, 6, 7, and 8 valence electrons, respectively.

When you examine the noble gases in group 8A you see that, except for helium, all of these “inert” or nonreactive elements have eight valence electrons. Having eight valence electrons gives certain stability to an element. Elements other than the noble gases have a tendency to lose or gain electrons so that they too will have eight valence electrons. This phenomenon is referred to as the octet rule. The root “oct” means eight. An octagon is an eight-sided figure. (October used to be the eighth month, before July and August were added in a tribute to Julius and Augustus Caesar.) Helium is a notable exception, achieving stability with two valence electrons.

Fluorine, with seven valence electrons, typically gains one electron to form a fluoride ion with a charge of –1. Remember the electron configuration of fluorine's nine electrons is 1s² 2s² 2p⁵ so if it gains one electron to form a fluoride ion the electron configuration would be 1s² 2s² 2p⁶ 1⁵.
electron, the second energy level will have eight electrons: \(1s^2 \ 2s^2 \ 2p^6\)

\[ F + e^- \rightarrow F^- \]

Sodium, with only one valence electron, will “give” it away to form a sodium ion with a \(+1\) charge. Its electron configuration is \(1s^2 \ 2s^2 \ 2p^6 \ 3s^1\). Losing that one electron in the \(3s\) shell will create an ion with a full outer shell (eight electrons in the second energy level).

\[
\text{Na} \rightarrow \text{Na}^{+} + e^- \\
1s^2 \ 2s^2 \ 2p^6 \ 3s^1 \rightarrow 1s^2 \ 2s^2 \ 2p^6
\]

Metals in group 2A all have two valence electrons, and if one loses these two electrons an ion with a \(+2\) charge will form.

\[ \text{Mg} \rightarrow \text{Mg}^{2+} + 2 \ e^- \]

For example, when the zinc metal was attached to the negative terminal of the voltmeter, the electrons flowed through the voltmeter to the copper terminal, giving a positive reading. When you reversed the wires of the system you got the opposite flow and a negative reading. From the investigation, you were then able to determine which metal is the easiest to oxidize (lose electrons). This metal is referred to as most active. Looking at all of the combinations that you investigated, you should now be able to place the metals in a reactivity order of easiest to most difficult to oxidize (lose electrons).

Here is a list of metals, including the ones you tested in the activity, from most active to least active:

Most active → lithium (Li), potassium (K), calcium (Ca), sodium (Na), magnesium (Mg), aluminum (Al), zinc (Zn), iron (Fe), nickel (Ni), tin (Sn), lead (Pb), hydrogen (H), copper (Cu), mercury (Hg), silver (Ag), platinum (Pt), gold (Au) → least active

**Reactivity of Metal and Art**

Reactive metals lose electrons easily and form compounds readily. Sometimes the properties of these new compounds are detrimental to the metal. For example, formation of rust (iron oxide) causes iron metal to deteriorate. In other metals, the new compounds that form can protect the underlying metal from further deterioration. For example, when aluminum is exposed to air, it forms aluminum oxide (\(\text{Al}_2\text{O}_3\)), which is less reactive than aluminum itself. This forms a protective coating, preventing the underlying aluminum from deteriorating.
Even copper, which is fairly low in reactivity, will react with substances in the air to form a protective coating. The natural protective coating of a blue-green patina is found on many old copper roofs, statues, and other copper surfaces. The Statue of Liberty is covered with a green patina finish. A patina, from the Latin word “to plate,” is a surface coating that develops on metals and protects them from further corrosion.

The main constituent of the patina found is a mixture of basic copper carbonate and basic copper sulfate. The color variations from greenish to blue-gray depend on differences in chemical composition. The decorative coating protects the underlying copper from further corrosion by acting as a barrier between the atmospheric chemicals and the copper.

In this activity, you coated the nickel with copper. This process is called electroplating. Some of the copper was released from the positive (+) terminal as copper ions and went into the solution of copper (II) sulfate. Then some of the copper ions from the copper (II) sulfate moved toward the negative terminal where it gained electrons and the copper atoms adhered to the nickel.

Metal ions in solution (like the solution of copper (II) sulfate) can accept electrons and turn back into metal atoms (copper) that no longer dissolve in water. Voltage applied to metals placed in a solution containing ions (electrolyte) will cause the metal connected to the positive terminal to dissolve. The positive ions of this metal flow through the solution and accept any excess electrons from the second metal connected to the minus terminal. Thus, the atoms of the first metal can be plated on the second. Electroplating is often used by sculptors and jewelers.
Active Chemistry

What Do You Think Now?
At the beginning of the activity, you were asked:

• How might the properties of metals be related to the atomic structure of the metal’s atoms?

How would you answer this question now?

Chem Essential Questions

What does it mean?
Chemistry explains a macroscopic phenomenon (what you observe) with a description of what happens at the nanoscopic level (atoms and molecules) using symbolic structures as a way to communicate. Complete the chart below in your Active Chemistry log.

<table>
<thead>
<tr>
<th>MACRO</th>
<th>NANO</th>
<th>SYMBOLIC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Which metal appeared to be the most reactive? The least? How did you measure this?</td>
<td>When two metals are connected to different terminals of a battery and placed in a solution containing ions, what happens at the molecular level?</td>
<td>Make a list of the reactivity of the metals you tested, from the most reactive to the least.</td>
</tr>
</tbody>
</table>

How do you know?
What evidence do you have to support the idea that one metal is more reactive than another? Use your data to explain how copper made its way onto nickel in Part C.

Why do you believe?
Report on a situation in your life where you would need to choose a less (or more) reactive metal for some everyday purpose.

Why should you care?
Understanding the reactivity of metals will help guide you as you create your work of art, should you choose to incorporate metal into it. The reasons may be for beauty or protection, but either way a meaningful explanation of your choice of metal will add credibility to your museum display.
Reflecting on the Activity and the Challenge

You have now seen that some metals lose their electrons more easily than others. This determines their reactivity with other substances. You saw this when you used different metals to produce a current that you measured with the voltmeter. You then used the octet rule of valence electrons to help explain this property of metals. Equations can also be written to show the loss of electrons.

Metals are often used in various ways when creating artwork. When an artist decides to incorporate some metal into her work it is important for her to understand the chemical reactivity of the metal. You saw that some metals react with acids; this phenomenon is used in creating etched metals for printmaking and other artwork. The use of patinas to enhance and protect the beauty of metals is used in sculpture and jewelry. Perhaps you might choose to create a work of art that incorporates a metal. It would be essential to have knowledge about the chemical reactivity of this metal for your project’s explanation.

Chem to Go

1. Using the periodic table, determine how many valence electrons the following elements have?
   a) Na  b) F  c) Mg  d) Ne  e) P  f) Al

2. For each of the atoms in Question 1:
   a) How many electrons will each atom either gain or lose in order to satisfy the octet rule?
   b) What will be the charge on each resulting ion?

3. State in your own words the octet rule.

4. In this activity you plated copper onto nickel. Describe the conditions you would use to perform the opposite process—nickel-plating a piece of copper metal.

5. Show an equation for the formation of a typical Mg (magnesium) ion from a neutral Mg atom.

6. Show an equation for the formation of a typical Cl (chlorine) ion from a neutral Cl atom.

7. Why are some items silver- or gold-plated rather than solid silver or gold?

8. Why might an artist choose to electroplate a sculpture?

9. Preparing for the Chapter Challenge

   Propose how you might electroplate some metal to change or enhance its appearance so that it might be used as a work of art. Be sure to make use of your data regarding the relative reactivities of metals when making your proposal.

Inquiring Further

Protecting metals in the ground

Protection of metal in the ground uses the principles of electroplating in a special way. This process is called cathodic protection. Research this process and report to your class.