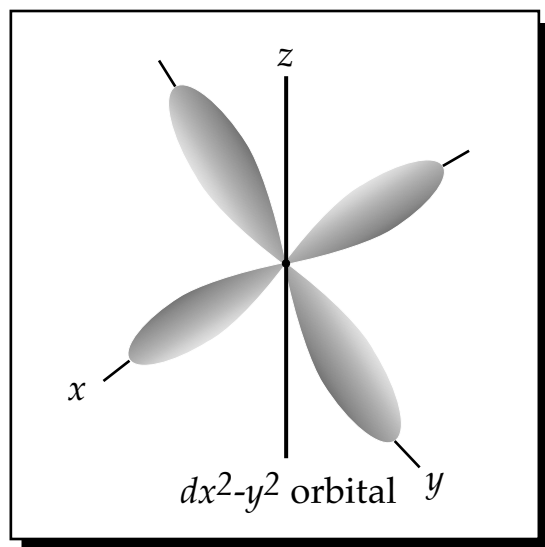


A SourceBook Module

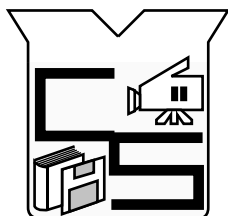
Version 1.0 1993

*Funded in part under
National Science Foundation
Grant No. TPE 88-50632*

*ChemSource Project Principal Investigator:
Mary Virginia Orna, OSU
Department of Chemistry
College of New Rochelle
New Rochelle, NY 10805
Phone: (914) 654-5302
FAX: (914) 654-5387*



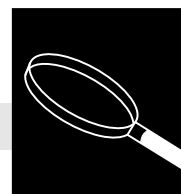
TRANSITION METALS



ChemSource

*Instructional Resources for Preservice and
Inservice Chemistry Teachers*

Topic Overview



CONTENT IN A NUTSHELL

The term “transition element” was originally coined to denote the elements in the middle of the Periodic Table that provide a “transition” between the “base formers” on the left and the “acid formers” on the right. Many textbooks refer to all the elements in both the *d*- and the *f*-blocks as transition elements, but some define them as those elements with partially filled *d*- or *f*-orbitals (the d^1 - d^9 and f^1 - f^{13} elements). SourceBook will refer to the transition elements as those in the *d*- and *f*-blocks.

Most transition elements have several oxidation states, and oxidation-reduction chemistry is important in studying these elements. For example, iron’s ability to change readily from 2+ to 3+ is vital to life. This allows Fe^{2+} in cytochrome proteins to oxidize carbohydrates. Both iron oxidation states are ubiquitous in our world. Fe^{3+} is present where oxygen is abundant, while Fe^{2+} is present in oxygen-poor, anaerobic environments.

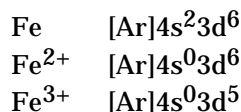
A pattern can be observed when the number of stable oxidation states is compared to a transition element’s position in the Periodic Table. Metals at the left and right sides of the transition element block have the fewest oxidation states (Sc and Zn display only 3+ and 2+, respectively) while those in the middle have the most (Mn has common oxidation states of 2+, 4+, and 7+).

Inorganic compounds of transition elements are often colored. Specific colors are characteristic of particular transition metal ions. These colors help identify ions and sometimes help chemists follow reaction progress. Color adds intrinsic interest to a student’s study of transition elements. For example, growing crystals of copper(II) sulfate is both artistically and aesthetically satisfying.

In a representative-element period, such as Period 3, atomic number increase is associated with predictable, distinct variations in element properties. This is not the case for transition elements, which “interrupt” the representative elements within Periods 4, 5, and 6. Periodic variation is still present among transition elements, but it is subtle and requires a more sophisticated interpretation.

This module concentrates on Period 4 transition elements; they are among the most familiar to students and the most accessible for teachers. The suggested laboratory and demonstration activities involve iron, copper, nickel, and manganese. Student activities involving compounds of chromium, nickel, and cobalt—once widely used—are omitted because they are now suspected carcinogens.

An explanation for multiple oxidation states is that electrons in the outermost *s*-orbital and five *d*-orbitals of the transition metal atom are all available for bonding. Because these six orbitals are of nearly identical energies, many electrons are candidates for ionization. For example, Fe can lose two electrons to form Fe^{2+} or it can lose three electrons, forming Fe^{3+} . Electron configurations for such ions are found by removing the outermost *s*-electrons from the neutral atom first, and then removing *d*-electrons as needed. Fe^{2+} is formed when Fe loses its two 4*s*-electrons; Fe^{3+} is formed when Fe loses its two 4*s*-electrons and one 3*d*-electron.



Many transition element orbitals can be involved in covalent bonding. For example, one manganese atom can covalently bond to one, two, or four oxygen atoms producing MnO , MnO_2 , or MnO_4^- . In lower oxidation states, the metal ion is often regarded as an individual cation (e.g., Mn^{2+}), although it is often hydrated. In higher states it is covalently bonded within a polyatomic ion (e.g., MnO_4^-). Binary compounds, such as MnCl_2 and CuCl_2 where each transition element is in a low oxidation state, have bonds with considerable ionic character. As the metal's oxidation number increases the bonds become more covalent in nature.

The presence of color in transition metal compounds is explained by the effect of bonding on d -orbitals. Molecules of nonmetals and anions, such as H_2O and Cl^- can act as ligands, bonding to transition metal atoms or ions through an unshared electron pair. The ligand's unshared pair of electrons is shared with the metal ion—thus the bond is regarded as primarily covalent. The entire bonded species, metal plus ligands, is called a coordination complex, or simply a complex. An example is the complex ion $[\text{Cu}(\text{H}_2\text{O})_4]^{2+}$, which has four water molecules coordinated to the Cu^{2+} ion.

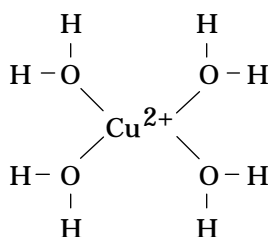


Figure 1. $[\text{Cu}(\text{H}_2\text{O})_4]^{2+}$ complex ion.

Ligands bond to metals in well-defined numbers and geometries. Over 99% of metal complexes have four or six ligands. Complexes with four ligands have either square planar or tetrahedral geometry, while all complexes with six ligands are octahedral.

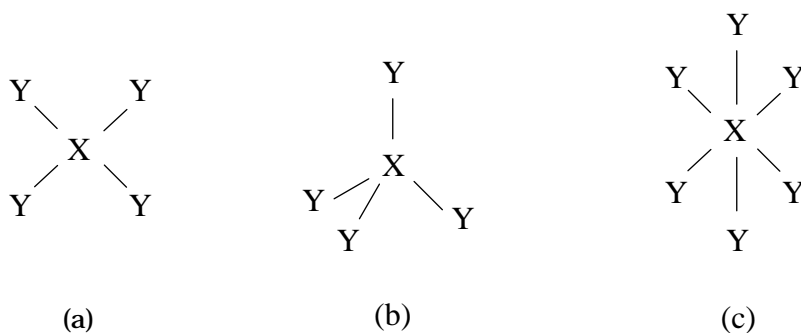


Figure 2. Square planar (a), tetrahedral (b), and octahedral (c) geometries.

$[\text{Cu}(\text{H}_2\text{O})_4]^{2+}$ is a square planar complex. This complex ion is responsible for the blue color of solid hydrated copper salts, such as $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$. (The fifth water molecule in this hydrated salt is hydrogen bonded between one coordinated water molecule and the sulfate ion.)

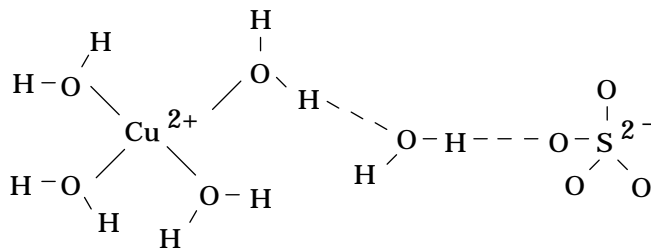
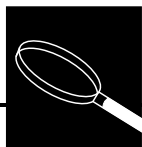


Figure 3. Bonding in $[\text{Cu}(\text{H}_2\text{O})_5]\text{SO}_4$.



The variety of colors exhibited by transition metal compounds is also explained by reference to the metal's d -electrons. When all five d -orbitals within a subshell participate in bonding with ligands, the d -orbitals no longer have the same energy. The size of the energy gap between two sets of d -electrons often matches the energy of certain photons of visible light. When an electron moves to a d -orbital of higher energy, it absorbs a photon of specific energy. The transmitted light is responsible for the colors. Different metal ions exhibit different colors. Different ligands bonded to the same metal ion generally result in complexes of different colors. Ions with either zero or ten d -electrons are colorless. Scandium (Sc^{3+}) has no d -electrons to promote; zinc (Zn^{2+}) has no vacant orbital to accommodate any additional electrons. Although not easy, colors of complexes can be predicted using extended forms of this theory.

Similarities in other properties within a transition metal series can be understood by considering structures. Differences in first ionization energies between successive elements within a transition metal series are generally much smaller than those of successive representative elements. An atom's outermost electrons do not feel the full attraction of protons in the nucleus. Some of the "pull" is cancelled by intervening electrons—in effect, the outermost electrons are partially "shielded" from the attractive force of the atom's protons. Even though all electrons are fully attracted to the protons in the nucleus, a given electron is also repelled by other electrons that are momentarily between it and the nucleus. This repulsion is called **shielding**. The net sum of these attractions and repulsions is known as the **effective nuclear charge**.

An example helps to clarify this concept. Selenium, a representative element, has one more proton in its nucleus than does arsenic. It also has an additional electron in a $4p$ -orbital. The added electron shields only 35% of the added proton from the other outer shell electrons. Selenium's outer electrons feel a net increase of 0.65 in effective nuclear charge when compared to the effective nuclear charge in arsenic.

In moving from vanadium to chromium, the added electron enters a $3d$ -orbital, although the highest-energy electrons are in the $4s$ -orbital. The $3d$ -electrons shield 85% of the increased positive charge in the nucleus from the $4s$ -electrons—the $3d$ -electrons reside between the $4s$ -electrons and nucleus about that percent of the time. In general, $n = 3$ electrons are closer to the nucleus than are $n = 4$ electrons. The $4s$ -electrons in chromium atoms experience only 0.15 more effective nuclear charge than do those in vanadium atoms. Effective nuclear charges experienced by outermost electrons increase faster from element to element among representative elements than they do among transition elements. Thus ionization energies for representative elements change more from element to element within a period than do similar values for transition elements. Similar arguments can be used to explain the small changes among atomic radii in the transition series.

The chemistry of transition elements can still be enjoyed without understanding such theoretical nuances. Since trends and relationships are more difficult to predict and explain among transition elements, most students will not benefit from such a theoretical treatment in their first course in chemistry.

PLACE IN THE CURRICULUM

Ideas, demonstrations, and activities from this module can be scattered through the curriculum, since they fit well with other topics (see *Links and Connections* for specific suggestions). If an entire unit on transition elements is taught, material in this module could be used near the end of the year for reinforcement and review of principles. Many activities can also be used to illustrate periodicity and bonding.

1. Transition elements are all metals.
2. Many trends in physical properties of transition elements (atomic radius, ionization energy, *etc.*) can be explained by referring to *d*-orbital electrons.
3. Most transition metals exhibit multiple oxidation states.
4. Many compounds of transition metals are colored.
5. Transition metals and their compounds play an important role in the real world.

CENTRAL CONCEPTS

1. Electron configurations can be written by assigning electrons to the available orbit of lowest energy.
2. The structure of the Periodic Table is a reflection of the electronic structure of atoms (atomic structure).
3. Bonds are formed when atoms share or transfer electrons (bonding).
4. Oxidation numbers can be assigned to atoms (oxidation-reduction).
5. Redox reactions involve a change in the oxidation number of two or more atoms during reaction (oxidation-reduction).

RELATED CONCEPTS

1. Recognize trends and patterns in families of the Periodic Table.
2. Calculate gram-gram relationships from a chemical equation.
3. Laboratory manipulations.

RELATED SKILLS

After completing their study of transition elements, students should be able to:

1. recognize that transition elements are those elements occupying the *d*- and *f*-blocks of the Periodic Table.
2. identify color as a property of many compounds of transition elements.
3. identify all transition elements as metals.
4. recognize that most transition elements have multiple oxidation states since *d*-electrons function as valence electrons.
5. identify transition elements that are important in daily life.
6. recognize that ions of the same element possessing different charges have different properties.

PERFORMANCE OBJECTIVES

Honors or second year students may also be expected to:

1. interpret some oxidation states in terms of electron structure.
2. identify the ligands and central ion in a complex ion.
3. use laboratory data to illustrate the law of multiple proportions as applied to compounds of transition elements.

Concept/Skills Development

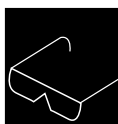


LABORATORY ACTIVITY: STUDENT VERSION

Activity 1: Identification of Iron Cations

Introduction

Transition elements form ions with different charges—for example, iron forms Fe^{2+} and Fe^{3+} cations. The properties of these two ions are different.



Purpose

To test for the presence of iron(II) and iron(III) ions with two different reagents and to use observations to design a procedure to test household products.

Safety

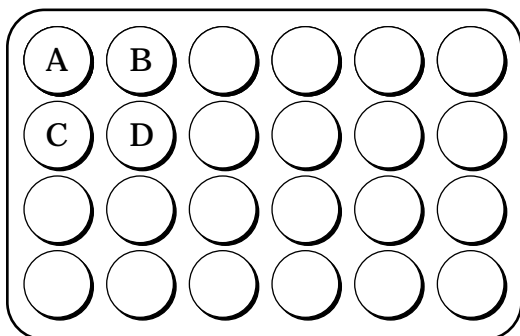
1. Wear protective goggles throughout the laboratory activity.
2. All usual safety precautions should be followed even when working with very small quantities.

Procedure

Prepare a data table and record all of your observations in it.

Part 1

Use a 24-well microtitration plate or six small test-tubes for the activity. Save all the test results until you finish the activity.



A

5 drops 0.1 M $\text{Fe}(\text{NH}_4)_2(\text{SO}_4)_2$
1 drop 3 M HCl
1 drop 0.01 M KMnO_4

B

5 drops 0.1 M $\text{Fe}(\text{NH}_4)_2(\text{SO}_4)_2$
1 drop 3 M HCl
1 drop 0.1 M KSCN

C

5 drops 0.1 M FeCl_3
1 drop 3 M HCl
1 drop 0.01 M KMnO_4

D

5 drops 0.1 M FeCl_3
1 drop 3 M HCl
1 drop 0.1 M KSCN

1. In each of two wells or test-tubes (labeled A and B) put five drops of 0.1 M $\text{Fe}(\text{NH}_4)_2(\text{SO}_4)_2$ [iron(II) ammonium sulfate] and one drop 3 M HCl (hydrochloric acid). Add one drop 0.01 M KMnO_4 (potassium permanganate) to one well and one drop 0.1 M KSCN (potassium thiocyanate) to the other. Record your observations.
2. Repeat Step 1, using 0.1 M FeCl_3 [iron(III) chloride] in place of $\text{Fe}(\text{NH}_4)_2(\text{SO}_4)_2$ (Wells C and D).
3. Repeat Step 1, using distilled water in place of $\text{Fe}(\text{NH}_4)_2(\text{SO}_4)_2$.
4. Have your teacher check your data table before starting Part 2.

Part 2

1. Obtain several samples of products you suspect might contain iron. Certain foods, food supplements, plant foods, and rust are examples. If the sample is solid, add 3 M HCl dropwise to make a solution.
2. Write a procedure to test each material for iron(II) and iron(III).
3. Design a data table to record your results.
4. After you obtain your teacher's approval of the proposed procedure, complete your analysis.
5. Thoroughly wash your hands before leaving the laboratory.

Data Analysis

1. Which iron ion was more common among the materials you tested?
2. Can you identify any relationship between the identity of the iron ion and the use of the product?
3. Why was distilled water tested in Part 1?

Implications and Applications

1. How could your procedure be adapted to determine how much iron ion (either Fe^{2+} or Fe^{3+}) is present in a sample?
2. Design a laboratory procedure based on your answer to Question 1.
3. Could your procedure be used to identify both iron(II) and iron(III) in the same sample? Explain.



**LABORATORY
ACTIVITY:
TEACHER
NOTES**

Activity 1: Identification of Iron Cations

Major Chemical Concept

Compounds of transition elements in different oxidation states exhibit different properties.

Level

General or Basic. (This activity could be adapted for use with honors students by adding more information about electron structures and bonding and/or requiring the *Extension* described later.)

Expected Student Background

Students should be able to recognize that different properties indicate different substances and that properties can be used to identify a substance.

Time

30 to 45 min

Safety

Read *Safety Considerations* in the *Student Version*. Students should be advised that all usual safety precautions should be followed even when working with very small quantities.

Materials (For 24 students working in pairs)

Nonconsumables

12 Microtitration plate or 72 13- x 100-mm test-tubes
Dropper bottles or thin-stem pipets

Consumables

0.1 M Iron(II) ammonium sulfate, $\text{Fe}(\text{NH}_4)_2(\text{SO}_4)_2$ [3.92 g $\text{Fe}(\text{NH}_4)_2(\text{SO}_4)_2 \cdot 6\text{H}_2\text{O}$ per 100 mL solution]
0.1 M Iron(III) chloride, FeCl_3 (2.70 g $\text{FeCl}_3 \cdot 6\text{H}_2\text{O}$ per 100 mL solution; add 4-5 drops 12 M HCl to water before dilution to prevent $\text{Fe}(\text{OH})_3$ formation)
0.01 M Potassium permanganate, KMnO_4 (0.158 g KMnO_4 per 100 mL solution)
0.1 M Potassium thiocyanate, KSCN (0.97 g KSCN per 100 mL solution)
Samples containing iron such as vitamins, raisins, rust, plant food

Advance Preparation

Both 0.1 M $\text{Fe}(\text{NH}_4)_2(\text{SO}_4)_2$ and 0.01 M KMnO_4 must be freshly prepared each day—the solutions are not stable. Put solutions in dropper bottles or thin-stem pipettes for each laboratory group.

The easiest way to obtain a variety of household products is to ask students to bring samples from home. This will also add relevancy to the activity. Tap water in some localities contains enough iron cations to give a positive test.

Pre-Laboratory Discussion

This activity could be completed early in the course, even before students have detailed knowledge of electron structure. In that case it would probably be sufficient to emphasize that a change in color generally indicates that a chemical reaction has occurred. The activity might also be used near the end of the course as an opportunity to review what students have learned about chemical analysis. You might ask students to compare electron configurations of an iron atom, and iron(II) and iron(III) ions. With advanced students, discuss the oxidizing properties of KMnO_4 and the reducing properties of iron(II) ions.

Teacher-Student Interaction

As you move through the laboratory, insure that students use all their data. A common error is for students to report that Fe(II) did not react with KMnO_4 because the solution became nearly colorless. Comparison to the reaction of KMnO_4 with water helps. Remind students that disappearance of color as well as appearance of color indicates chemical change. Students will discover that some household products are difficult to test because they possess color. This would be a good time to talk about limitations of tests. If you use microtitration plates be sure that students clean them immediately after use.

Anticipated Student Results

	$\text{KMnO}_4(\text{aq})$	$\text{KSCN}(\text{aq})$
Fe(II)	Color fades	No change
Fe(III)	No change	Deep red color
Distilled water	No change	No change

The student-designed laboratory procedure should include testing each substance with both reagents. Results can be compared to tests performed on known materials. A sample data sheet is shown below.

	$\text{KMnO}_4(\text{aq})$	$\text{KSCN}(\text{aq})$
Vitamin		
Rust		
Plant food		
Raisin		
Cream of Wheat		
Distilled water (control)		

Answers to Data Analysis

- Answers may vary.
- Answers may vary. Rust contains iron(III) while vitamins contain iron(II).
- Distilled water was tested to provide a control. This control allows students to observe the colors of the reagents when no iron(II) or iron(III) is present.

Post-Laboratory Activities

Discuss *Data Analysis* and *Implications and Applications* questions with students. If time permits, students could try out their procedures for the quantitative determination of iron ions. Discuss the concept of the control.

Extensions

- A Spectronic 20 (or other student spectrophotometer) can be used to determine the amount of a colored substance present in a solution. Activity 18 in *Laboratory Assessment Builds Success* gives instructions for such an activity. This activity describes the spectrophotometric analysis of Cu^{2+} ion through conversion to deep blue copper-ammonia complex $[\text{Cu}(\text{NH}_3)_4]^{2+}$.



2. Potassium hexacyanoferrate(III), $\text{K}_3\text{Fe}(\text{CN})_6$ reacts with Fe^{2+} to produce $\text{KFe}[\text{Fe}(\text{CN})_6]$, a deep blue compound sometimes called Prussian blue. Potassium hexacyanoferrate(II), $\text{K}_4\text{Fe}(\text{CN})_6$ reacts with Fe^{3+} to produce the same compound. Students can devise an additional procedure for testing for the presence of Fe^{2+} and Fe^{3+} using this knowledge.

Assessing Laboratory Learning

1. During the laboratory activity check for the following:
 - a. Results of preliminary activity.
 - b. Preparation of data table.
 - c. Design for testing household products.
2. A substance containing one of the iron cations can be used as an unknown.
3. Paper-pencil questions:
 - a. A plant food was tested and the following results were obtained: KMnO_4 solution—colorless, KSCN solution—colorless. Which iron ion may have been present? [Fe^{2+}]
 - b. A dietary supplement was tested with both solutions. The results: KMnO_4 remained purple and KSCN changed to red. What is your conclusion about the type of iron in the vitamin? [Fe^{3+}]
 - c. Is it possible to have a material that decolorizes KMnO_4 and also turns red when KSCN is added? [*Yes, it must contain both Fe^{2+} and Fe^{3+} .*]

Activity 2: The Amount of Copper in Copper(I) Oxide and Copper(II) Oxide

LABORATORY ACTIVITY: STUDENT VERSION



Introduction

Copper forms two compounds with oxygen. In this activity the two copper-oxygen compounds will be dissolved in hydrochloric acid. The amount of copper in each will be determined by displacing the copper with aluminum wire.

Purpose

To compare the amounts of copper combined with a fixed amount of oxygen in two compounds.

Safety

1. Wear protective goggles throughout the laboratory activity.
2. Dispose of all solutions in the container provided by your teacher.

Procedure

1. Label one 100-mL beaker Cu_2O and another CuO . Determine the mass of each beaker.
2. Add about 1 gram Cu_2O to the appropriately labeled beaker and determine the mass of the beaker and contents.
3. Add about 1 gram CuO to the other beaker and determine the mass of this beaker and contents.
4. Add 45 mL 1 M HCl to each beaker and observe. (*CAUTION: Avoid contact of both skin and clothing with hydrochloric acid; it can burn.*)
5. Heat gently with stirring until the oxides dissolve. Copper (II) chloride forms a green solution and the Copper(I) chloride is a white solid. Cool.
6. Make a loop with a handle from each of two pieces of 25-cm aluminum wire. Put one loop of wire in each beaker. Allow the wire to remain in the beaker until there is no further evidence of reaction (*i.e.*, until no more aluminum appears to dissolve).
7. Remove the aluminum wire, with forceps if necessary. Rinse the wire with distilled water from a squeeze bottle. Dislodge any pieces of copper that cling to the wire with a stirring rod. Dispose of the wire as your teacher suggests.
8. Carefully decant the liquid from the solid. Rinse the solid with 10 mL tap water, then with 10 mL distilled water. Pour off as much liquid as possible.
9. Carefully dry the solid by heating the beaker with a burner flame.
10. When the beaker is cool, find the mass of beaker and contents.
11. Heat the beaker and contents for an additional minute. Cool and find the mass. If the mass does not differ significantly from the previous determination, dispose of the copper as your teacher directs.
12. If the mass does differ, repeat Step 11.
13. Thoroughly wash your hands before leaving the laboratory.



Data Analysis

1. Describe the reactants and products.
2. Describe changes in the aluminum wire.
3. Calculate the mass of copper in each compound.
4. Calculate the mass of oxygen in each compound.
5. Calculate the ratio mass Cu/mass O for each compound.
6. Calculate mol Cu/mol O for each compound.
7. Compare the two ratios.
8. Compare the two ratios in terms of atoms.
9. Write chemical equations for all reactions occurring in this activity.

Implications and Applications

1. Explain what effect each of the following would have on the value of the ratio mol Cu/mol O:
 - a. The copper was not completely dry before it was weighed.
 - b. The reaction was not complete before the aluminum wire was removed from the beaker.
 - c. A small piece of aluminum wire remained with the copper.
 - d. The copper was not washed thoroughly.
2. Choose symbols to represent copper, aluminum, hydrogen, oxygen, and chlorine atoms. Draw what you would expect to see on an atomic/molecular level at each step of the activity.

Activity 2: The Amount of Copper in Copper(I) Oxide and Copper(II) Oxide**LABORATORY
ACTIVITY:
TEACHER
NOTES****Major Chemical Concept**

The Law of Multiple Proportions: If two elements combine to form more than one compound, the amounts of one element combining with a fixed amount of the other element are in the ratio of small whole numbers.

Level

General or Honors

Expected Student Background

Students should be able to:

1. convert from units of grams to moles.
2. use a balance effectively.
3. recognize the need for quantitative separations.
4. perform mole calculations.

Time

45 to 50 min

Safety

Read the *Safety Considerations* in the *Student Version*. Remind students of the hazards involved in using hydrochloric acid.

Materials (For 24 students working in pairs)**Nonconsumables**

- 24 Beakers, 100-mL
- 12 Burners
- 12 Spatulas
- 12 Test-tube holders
- 12 Forceps
- 12 Ringstands and rings
- 12 Wire gauze

Consumables

- Copper(I) oxide, Cu_2O , 12 g
- Copper(II) oxide, CuO , 12 g
- 12 Pieces aluminum wire, Al, 18 gauge, 25 cm
- 1 M Hydrochloric acid, HCl, 540 mL [83 mL conc. (12.0 M) HCl diluted to 1.00 L]
- Acetone, 250 mL (*OPTIONAL*: You can hasten the drying process by having students rinse precipitate with ~10 mL acetone. Be sure to use proper safety precautions and disposal procedures. Since acetone is flammable, substitute hot plates for burners if you choose this alternative.)

Advance Preparation

Cut aluminum wire into 25-cm long pieces. It is economical to have students rinse and return pieces of wire remaining after the activity. Be sure the pieces are dry before you store them. Provide spatulas for students to use in transferring the oxides from bottles to beakers.



Pre-Laboratory Discussion

Remind students to make careful measurements and complete separations. It would be a good idea to have students write their mol Cu/mol O ratios on the board. Comparison of several results will help them draw reliable conclusions.

Review the following topics as needed:

1. Data Table Preparation
2. Determining Mass by Difference

$$(\text{Mass beaker} + \text{Contents}) - \text{Mass beaker} = \text{Mass contents}$$

$$\text{Mass compound} - \text{Mass copper} = \text{Mass oxygen}$$

Do not discuss the law of multiple proportions until student data are available. Review the molecular picture of solids and solutions.

Teacher-Student Interaction

During the activity comment on the evidence for change and point out how to determine if the reaction in question is complete. The solutions made by dissolving the copper oxides in acid will be distinctly different. The oxides dissolve somewhat slowly. The "solution" produced by dissolving copper(I) oxide is milky due to the low solubility of copper(I) chloride. The copper(II) chloride solution is blue. Ask students to identify the composition and source of the bubbles that appear when aluminum wire is put in the solution. [*Excess HCl reacts with aluminum to produce hydrogen gas.*] Allow students to make their observations and measurements without focusing on the calculations during the activity. Many students will need help in performing the calculations even if adept at stoichiometry. Comparison of the ratios, if they are put on the board, will help laboratory groups identify sources of error in their results. Students should be able to identify (and reject) ratios that are widely different from those of most other groups.

Anticipated Student Results

Sample Data Table

Mass of Beaker 1	65.26 g
Mass of Beaker 2	64.84 g
Mass of Beaker 1 + Cu ₂ O	66.26 g
Mass of Beaker 2 + CuO	65.84 g
Mass of Beaker 1 + Cu	66.15 g
Mass of Beaker 2 + Cu	65.64 g
Mass of Cu in Cu ₂ O	0.89 g
Mass of Cu in CuO	0.80 g

Answers to Data Analysis

1. Copper(I) oxide is a red powder; copper(II) oxide is a black powder. The products in both beakers are a reddish brown solid and a clear liquid.
2. The aluminum wire became thinner.

3. Mass Cu in Beaker 1 (66.15 g - 65.26 g) = 0.89 g

Mass Cu in Beaker 2 (65.64 g - 64.84 g) = 0.80 g

4. Mass O in Cu₂O (66.26 g - 66.15 g) = 0.11 g

Mass O in CuO (65.84 g - 65.64 g) = 0.20 g

5. $\frac{\text{Mass Cu}}{\text{Mass O}}$ in Cu₂O = $\frac{0.89 \text{ g}}{0.11 \text{ g}} = \frac{8}{1}$

$\frac{\text{Mass Cu}}{\text{Mass O}}$ in CuO = $\frac{0.80 \text{ g}}{0.20 \text{ g}} = \frac{4}{1}$

6. Moles Cu in Cu₂O = 0.89 g Cu x $\frac{1 \text{ mol Cu}}{63.5 \text{ g Cu}} = 0.014 \text{ mol Cu}$

Moles O in Cu₂O = 0.11 g O x $\frac{1 \text{ mol O}}{16.0 \text{ g O}} = 0.0069 \text{ mol O}$

Moles Cu in CuO = 0.80 g Cu x $\frac{1 \text{ mol Cu}}{63.5 \text{ g Cu}} = 0.0126 \text{ mol Cu}$

Moles O in CuO = 0.20 g O x $\frac{1 \text{ mol O}}{16.0 \text{ g O}} = 0.012 \text{ mol O}$

$\frac{\text{Moles Cu}}{\text{Moles O}}$ in Cu₂O = $\frac{0.014 \text{ mol Cu}}{0.0069 \text{ mol O}} = 2:1$

$\frac{\text{Moles Cu}}{\text{Moles O}}$ in CuO = $\frac{0.0126 \text{ mol Cu}}{0.012 \text{ mol O}} = 1:1$

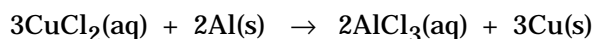
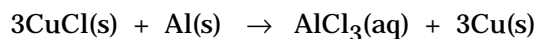
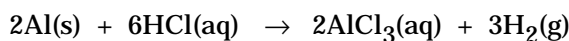
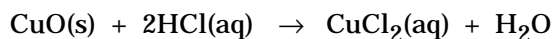
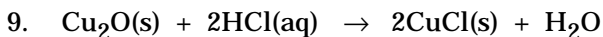
7. The ratio of moles Cu in the two compounds is 2:1

8. The following statements are involved in an atomic-level explanation of this phenomenon:

a. All atoms of an element are identical.

b. Atoms combine in whole number ratios.

c. One mole of any substance has the same number of entities.



Implications and Applications

1. a. Ratio too large

b. Ratio too small

c. Ratio too large

d. Ratio too large



2. One possible response is:

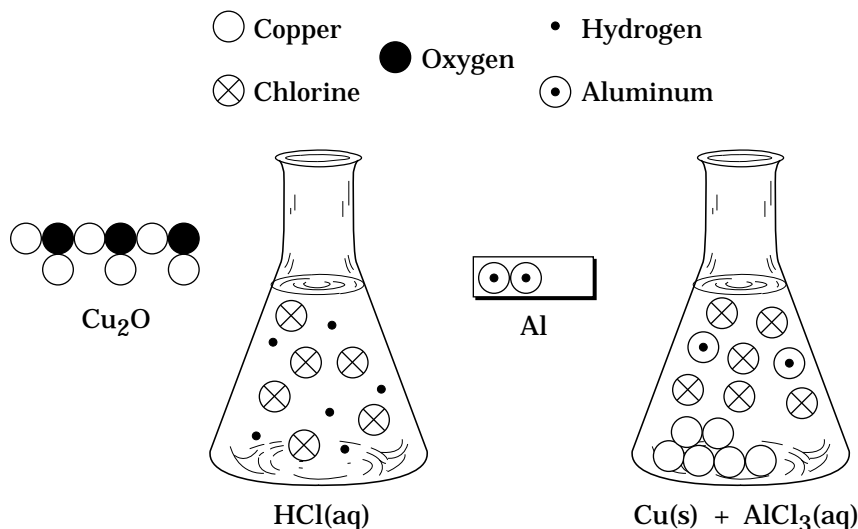


Figure 4. Response for Implications and Applications Question 2.

Post-Laboratory Discussion

The post-laboratory discussion can focus on interpretation of student results. The *Implications and Applications* questions provide a starting point. One or two groups will have data that differs widely from the rest of the class. Data on the board are anonymous; you can discuss reasons for discrepancies without humiliating any laboratory group. *Implications and Applications* Question 1 will focus on possible errors. Perhaps students can think of reasons other than those given for lack of precision. Often students with “poor” results know what happened and are willing to offer suggestions. Sometimes results that are far from the norm are due to incorrect calculations. Encourage students to recalculate results that don’t seem to fit.

Students may have some difficulty comparing the two ratios. Help them see that we are comparing the amount of copper that combines with a fixed amount of oxygen—one mole. It should be possible from overall class results to conclude that the mole ratio of copper in the two compounds is 2:1.

Once students have mastered the calculations, it is important to focus on matter at the molecular level. Students should share their molecular pictures, since they may have chosen different ways to depict the reactions. Look for consistency in the ratios of copper to oxygen and copper to chlorine.

Assessing Laboratory Learning

- One chloride of iron is green, the other is orange. What can you predict about the relationship of the mole ratios of iron to chlorine in the two compounds? [*The mole ratios should be small whole numbers because they are two different compounds.*]
- Would you predict the existence of two different chlorides of magnesium? Explain. [*No. Magnesium is not a transition element and has only one stable oxidation state other than 0.*]
- Choose symbols to represent manganese and oxygen atoms. Illustrate the formulas for MnO and MnO_2 .

• Mn

⊕ O

• ⊕ = MnO

⊕ • ⊕ = MnO_2

CAUTION: Use appropriate safety guidelines in performing demonstrations.

DEMONSTRATIONS

Demonstration 1: Oxidation States of Manganese

Introduction

Manganese exhibits several oxidation states, and compounds containing manganese have different and interesting colors. Showing them on an overhead projector makes a colorful display. The purpose of this demonstration is to examine oxidation-reduction reactions involving aqueous solutions of manganese ions; to develop a flow chart for the reactions; and to write appropriate equations for the reactions.

Safety

Wear eye protection and an apron throughout the demonstrations. Sulfuric acid is a corrosive substance. Properly dispose of the products.

Materials

Nonconsumables

- 6 Dropper bottles, 2-4 oz
- 6 Beakers, 50-mL
- Transparency sheet
- Overhead projector

Consumables

- 0.13 M Manganese sulfate, MnSO_4 (2.0 g per 100 mL H_2O)
- 0.0063 M Potassium permanganate, KMnO_4 (0.1 g per 100 mL H_2O)
- 0.16 M Sodium sulfite, Na_2SO_3 (2.0 g per 100 mL H_2O)
- 6 M Sodium hydroxide, NaOH (24 g per 100 mL H_2O)
- 50% Sodium hydroxide, NaOH (50 g dissolved in 50 mL water)
- 6 M Sulfuric acid, H_2SO_4 (33 mL concentrated H_2SO_4 per 100 mL;
CAUTION: Add the acid very slowly to the water.)

Procedure

1. Place the six small beakers on a transparency sheet on an overhead projector. Using a marking pen, label the beakers *on the underlying transparency*: 2+, 3+, 4+, 5+, 6+, and 7+.
2. Place 3 mL MnSO_4 in the 2+ beaker. (*The color will be very pale pink.*)
3. Place 3 mL MnSO_4 in the 3+ beaker. Add several droppers of 6 M H_2SO_4 . Then add KMnO_4 a few drops at a time, swirling the beaker after each addition, until the solution takes on a reddish color.
4. Place 3 mL MnSO_4 in the 4+ beaker. Then, without mixing, add 2 or 3 drops of KMnO_4 . (*Brown spots of MnO_2 will form wherever the drops of potassium permanganate fall.*)
5. Place 3 mL KMnO_4 in the 5+ beaker. Add about the same volume of 50% NaOH . Swirl the beaker rapidly until the solution turns blue. (*The color of MnO_4^{3-} .*)
6. Place 3 mL KMnO_4 in the 6+ beaker. Add several droppers of 6 M NaOH . Then add several droppers of Na_2SO_3 . (*The color changes from purple to green as the MnO_4^- ion is reduced to MnO_4^{2-} , manganate ion.*)
7. Place 3 mL KMnO_4 in the 7+ beaker. (*Familiar purple color of MnO_4^- .*)

[This demonstration could easily be adapted for use as a student activity using 24-well microtitration plates.]



Demonstration 2: Paramagnetism in Transition Metal Compounds

Introduction

Some compounds of transition elements display paramagnetism—the property of being attracted by a magnetic field. This demonstration makes paramagnetism real. It illustrates paramagnetism in a compound of a transition metal and the lack of paramagnetism in a compound such as NaCl.

Materials

Magnet capable of lifting 50 to 100 pounds
Gelatin capsule filled with iron(II) sulfate, FeSO_4
Gelatin capsule filled with sodium chloride, NaCl

Procedure

Put the capsules next to the ends of the powerful magnet. As you slowly pull the magnet, the capsule filled with iron(II) sulfate will follow the magnet. The one filled with sodium chloride will not.

Demonstration 3: Nickel One-Pot Reaction

Introduction

In one-pot reactions several reagents are added successively to a single vessel. These are particularly effective when used with transition element compounds—many colors are produced. Precipitations, dissolutions, and reprecipitations are observed in this nickel one-pot reaction. Various reactions of nickel compounds with different reagents are observed. This demonstration offers an opportunity to review descriptive chemistry if you pause between each addition to invite students to predict products and write equations.

Materials

Beaker, 100-mL
Beaker, 1000-mL
Magnetic stirring motor and magnet
Nickel sulfate, $\text{NiSO}_4 \cdot 6\text{H}_2\text{O}$, 3 g
12 M (concentrated) Hydrochloric acid, HCl, 5 mL
2.5 M Sodium carbonate, Na_2CO_3 , 23 mL (26.5 g Na_2CO_3 per 100 mL)
6.0 M Nitric acid, HNO_3 12 mL (40 mL 15 M HNO_3 per 100 mL)
0.50 M Sodium hydroxide, NaOH, 110 mL (5 g NaOH per 250 mL)
15 M (concentrated) Ammonia, $\text{NH}_3(\text{aq})$, 20 mL
6.0 M Sodium bromide, NaBr, 100 mL (61.8 g NaBr per 100 mL)
3.0 M Sodium hydroxide, NaOH, 100 mL (12 g NaOH per 100 mL)
3.0 M Nitric acid, HNO_3 , 250 mL (50 mL 15 M HNO_3 per 250 mL)
1.0% Dimethylglyoxime, 25 mL (1 g dimethylglyoxime per 100 mL water)
25% Ethylenediamine, $\text{H}_2\text{NCH}_2\text{CH}_2\text{NH}_2$, 150 mL (37.5 g ethylenediamine per 100 mL water)
1.0 M Sodium sulfide, Na_2S , 15 mL (1.17 g Na_2S per 15 mL)

Safety

Caution is required when handling 12 M HCl, 15 M NH_3 , 3 M HNO_3 , and 3 M NaOH. All are caustic or corrosive. Sodium sulfide is highly toxic in the presence of an acid. It is recommended that this entire one pot reaction be performed in a hood.

Procedure

1. Begin the pot with 3 g of $\text{NiSO}_4 \cdot 6\text{H}_2\text{O}$ in a 50-mL beaker. Add 5 mL 12 M HCl. Pour this solution into 100 mL distilled water in a 1000-mL beaker on a magnetic stirrer. Rinse any nickel sulfate crystals that remain into the larger beaker.
2. Add 23 mL 2.5 M sodium carbonate.
3. Dissolve the precipitate with 12 mL 6.0 M nitric acid.
4. Add 110 mL 0.50 M sodium hydroxide.
5. Add 20 mL 15 M ammonia.
6. Add 100 mL 6.0 M sodium bromide. Allow enough time for the precipitate to form.
7. Add 100 mL 3.0 M sodium hydroxide.
8. Acidify the pot with 250 mL 3.0 M nitric acid.
9. Add 15 mL 25% ethylenediamine.
10. Add 25 mL 1.0% dimethylglyoxime solution.
11. Add 15 mL 1.0 M sodium sulfide.

Teacher Notes

Colors of Nickel Complexes		
Formula	Color	Geometry
NiCl_4^{2-}	Yellow	Tetrahedral
$\text{Ni}(\text{H}_2\text{O})_6^{2+}$	Green	Octahedral
$\text{Ni}(\text{NH}_3)_6^{2+}$	Blue	Octahedral
* $\text{Ni}(\text{en})_3^{2+}$	Purple	Octahedral
* $\text{Ni}(\text{dmg})_2$	Red	Square planar

*en = ethylenediamine, dmg = dimethylglyoxime

Equations for reactions:

- 1a. $\text{Ni}^{2+}(\text{aq}) + 4\text{Cl}^{-}(\text{aq}) \rightarrow \text{NiCl}_4^{2-}(\text{aq})$
- 1b. $\text{NiCl}_4^{2-}(\text{aq}) \rightarrow \text{Ni}^{2+}(\text{aq}) + 4\text{Cl}^{-}(\text{aq})$
2. $\text{Ni}^{2+}(\text{aq}) + \text{CO}_3^{2-}(\text{aq}) \rightarrow \text{NiCO}_3(\text{s})$
3. $\text{NiCO}_3(\text{s}) + 2\text{H}^{+}(\text{aq}) \rightarrow \text{Ni}^{2+}(\text{aq}) + \text{H}_2\text{O}(\text{l}) + \text{CO}_2(\text{g})$
4. $\text{Ni}^{2+}(\text{aq}) + 2\text{OH}^{-}(\text{aq}) \rightarrow \text{Ni}(\text{OH})_2(\text{s})$
5. $\text{Ni}(\text{OH})_2(\text{s}) + 6\text{NH}_3(\text{aq}) \rightarrow \text{Ni}(\text{NH}_3)_6^{2+}(\text{aq}) + 2\text{OH}^{-}(\text{aq})$
6. $\text{Ni}(\text{NH}_3)_6^{2+}(\text{aq}) + 2\text{Br}^{-}(\text{aq}) \rightarrow \text{Ni}(\text{NH}_3)_6\text{Br}_2(\text{s})$
7. $\text{Ni}(\text{NH}_3)_6\text{Br}_2(\text{s}) + 2\text{OH}^{-}(\text{aq}) \rightarrow \text{Ni}(\text{OH})_2(\text{s}) + 2\text{Br}^{-}(\text{aq}) + 6\text{NH}_3(\text{aq})$
8. $\text{Ni}(\text{OH})_2(\text{s}) + 2\text{H}^{+}(\text{aq}) \rightarrow \text{Ni}^{2+}(\text{aq}) + 2\text{H}_2\text{O}(\text{l})$
9. $\text{Ni}^{2+}(\text{aq}) + 3\text{en}(\text{aq}) \rightarrow \text{Ni}(\text{en})_3^{2+}(\text{aq})$
10. $\text{Ni}(\text{en})_3^{2+}(\text{aq}) + 2\text{dmg}^{-}(\text{aq}) \rightarrow \text{Ni}(\text{dmg})_2(\text{s}) + 3\text{en}(\text{aq})$
11. $\text{Ni}(\text{dmg})_2(\text{s}) + \text{S}^{2-}(\text{aq}) \rightarrow \text{NiS}(\text{s}) + 2\text{dmg}^{-}(\text{aq})$



GROUP AND DISCUSSION ACTIVITIES

Key Questions

1. What type of electron configuration do the transition elements have in common? *[All have one or more electrons in their d-sublevel. Only the zinc group has a completely filled d-sublevel.]*
2. Transition elements exhibit a high frequency of multiple oxidation states. How can this be explained? *[The d-electrons as well as the s-electrons can be used as bonding electrons.]*
3. Compounds of transition elements often exhibit color. To what can this color be attributed? *[If the transition element forms a compound in which its five d-orbitals do not all have the same energy, the result is an energy gap that matches the energy of visible light photons. When white light strikes the compound, those photons are absorbed. The color we see is the result of the colors that are not absorbed.]*
4. How is a gemstone different from a mineral? *[A gemstone forms when a particular transition element atom is incorporated as an impurity in a parent mineral. For example, ruby results from Cr^{3+} ions replacing some of the Al^{3+} ions in the mineral corundum, Al_2O_3 . A mineral is a naturally occurring chemical compound.]*
5. Consider the periodic relationships in the transition series following:

	Element	1st Ionization Energy, kJ/mol	Atomic Radius, pm
3rd period	Na	496	157
	Mg	738	136
	Al	577	125
	Si	787	117
	P	1012	110
	S	1000	104
	Cl	1251	99
4th period	K	419	203
	Ca	590	174
	Sc	631	144
	Ti	658	132
	V	650	122
	Cr	653	117
	Mn	717	117
	Fe	759	117
	Co	760	116
	Ni	737	115
	Cu	745	117
	Zn	906	125
	Ga	579	125
	Ge	762	122
	As	947	121
	Se	941	117
	Br	1140	114
	Kr		

Using data in the table, prepare the following graphs:

- a. Atomic Radii *vs.* Atomic Number
- b. Ionization Energy *vs.* Atomic Number

For elements in Period 4, plot number of *d*-electrons *vs.* atomic number.

Answer these questions about the graphs:

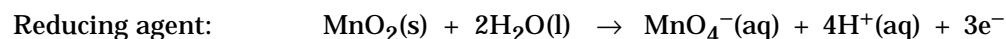
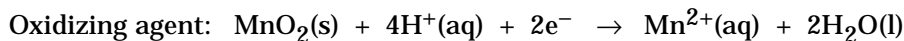
1. How do the graphs for atomic radii differ for the two periods? [*Period 4 has a group of atoms with similar radii while Period 3 shows a general decrease.*]
2. How do the graphs for ionization energy differ for the two periods? [*Period 4 increases and then remains fairly constant while Period 3 shows a general increase.*]
3. How do these trends in ionization energy and atomic radius help in predicting properties of these elements? [*Those properties dependent upon effective nuclear charge will remain fairly constant throughout the d-block. Such properties, in addition to ionization energy and atomic radius, are ionic radius and density. By contrast, some properties such as paramagnetism, melting point and boiling point, depend upon the number of unpaired electrons and vary widely across the d-block. You may wish to use this fact for extension studies.*]
4. Use the graph of number of *d*-electrons *vs.* atomic number to explain the following oxidation states of Period 4 elements. (These represent only a few oxidation states for these elements. Some can only be predicted with considerably more information.)
 - a. Ca 2⁺ only b. Sc 3⁺ c. Mn 7⁺
 - d. Cr 6⁺ e. Fe²⁺ and Fe³⁺ f. Zn 2⁺ only

[All period 4 elements initially lose their 4s-electrons upon oxidation. Period 4 elements with a partially filled d-subshell can also lose d-electrons up to the number contained in the subshell.]

- a. $\text{Ca} \rightarrow \text{Ca}^{2+} + 2e^- [\text{Ar}] 3d^0 4s^2 \rightarrow [\text{Ar}] 3d^0 4s^0$
- b. $\text{Sc} \rightarrow \text{Sc}^{3+} + 3e^- [\text{Ar}] 3d^1 4s^2 \rightarrow [\text{Ar}] 3d^0 4s^0$
- c. $\text{Mn} \rightarrow \text{Mn}^{7+} + 7e^- [\text{Ar}] 3d^5 4s^2 \rightarrow [\text{Ar}] 3d^0 4s^0$
- d. $\text{Cr} \rightarrow \text{Cr}^{6+} + 6e^- [\text{Ar}] 3d^4 4s^2 \rightarrow [\text{Ar}] 3d^0 4s^0$
- e. $\text{Fe} \rightarrow \text{Fe}^{2+} + 2e^- [\text{Ar}] 3d^6 4s^2 \rightarrow [\text{Ar}] 3d^6 4s^0$
 $\text{Fe} \rightarrow \text{Fe}^{3+} + 3e^- [\text{Ar}] 3d^6 4s^2 \rightarrow [\text{Ar}] 3d^5 4s^0$
- f. $\text{Zn} \rightarrow \text{Zn}^{2+} + 2e^- [\text{Ar}] 3d^{10} 4s^2 \rightarrow [\text{Ar}] 3d^{10} 4s^0$

Counterintuitive Examples

1. Compounds with formulas such as Fe₃O₄ and MnO_{1.85} are examples of nonstoichiometric compounds. They are generally compounds where transition elements exist in two or more oxidation states.
2. Manganese (IV) oxide is an example of a compound that can act as either an oxidizing agent or a reducing agent. The relevant half reactions are:





TIPS FOR THE TEACHER

Language of Chemistry

- coordination complex** species made up of metallic ion and the ligands that surround it.
- covalent bonding** bonding pattern in which a bond consists of one or more pairs of shared electrons.
- diamagnetism** weak repulsion by a magnetic field.
- effective nuclear charge** net sum of all the attractive and repulsive forces experienced by an electron in an atom.
- electron configuration** shorthand notation describing the distribution of electrons among the energy levels of an atom.
- ferromagnetism** ability of a substance to become permanently magnetized by exposure to an external magnetic field.
- ionic bonding** bonding pattern characterized by the transfer of electrons from one bonding atom to the other which results in the formation of ions.
- ionization energy** energy required to remove an electron from an atom.
- ligands** molecules or ions that surround a metal ion in a complex.
- octahedral configuration** shape in which six species are equally spaced around a central species.
- oxidation** loss of electrons by a species.
- oxidation state** the apparent charge on an atom if the electrons are assigned according to established rules.
- paramagnetism** attraction toward a magnetic field (stronger than diamagnetism, weaker than ferromagnetism).
- reduction** gain of electrons by a species.
- refractory** high melting.
- representative elements** elements of the *s*- and *p*-blocks.
- square planar configuration** arrangement in which four species are at the corners of a square surrounding a fifth species in the center.
- transition elements** elements of the *d*- and *f*-blocks.
- valence electrons** outer energy level electrons involved in bonding, which include the *d*-electrons for the *d*-block transition elements.

Pattern Recognition

A Comparison of Representative and Transition Elements

Representative Elements

- About half are metals.
- Atomic size increases from F to Cs.
- Vary in electronegativity from 0.7 (Cs) to 4.0 (F).
- Simple ions in water are usually colorless.
- Metals usually exhibit only one oxidation state.
- Valence electrons are all in the outermost shell.
- Oxides are normal (metal oxides are basic, nonmetal oxides are acidic).
- Simple hydrides are normal in composition and properties.
- Not usually associated with catalytic activity.
- Not usually magnetic (maximum number of unpaired electrons is only three).
- Metallic activity increases from top to bottom within a group.
- Electronic structures of succeeding elements differ by one electron in the outer shell.

Transition Elements

All are metals.

Atomic sizes about the same within a period.

Electronegativity relatively constant (about 1.7).

Simple ions in water usually colored.

Metals can usually have a number of different oxidation states.

Valence electrons are in more than one shell.

Oxides are abnormal, some basic, some acidic, some refractory (ceramic compounds with low thermal conductivity able to withstand very high temperatures).

Hydrides are usually abnormal in composition and properties.

Most exhibit pronounced catalytic activity.

Often paramagnetic, sometimes ferromagnetic (as many as seven unpaired electrons in *f*-block).

Metallic activity decreases from top to bottom within a group.

Generally electronic structures of succeeding elements differ by one electron in an inner shell while the number of outer shell electrons is constant.

Common Student Misconceptions

1. "All metals are magnetic."

Demonstration 2 can correct this misconception.

2. "All compounds of transition elements are colored."

Examples of zinc and/or scandium compounds can be used to disprove this idea. For honors students, the explanation for lack of color is that zinc has a filled *d*-shell and scandium has no *d*-electrons.

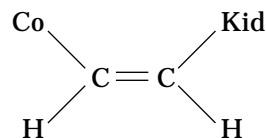
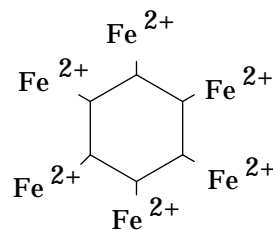
In 1893, Alfred Werner, a 26-year-old Swiss chemist described the nature of complex ions by proposing that ammonia, chloride ion and similar ligands could be strongly attracted to metal ions to form complex ions. His predictions were based on the reactions of cobalt complexes with silver nitrate. From observing quantities of silver nitrate required to precipitate chloride ions, he suggested that chloride ions could be bonded ionically or by what he called "secondary bonds." He even predicted the geometries of the compounds that were confirmed many years later by x-ray crystallography. His accomplishments are even more astounding when it is realized that his work preceded Lewis bonding theory by 23 years. He received the Nobel Prize in chemistry in 1913.

1. Students enjoy, even though they will groan loudly, these puns based on transition elements.

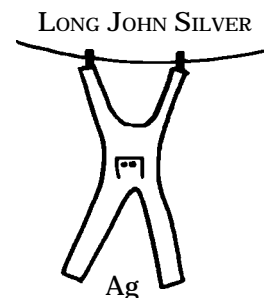
HIOAg **Hi O Silver!**

Ferrous Wheel

[Explain the now obsolete nomenclature of Fe^{2+} (ferrous) and Fe^{3+} (ferric) ions.]


Cisco Kid

[Explain about *cis*- and *trans*-geometric isomers. See *Organic Chemistry* module.]

HISTORY: ON THE HUMAN SIDE
HUMOR: ON THE FUN SIDE




2. **New scientific fiction book:** "Where's Mercury Found?" by H. G. Wells.
CHEM 13 NEWS, September 1979, p. 11

3. **Nomenclature riddles:**

a. What is CFe_2O_3 ? **Answer:** Crust

CHEM 13 NEWS, November 1976, p. 1107

b. Who is $\text{Ni(II)} + \text{Cu} + \text{Ni(II)}$ [short form]? **Answer:** Nicolaus Copernicus

c. What is $\text{Fe}^{2+} \text{C}_{10}\text{H}_{22}$? **Answer:** Ferris Wheel

CHEM 13 NEWS, September 1974, p. 783

4. **LANTHANIDE MNEMONIC**

Lettuce can provide nourishing protein, so everyone

La Ce Pr Nd Pr Sm Eu

gets tender, delicious, wholesome, enriched, young lettuce.

Gd Tb Dy Ho Er Yb Lu.

CHEM 13 NEWS, May 1981, p. 9

5. **CHEMTOON**

Fe

Cr

Let's get a shine on!

CHEM 13 NEWS, October 1983, p. 16

5. **Roaming Through the Elements—How Many Can You Name?**

- Eight elements mentioned in the Bible.
- Three elements named after women.
- Eight elements named after countries.
- Seven elements named after famous scientists.
- Ten elements named after celestial bodies.
- Five elements whose names are of German origin.
- One element whose name is of Spanish origin; one Swedish.
- Three elements named after continents or states.
- Eleven elements named after districts, cities, towns, or villages.
- Twenty-seven elements whose names or symbols are of Latin origin.
- Thirty elements whose names are of Greek origin.

The answers are:

- Au, Ag, Fe, Sn, Pb, Cu, C (as diamonds), S (as brimstone)
- Cm (Marie Curie); Nb (Niobe, daughter of Tantalus); V (Vanadis, Scandinavian goddess)
- Fr, Ga (Gallia, Latin name for France), Ge, Po, Ru (Ruthenia, Latin name for Russia), Sc (Scandia, Latin name for Scandinavia), Tm (Thulium, ancient name for Scandinavia), In.
- Cm, Es, Fm, Gd, Lr, No, Md
- Ce (Ceres, an asteroid); He (Helios, Greek name for the Sun); Hg; Np; Pd (Pallas, an asteroid); P (ancient name for Venus when appearing before sunrise); Pu; Se (Selene, Greek name for the Moon); Te (Tellus, Latin name for the earth); U
- Bi (Latinized form of Wismuth, Weisse Masse = white mass); Co (Kobold = goblin or evil spirit); Ni (from Kupfernickel = Old Nick's copper); Zn; Sn

- g. Pt (Platina = silver); W (Tung = heavy, sten = stone)
- h. Am, Eu, Cf
- i. Bk (home of the University of California); Er, Tb, Yb, Y (all for Ytterby, a village in Sweden); Hf (Hafnium, the Latin name for Copenhagen); Ho (Holmium, the Latin name for Stockholm); Lu (Lutetia, an old name for Paris); Mg (Magnesia, a district in Thessaly); Re (Rhenium, the Latin name for Rhine); Sr (Strontian, a town in Scotland)
- j. Sb (stibium = mark), Ca (Calx = lime), Cs (caesium = sky blue), Cu (cuprum = from Cyprus), F (fluere = flux or flow), Ga (Gallia = France), Au (aurum = shining dawn), Hf (Hafnia = Copenhagen), Ho (Holmia = Stockholm), Ir (iris = rainbow), Fe (ferrum, Latin name for iron), Pb (plumbum, Latin for lead), Mn (magnes = magnet), Hg (hydrargyrum = liquid silver), K (kalium = alkali), Ra (radius = ray), Rn (radon from radium), Re (Rhenus = Rhine), Rb (rubidius = deepest red), Ru (Ruthenia = Russia), Sc (Scandia = Scandinavia), Si (silex = flint), Ag (argentum, Latin for silver), Na (natrium, Latin for sodium), Te (tellus = earth), Sn (stannum, Latin for tin), Ti (titans = first men on earth)
- k. Ac (actinos = beam or ray), Ar (argon = inactive), As (arsenicon = yellow orpiment), At (astatos = unstable), Ba (barys = heavy), Br (bromos = stench), Cl (chloros = greenish yellow), Cr (chroma = color), Dy (dysprositos = hard to get at), He (helios = sun), H (hydro = water, genes = forming), I (iodes = violet), Kr (kryptos = hidden), La (lanthanein = to lie hidden), Li (lithos = stone), Mo (molybdos = lead), Nd (neo = new, didymos = twin), Ne (neos = new), N (nitron = native soda, genes = forming), Os (osme = smell), O (oxys = sharp, acid, genes = forming), P (phosphoros = light-bearing), Pr (praseos = green, didymos = twin), Pa (protos = first), Rh (rhodos = rose), Se (selene = moon), Ta (Tantalus = father of Niobe), Tc (technecos = artificial), Tl (thallos = green shoot or twig), Xe (xenos = stranger)

CHEM 13 NEWS, October 1980, p. 5

6. CHEMISTRY CAN BE FUN

Fill in each blank with the name of the chemical element from the alphabetized list. One element is used twice.

The 1 and jewels 2. That 3 must have stolen them. Call the 4 before he has had a chance to 5 or 6. There should be a 7 his place before he has got 8. When they break 9 the 10 will 11 and 12 to give them back. If he doesn't, I wouldn't give a plugged 13 for his chances. He will be behind 14 bars in no time. Maybe that will 15.

Alphabetized list:

1. argon 2. barium 3. cesium 4. copper 5. curium 6. dysprosium 7. gold 8. indium 9. iridium 10. iron 11. nickel 12. radon 13. silicon 14. tellurium

CHEM 13 NEWS, April 1977, p. 14

7. Transition Metals Trivial Pursuit (Adapted from CHEM 13 NEWS, September, 1983, p. 11)

Choose the symbol of one of the following elements that, either in the free or in the combined state, best satisfies each clue: Ti, Cr, Fe, Ni, Zr, Ce, Pr, Nd, Sm, Tb, W, Re, Os, Pt



- a. The hardest metal.
- b. Lanthanide discovered by Mosander in 1842.
- c. Strongest reductant of the rare earth dipositive ions.
- d. Green twin.
- e. Relative of manganese
- f. Ferberite is one of its ores.
- g. An oxide of this metal is yellow when cold, orange when hot.
- h. A dipositive rare earth insoluble sulfate.
- i. The sulfuric acid solution of the peroxidized form of this tetrapositive metal is bleached by Hf.
- j. An aqueous mixture of the salts of neodymium and this rare earth is colorless, analogous to Ni - Co mixture.
- k. Didymium glass used in glassblowers' goggles contains a mixture of the oxides of praseodymium and this rare earth.
- l. An oxide of this metal is white when cold, yellow when hot.
- m. The compounds of this element exhibit disproportionation to a greater extent than any other element.
- n. This element is quantitatively precipitated by phosphoric acid in (1 : 9) sulfuric acid solution containing H_2O_2 .
- o. An oxide of this metal, sometimes erroneously named as an acid, is used as a histological reagent.
- p. The highest melting metal.
- q. In the dipositive state it is quantitatively precipitated in slightly acid solution by dimethylglyoxime as fine blue crystals with a metallic bronze luster.

Answers:

- | | | | | | |
|-------|-------|-------|-------|-------|-------|
| a. Cr | d. Pr | g. W | j. Pr | m. Re | p. W |
| b. Tb | e. Re | h. Sm | k. Nd | n. Zr | q. Pt |
| c. Sm | f. W | i. Ti | l. Ti | o. Os | |

8. Word Search (see *Appendix* for master copy)

~~D N A G I L O X M X O B X L K N S~~
~~B F O D H Y C H N P U R P L E O J~~
~~I W U L U G U H D T L V D M S I P~~
~~Y N M I W O N D R A O Z T C T T L~~
~~N R Z O P N R O R O D O D Q U A H~~
~~L E P N Y G R D I N M W N H M N U~~
~~E P N I U D E W M T L I F R G I Z~~
~~W P S Z L H N U W T I E U X Z D K~~
~~K O I A A U R X D Y M S W M I R I~~
~~I C V T K E E A T J C L N D X O G~~
~~G N C I N D W R R S D E S A H O Y~~
~~F O N O V M K C V M K S U C R C K~~
~~M V R N R A J N O R I Z C G H T C~~

Words about the concepts in this module can be obtained from the clues given. Find these words in the block of letters:

1. Molecule or ion surrounding a metal ion in a complex.
2. Adjective for the *d*- and *f*-block elements.
3. Shape associated with six species equally spaced around a central species.
4. Transition element identified by electron configuration $[\text{Ar}]3d^64s^2$.
5. Color of aqueous solution of permanganate ion.
6. In addition to tin, bronze statues contain this transition metal that turns them green upon aging.
7. Transition element responsible for the red color in rubies.
8. Type of energy required to remove an electron from an atom.
9. Type of complex composed of a metallic ion and its surrounding ligands.
10. Swiss chemist who predicted geometries of complex ions.

Answers: 1. LIGAND 2. TRANSITION 3. OCTAHEDRAL 4. IRON
5. PURPLE 6. COPPER 7. CHROMIUM 8. IONIZATION
9. COORDINATION 10. WERNER

9. See cartoons at end of module.

MEDIA

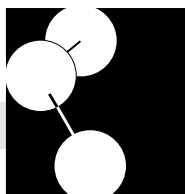
1. The *World of Chemistry* videotape "Number 19: Metals." World of Chemistry Videocassettes. Annenberg/CPB Project, P.O. Box 1922, Santa Barbara, CA 93116-1922; (800) 532-7637; World of Chemistry Series, Atlantic Video, 150 South Gordon Street, Alexandria, VA 22304; (703) 823-2800 or QUEUE Educational Video, 338 Commerce Drive, Fairfield, CT 06430; (800) 232-2224. A secondary school version of this series is available from WINGS for Learning/SUNBURST, 101 Castleton Street, Pleasantville, NY 10570; (914) 747-3310; (800) 321-7511; (914) 747-4109 (FAX).
2. Software published by *JCE: Software*, a publication of the *Journal of Chemical Education*, Department of Chemistry, University of Wisconsin-Madison, 1101 University Avenue, Madison, WI 53706-1396: (608) 262-5153 (voice) or (608) 262-0381 (FAX).
 - a. *KC? Discoverer with Knowledgeable Counselor*, by Daniel Cabrol, John W. Moore and Robert C. Rittenhouse. Special Issue 2, for IBM PS/2, PC compatible computers.
 - b. *KC? Discoverer: Exploring the Properties of the Chemical Elements*, by Aw Feng and John W. Moore. Vol. I B, No. 1, for IBM PS/2, PC compatible computers.
 - c. *KC? Discoverer?*, by Michael Liebl, Vol. IV A, No. 2, for all Apple II computers.
 - d. *The Periodic Table Stack*, by Michael Farris. Vol. I C, No. 1, for the Apple Macintosh.
 - e. *The Periodic Table (Toolbook)*, by Paul F. Schatz, John C. Kotz and John W. Moore, in press. For Windows running on IBM PS/2 and PC-compatible computers.



- f. *Notebook: A Column Calculator and Plotter*, by Robert Rittenhouse. Vol. IV B, No. 1, for IBM PS/2 PC-compatible computers.
- g. *The Computer-Based Laboratory*, by Daniel Krause. Vol. I A, No. 2, for the Apple II computer.
3. Software published by Project SERAPHIM, Department of Chemistry, University of Wisconsin-Madison, 1101 University Avenue, Madison, WI 53706-1396: (608) 263-2837 (voice) or (608) 262-0381 (FAX).
- a. For the Apple II computer running on ProDOS: AR 601, AR 1201.
- b. For the Apple II computer: AP 301, AP 608, AP 1201; Laboratory modules LM 002, LM 003, LM 004, LM 005, LM 006, LM 012, LM 015, LM 016, LM 021 (for the Project SERAPHIM Blocktronic and Thermistor).
- c. For IBM PCs and PC-compatibles: PC 3301, PC 3401, PC 4201; Laboratory modules LM 002, LM 003, LM 004, LM 005, LM 006, LM 012, LM 015, LM 016 (for the Project SERAPHIM Blocktronic and Thermistor).
4. Videodisc published by *JCE: Software*, a publication of the *Journal of Chemical Education*, Department of Chemistry, University of Wisconsin-Madison, 1101 University Avenue, Madison, WI 53706-1396: (608) 262-5153 (voice) or (608) 262-0381 (FAX).
- The Periodic Table Videodisc* (single side, 30 min.). Special Issue 1.
5. *The Periodic Table*, Minnesota Educational Computing Consortium, St. Paul, MN (MECC; a computer program, database, and related instructional materials).
6. *Doing Chemistry* (some reactions on this videodisc series are reactions of transition elements). Available from American Chemical Society, 1155 Sixteenth Street, N.W., Washington, DC 20036.

EQUIPMENT AND INSTRUMENTA- TION

1. Computer and software to plot graphs and use the MECC program (see *Media*).
2. Colorimeter, spectrophotometer, or computer interface (Blocktronic).



Links/Connections

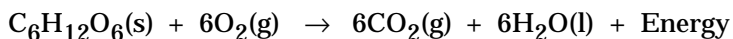
1. **Reactions Module.** Many reactions in the laboratory activities and demonstrations involve transition metal compounds.
2. **Redox Module.** One reaction in “Identification of Iron Ions” laboratory activity is an example of a redox reaction:
$$5\text{Fe}^{2+}(\text{aq}) + \text{MnO}_4^{-}(\text{aq}) + 8\text{H}^{+}(\text{aq}) \rightarrow 5\text{Fe}^{3+}(\text{aq}) + \text{Mn}^{2+}(\text{aq}) + 4\text{H}_2\text{O}(\text{l})$$
3. **Periodicity Module.** The ionization energy and radii plotting exercise for all Period 4 elements can be used as an extension during the discussion of periodicity. The graphs will make the point—quite strongly—that changes are less pronounced among transition metals.

WITHIN CHEMISTRY

Biology

Hemoglobin binds and transports O_2 to cells with the help of a transition metal complex. The O_2 actually is the sixth ligand in a Fe^{2+} complex. The other five ligands include N atoms. At the cellular level, O_2 transfers to myoglobin, which stores it until it is needed by the muscle. Myoglobin also binds oxygen as the sixth ligand of a Fe^{2+} complex. Poisoning by carbon monoxide occurs because CO competes with O_2 for bonding positions to the Fe^{2+} in hemoglobin and myoglobin (and wins).

Cytochromes are a class of enzymes that catalyze the oxidation of carbohydrates, an essential energy reaction in the body.



The cytochrome enzyme molecule aids this reaction by being a repository for (and source of) electrons.



As with hemoglobin, the iron ion forms an octahedral complex. Unlike hemoglobin, the iron ion in cytochrome has all six positions firmly bonded; thus iron’s only action is to accept and then give off an electron.

A copper compound, hemocyanin, serves the same oxygen-carrying function in lobsters and oysters that hemoglobin serves in higher animals.

Earth Science

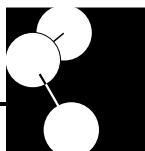
About three billion years ago primitive plants began to produce oxygen as a product of photosynthesis. One intriguing observation is the slow rate at which oxygen accumulated in the primitive atmosphere. The element iron in earth’s crust is the key. Prior to the existence of free oxygen, molten iron combined with silica to form iron silicates. When free oxygen became available as the result of photosynthesis, iron combined with it to form abundant quantities of iron oxides. So the earth rusted, using up free oxygen until all elementary iron near the surface was combined. Then the free oxygen accumulated in the atmosphere and ultimately allowed for the appearance of land-based animals.

Personal

1. Transition elements are of considerable commercial importance. The metallurgy industry employs many chemists.

BETWEEN CHEMISTRY AND OTHER DISCIPLINES

TO THE CONTEMPORARY WORLD



2. A knowledge of the properties of metals such as copper, silver and gold is advantageous to jewelers.

Community

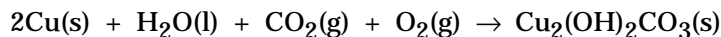
Field Trips

- To a plating plant.
- To a film developing business to observe the role of silver in this process.

Knowledgeable Individuals

- Dentist—use of mercury amalgams for filling teeth.
- Environmental scientist—role of heavy metals in environmental pollution.
- Jeweler—use of gold and silver.
- Artists who work with metals.
- Physician—role of iron in human health.

1. **Color in gemstones.** The color in most gemstones comes from transition metal ions present as impurities in a parent mineral. For example, rubies are simply the mineral corundum, Al_2O_3 , with Cr^{3+} ions replacing a few Al^{3+} ions in the structure. Blue sapphires involve Fe^{2+} and Ti^{4+} ions replacing some Al^{3+} . Emeralds are the mineral beryl, $\text{Be}_3\text{Al}_2(\text{SiO}_3)_6$, with Cr^{3+} ions replacing a few Al^{3+} ions (see *The Chemistry of Rocks, Minerals and Gems* module).
2. **Bluing.** Prussian Blue (also called Paris blue, Berlin blue, Hamburg blue, and Chinese blue) is the salt $\text{Fe}_4[\text{Fe}(\text{CN})_6]_3$, formed from Fe^{3+} cations and the iron(II) complex $\text{Fe}(\text{CN})_6^{4-}$. Prussian Blue is the bluing agent in laundry products and the source of color in engineering blueprints.
3. **Bronze statues.** Bronze is an alloy containing 90% copper and 10% tin. Bronze statues form a green surface coating as they age, which actually protects them from further weathering. The reaction involves copper and constituents of moist air:

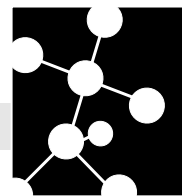


The green product can be viewed as a solid-state mixture of $\text{Cu}(\text{OH})_2$ and CuCO_3 .

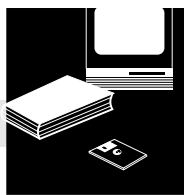
4. Many transition elements contribute to the colors in major artists' pigments. Some examples are chrome yellow (PbCrO_4), manganese violet [$(\text{NH}_4)_2\text{Mn}_2(\text{P}_2\text{O}_7)_2$], the iron(III) oxide reds, which go by many names including Venetian red, Turkey red and Indian reds (Fe_2O_3), cobalt blue [$\text{CoO} \cdot \text{Al}_2\text{O}_3$], blue copper phthalocyanine ($\text{C}_{23}\text{H}_{16}\text{N}_8\text{Cu}$) and molybdate orange (mixture of PbCrO_4 , PbSO_4 , and PbMoO_4).
5. Transition elements are commonly used in industry and medicine, for example:
 - a. Titanium metal is used in place of iron in both aircraft and racing bicycles. Titanium tetrachloride (TiCl_4) is a volatile liquid whose vapors react with air to give a dense smoke of TiO_2 . This reaction was once used by the U.S. Navy to make smoke screens during naval battles. Titanium dioxide (TiO_2) is the most common white pigment in paint. It is also used as a brightener and a sunscreen.

- b. Chromium is mixed with nickel and iron to produce stainless steel. Nichrome, an alloy of chromium and nickel, is often used as the wire heating element in toasters.
- c. Cobalt is used to prepare an alloy called alnico, which forms powerful magnets. Gamma radiations from cobalt-60 are used in cancer treatment.
- d. Cadmium is used to make nickel-cadmium batteries.
- e. Mercury dissolves many other metals to form solutions called amalgams. Dentists use a silver amalgam to fill teeth. This amalgam contains an excess of silver. Mercury(II) nitrate $[\text{Hg}(\text{NO}_3)_2]$ was once used in the manufacture of felt for hats. Workers often developed severe mercury poisoning. This affliction leads to nervous disorders, loss of hair and teeth, memory loss, and insanity. The phrase “mad as a hatter” refers to these symptoms of mercury poisoning.
- f. At one time platinum was known as “white gold,” but this term is now applied to an alloy of gold and platinum. The most exciting use of platinum compounds is as the cancer chemotherapy agent cisplatin $[(\text{H}_3\text{N})_2\text{PtCl}_2]$ —see *Chemistry in Medicine* module. Finely divided platinum, functioning as a catalyst, is used to reform straight-chain hydrocarbons with low octane numbers into their branched-chain isomers, which have higher octane numbers.

Extensions



1. If a spectrophotometer is available, students may enjoy analyzing colored solutions. (Laboratory Assessment Builds Success, Activity 18)
2. Many chromium compounds are alleged carcinogens, yet there is evidence that chromium is necessary to health. This would make a good library research project.
3. Chlorophyll and hemoglobin are very similar. Chlorophyll contains Mg, while hemoglobin contains iron. Hemocyanin, found in certain marine animals (such as squid), contains a heme-like porphyrin with a Cu^{2+} ion in place of Fe^{2+} . Invite students to investigate these substances, their formulas and properties.
4. In some localities small quantities of transition metals are allowed to enter the water supply through discharge into streams and lakes. An interesting Science Fair Project would be to find a method to determine trace quantities of hazardous ions in your community's streams.
5. The history of detecting mercury in fish is interesting because it depends in part on increasingly sensitive detection methods. Students could compare methods used to determine mercury 50 years ago to methods used today. The *World of Chemistry Secondary School Project* has an introduction to such a project: Tape 2, Measurement.
6. Natural deposits of transition element ores are not evenly distributed on earth. Have each student choose one transition element and locate where its ores are concentrated. Plot the sites on a world map and speculate about economic and political consequences.



References

Module developed by Diana Doepken-Rischling, Michael Pavelich, and Patricia Smith, the Colorado (South) team.

Dreyfus, C., and Dreyfus, H. (1984). *A one pot reaction, Volume III*. A Camille and Henry Dreyfus Institute Curriculum Module.

Emsley, J. (1991). *The Elements* (2nd Ed.). Oxford: Clarendon Press.

Key facts and data about the chemical elements that make up the world around us are brought together in a systematic and easy to use format.

Gardner, M., Heikkinen, H., and Smith, P. (1990). *Laboratory assessment builds success*. Madison, WI: Institute for Chemical Education.

Eighteen laboratory activities for secondary level that feature various patterns of laboratory activity including computer interfacing, microscale techniques, and a variety of hands-on, minds-on efforts to make important chemistry concepts understandable to high school students.

Greenwood, N.N., and Earnshaw, A. (1984). *Chemistry of the elements*. New York, NY: Pergamon.

Presents a balanced, coherent and comprehensive account of the chemistry of the elements for both undergraduate and post-graduate students. Full of ingenious experiments, intriguing compounds and exciting new discoveries.

Kolb, D. (1988, November). *Journal of Chemical Education*, 65, 1004.

A colorful demonstration showing six oxidation states of manganese on the lighted stage of an overhead projector.

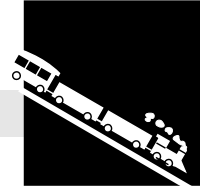
Kolb, D. (1987, April). *Journal of Chemical Education*, 64, 349.

Some demonstrations illustrating basic chemical concepts of transition metals or complex ions that can be carried out on the lighted stage of an overhead projector.

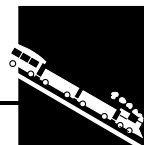
Russo, T. (1990). *Microchemistry 2*. WestChester, OH: Kemtec Educational Corp., 9889 Crescent Park Drive.

This microchemistry laboratory manual contains an experiment about the transition metal vanadium.

Appendix



- **Transparency Master**
 1. Word Search
- **Humor**

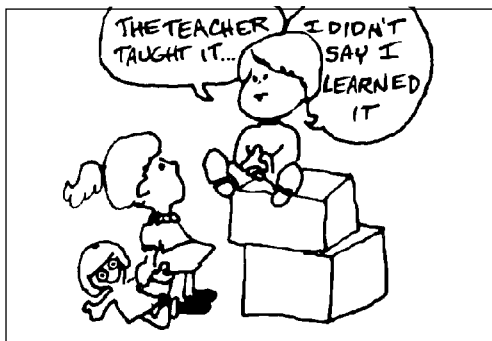
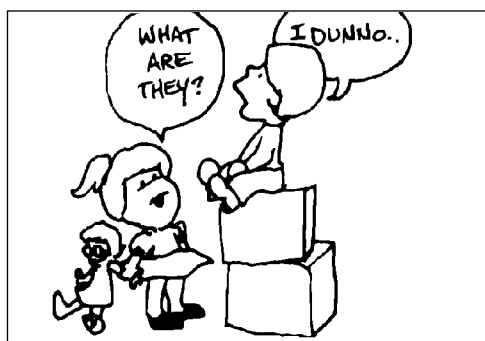
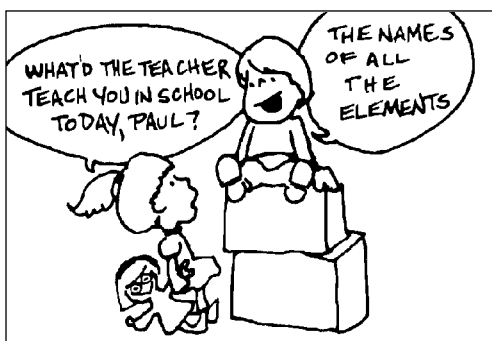
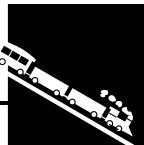


Word Search

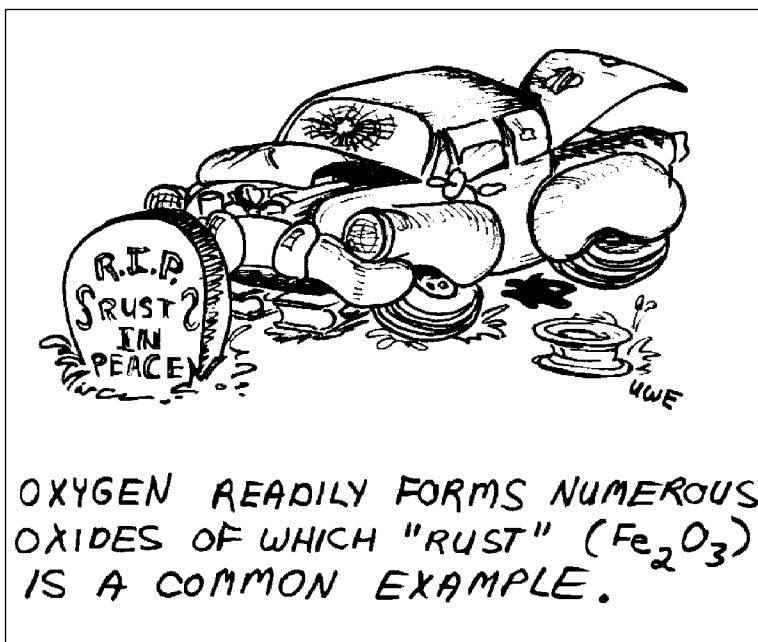
D N A G I L O X M X O B X L K N S
B F O D H Y C H N P U R P L E O J
I W U L U G U H D T L V D M S I P
Y N M I W O N D R A O Z T C T T L
N R Z O P N R O R O D O D Q U A H
L E P N Y G R D I N M W N H M N U
E P N I U D E W M T L I F R G I Z
W P S Z L H N U W T I E U X Z D K
K O I A A U R X D Y M S W M I R I
I C V T K E E A T J C L N D X O G
G N C I N D W R R S D E S A H O Y
F O N O V M K C V M K S U C R C K
M V R N R A J N O R I Z C G H T C

Words about the concepts in this module can be obtained from the clues given.
Find these words in the block of letters:

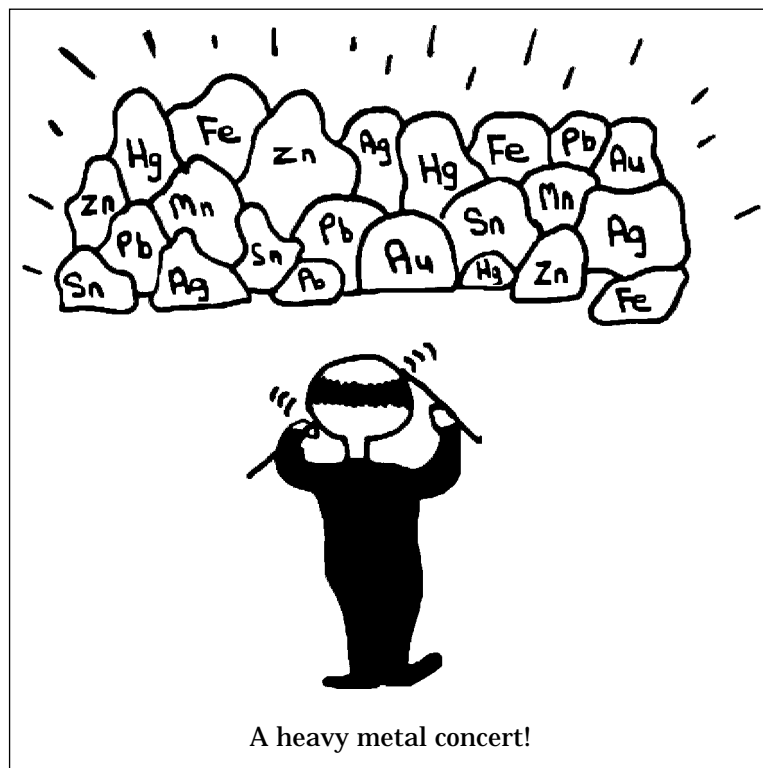
1. Molecule or ion surrounding a metal ion in a complex.
2. Adjective for the *d*- and *f*-block elements.
3. Shape associated with six species equally spaced around a central species.
4. Transition element identified by electron configuration $[\text{Ar}]3d^64s^2$.
5. Color of aqueous solution of permanganate ion.
6. In addition to tin, bronze statues contain this transition metal that turns them green upon aging.
7. Transition element responsible for the red color in rubies.
8. Type of energy required to remove an electron from an atom.
9. Type of complex composed of a metallic ion and its surrounding ligands.
10. Swiss chemist who predicted geometries of complex ions.



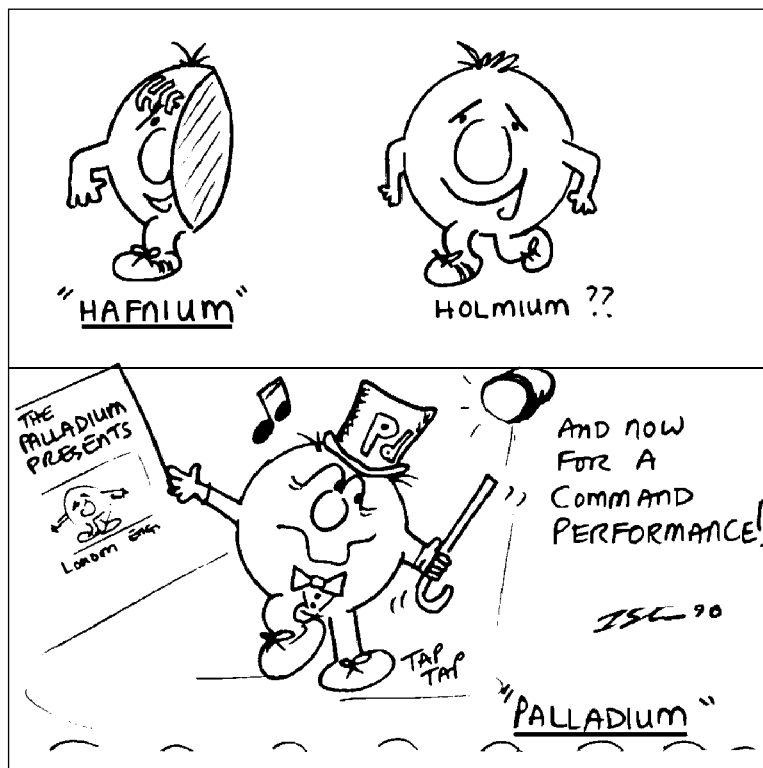
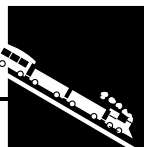
CHEM 13 NEWS, February 1975, p. 851.
Reprinted with permission.



CHEM 13 NEWS, December 1980, p. 8. Reprinted with permission.



CHEM 13 NEWS, December 1983, p. 3. Reprinted with permission.



CHEM 13 NEWS, September 1991, p. 6. Reprinted with permission.



CHEM 13 NEWS, March 1979, p. 5. Reprinted with permission.