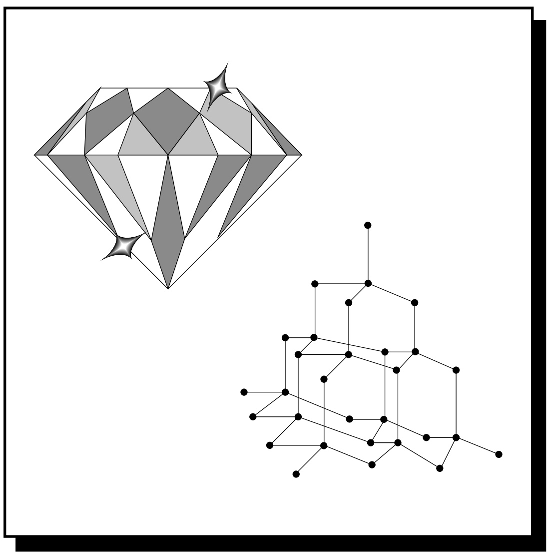
A SourceBook Module

Version 1.0 1994

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

The Chemistry of Rocks, Minerals, and Gems



ChemSource

Instructional Resources for Preservice and Inservice Chemistry Teachers

Topic Overview

Content in a Nutshell

The planet earth is composed of three distinct regions, the core, the mantle, and the crust (Figure 1). The core is believed to be mainly a sphere of iron and nickel which extends about 3500 km from the center. There is an inner core that appears to be solid, and an outer core that is molten. The mantle is thought to be mostly the silicate mineral olivine, $(Fe,Mg)_2SiO_4$. This extends another 3000 km. The region about which we know the most, the crust, has a thickness of 5 to 100 km. It is composed of the hydrosphere and the lithosphere. The lithosphere, which is hard, brittle, and relatively cool, rides on the upper portion of the mantle, the asthenosphere, which is hot, plastic, and semiliquid. Heat and pressure only partially explain the existence of the semiliquid layer between two solid layers. A jelly sandwich is an effective analogy.

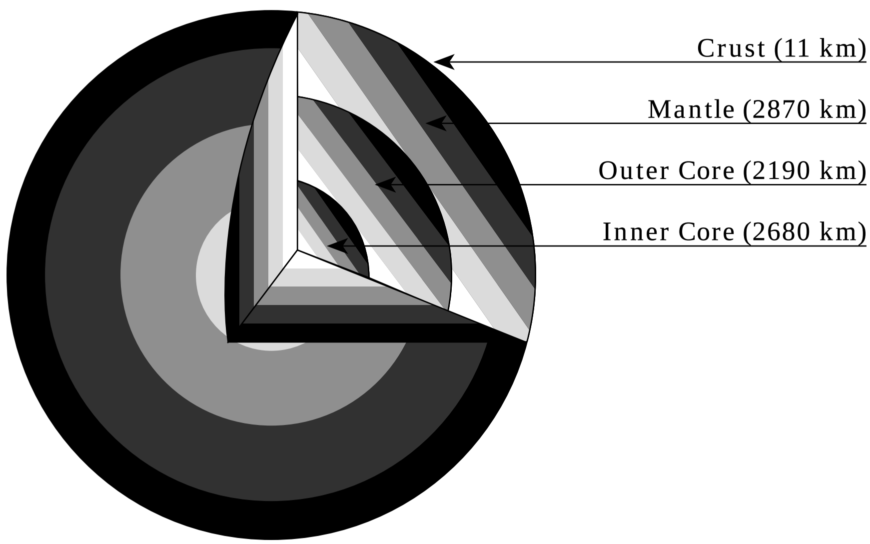


Figure 1. Regions of the earth.

Figure 2 shows how the temperature of the regions varies. The temperature increases from the crust to the inner core.

Depth, km	**Temperature, °C**
30	500
100	1100
200	1400
1000	2000
3000	2700
6000	3000

Figure 2. Temperatures beneath the earth's surface.

The ten most abundant elements in the crust are shown in Figure 3. Oxygen is the most abundant nonmetal and aluminum is the most abundant metal.

Oxygen, the most abundant element, comprises about 20% of the atmosphere, but most of the oxygen in the crust is found in the lithosphere not as an element, but combined with other elements. The second most abundant element, silicon, is found combined with oxygen in silicon dioxide and over a thousand different silicates. The numerous variations are due to the ability of silicon to bond to oxygen to form SiO_4^{4-} tetrahedra and the ability of these tetrahedra to join by sharing a common oxygen.

Element	**Mass %**	**Mole %**
Oxygen	49.4	42.5
Silicon	25.8	25.4
Aluminum	7.5	7.7
Iron	4.7	2.2
Calcium	3.4	2.5
Sodium	2.6	3.0
Potassium	2.4	1.7
Magnesium	1.9	2.2
Hydrogen	0.9	12.4
Titanium	0.6	0.2

Figure 3. Most abundant elements in the crust.

Silicon's position in the mineral kingdom is analogous to that of carbon in the animal and vegetable kingdoms. Silicon, like carbon, is tetravalent, and forms various giant molecules and polymers. Unlike carbon, however, silicon cannot form endless bonds with its own atoms and has limited ability to form multiple bonds. The strikingly different properties of SiO_2(s) and CO_2(g) illustrate this dissimilarity. Silicon dioxide is a network of joined tetrahedral SiO_4 units, while carbon dioxide consists of discrete molecules, O=C=O. The silicates also contain the SiO_4 units joined to form chains, layers, sheets, or three-dimensional arrangements. Synthetic silicone polymers also contain Si–O bonds, as well as carbon-containing organic groups.

The uses of silicon compounds are related to their thermal stability and inertness. The bond energy of the Si–O bond is 430 kJ/mol compared to 190 kJ/mol for Si–Si and 340 kJ/mol for C–C. Although many elements are found as silicates, silicates are not generally useful as sources of these elements because of the difficulty of extracting them. Silicates are primarily used with only small modifications of their structure—as glasses, ceramics, and cement. Because of the strength of the Si–O bond, synthetic silicones—$(R_2SiO)_n$ with R = CH_3, C_2H_5, C_6H_5—are used as lubricants, waxes, greases, and water repellents.

Minerals are inorganic solids of definite composition found in the crust. They include the silicate minerals as well as uncombined elements (*e.g.*, Cu, Ag, Au, and S) and compounds such as oxides, carbonates, sulfates, sulfides, halides, and phosphates. Iron, the fourth most abundant element in the earth's crust, is of great economic importance as a structural material. The major sources of iron are ores containing 30–40% iron in the form of hematite, Fe_2O_3, or magnetite, Fe_3O_4. Aluminum is also of considerable economic importance. It is chiefly obtained from bauxite, a mixture of alumina, Al_2O_3, with major impurities of Fe_2O_3 and SiO_2. After separation from these impurities the alumina is reduced by electrochemical means. Calcium, the fifth most abundant element is found as limestone, marble, and chalk (all varieties of $CaCO_3$), anhydrite, $CaSO_4$, gypsum, $CaSO_4 \cdot 2H_2O$, fluorite, CaF_2, and apatite, $Ca(F,Cl)_2 \cdot 3Ca_3(PO_4)_2$. Some of these materials (limestone, marble, and gypsum) are used without modification for structural purposes. Modifications and combinations with silicates produce plaster of Paris, cement, ceramics, and bricks.

Although the earth seems permanent to us, it is constantly changing. Movement of the solid lithosphere on the plastic asthenosphere causes cataclysmic changes such as earthquakes and volcanoes. The exposure of the rocks at the surface to atmospheric gases, water, and temperature changes also brings about significant alteration of the crust. These changes are called weathering and ultimately result in converting rocks to soil. The geologist divides weathering into mechanical and chemical. Some chemists might argue that even mechanical weathering is primarily chemical since most of the mechanical changes are brought about by the actions of water. Freezing water causes rocks to break and chip. Water dissolves minerals and transports them to distant locations and deposits them. Mineral ore deposits are created when water concentrates minerals in a small region. Chemical changes result when water, oxygen, and carbon dioxide react with rocks, producing new compounds and often causing rocks to crumble. Carbon dioxide dissolves in water, producing an acidic solution that reacts with some minerals. These processes have been active for millions of years and result in a land surface covered with rock fragments.

Place in the Curriculum

If this module is taught as a separate unit, the student should have some background in equilibrium, chemical bonding, solutions, and molecular geometry. You may wish to use one or more of these activities to apply the chemistry in other modules.

Central Concepts

1. Minerals can be formed by crystallizing from a melt or by deposition from water.
2. Minerals can be identified by chemical tests such as flame tests, bead tests, reactions with acids, and fluorescence.
3. Bonding determines structure, and structure determines properties.
4. Rocks are mixtures of minerals with variable composition.
5. Organic, inorganic, and physical processes called weathering result in changing rocks to soil.
6. Gems are often minerals that contain small amounts of transition elements as impurities.

Related Concepts

1. Covalent network solids have atoms covalently bonded in three-, two-, or one-dimensional networks (see *Chemical Bonding* module).
2. Chemical reactions can reach a state of dynamic balance: equilibrium (see *Equilibrium* module).
3. LeChatelier's Principle: If a system is stressed it will tend to react in a way to counteract the stress (see *Equilibrium* module).
4. The solubility of a precipitate can be altered by adding a common ion or adjusting the pH (see *Solubility and Precipitation* module).
5. Accumulated data allow prediction of the degree of solubility of many substances (see *Solubility and Precipitation* module).
6. Properties of network solids can be related to their structures (see *Materials Science* module).
7. Concepts of solution concentration (concentrated, dilute, supersaturated, saturated, unsaturated, and solubility curves) are reviewed in *Solubility and Precipitation* module.

Related Skills

1. Predict bond type from a knowledge of the Periodic Table and electron configurations.
2. Understand the three-dimensional character of network solids.
3. Analyze data from qualitative analysis activities.
4. Translate from two-dimensional drawings to three-dimensional models.

Performance Objectives

After completing their study of rocks, minerals and gems, students should be able to:

1. define a mineral.
2. distinguish between the two main mineral groups.
3. identify the elements found most abundantly in common minerals.
4. prepare a crystal.
5. distinguish between mineral and gemstone.

Concept/Skills Development

Laboratory Activity: Student Version

Activity 1: Making Crystals

Introduction

Atoms, molecules, and ions can fit together in a regular pattern to form a crystal. There are several types of crystals and crystalline structures. One of the ways to grow crystals is to allow water to evaporate so that the ions or molecules can come together to form crystals.

Purpose

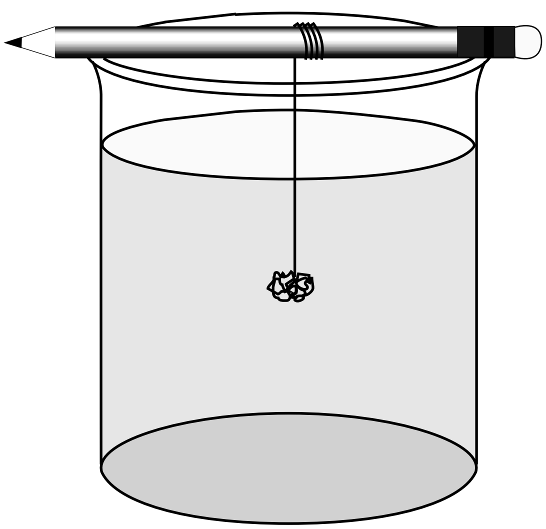
To investigate sugar and salt crystals. To produce salt crystals by allowing sodium ions and chloride ions to come together in solution. To produce sucrose crystals (sometimes called rock candy) by allowing sugar molecules to come together in solution.

Safety

Wear protective goggles throughout the laboratory activity.

Procedure

Part I. Preparing Salt Crystals



1. Fill a 250-mL beaker about three-fourths full of water.
2. Add salt (about 20 g) to the water until no more will dissolve.
3. Heat the solution (to about 90 °C), but do not boil it.
4. While the solution is hot, add salt (about 15 g) until no more will dissolve. Remove the beaker from the hot plate. Be sure that no undissolved salt remains in the bottom of the beaker.
5. Suspend a string in the solution by tying the string onto a pencil, soda straw or wood splint and suspending it across the top of the beaker.
6. Cover the beaker with a watch glass but do not seal it. Put the beaker where it will not be disturbed for a few days. Make observations daily. Record your observations.

Part II. Preparing Sugar Crystals

1. Boil 150 mL water in another 250-mL beaker.
2. Add as much sugar (about 110 g) as will dissolve in the hot water.
3. Repeat Steps 5 through 7 from Part A.
4. Compare both types of crystals. Look at them with a microscope if available.
5. Thoroughly wash your hands before leaving the laboratory.

Data Analysis and Concept Development

1. Describe the results of this activity. What did the crystals look like? Draw diagrams to show the crystals.
2. What are the characteristics of each type crystal?
3. What purpose does the string serve?

Implications and Applications

1. Imagine how the particles of each substance must be arranged to produce the crystals you described. Draw a “particle nature of matter” picture to describe what you imagine.
2. If sugar crystals are made of sugar molecules, and salt crystals are made up of sodium ions and chloride ions, how would the particle pictures differ?
3. Explain how the process of crystallization might have been involved in forming deposits of minerals.

Laboratory Activity: Teacher Notes

Activity 1: Making Crystals

Major Chemical Concept
Substances crystallize in predictable, regular patterns.

Level
General or Basic

Expected Student Background
None.

Time
45 min the first day and 5 min on successive days (for observations).

Safety
Students should be reminded not to taste anything in the laboratory, even things that can ordinarily be ingested.

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

Nonconsumables

24 Beakers, 250-mL
12 Hot plates

Consumables

Sugar, 600 g
Salt, 480 g
12 Kite strings, 10 cm

Advance Preparation
No advance preparation is needed. *NOTE*: A heavy-gauge pre-soaked string works best since it will tend to sink.

Pre-Laboratory Discussion
This activity might be preceded by showing shapes of some naturally occurring crystals and speculating about what might happen when solids are crystallized by evaporation. A discussion of the changes in concentration of a solute that occur when the water evaporates will help students understand what happens in the activity. The terms "dissolve" and "saturated" should be reviewed.

Teacher-Student Interaction
This activity is easy to perform and little interaction is needed. If necessary, students can be reminded that if solid remains in the beaker after heating, the solution is saturated, and no more solute should be added.

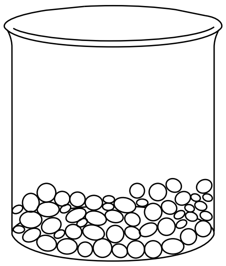
Anticipated Student Results
Both sugar and salt crystallize in the cubic form. Students may observe several small crystals or fewer larger ones.

Answers to Data Analysis

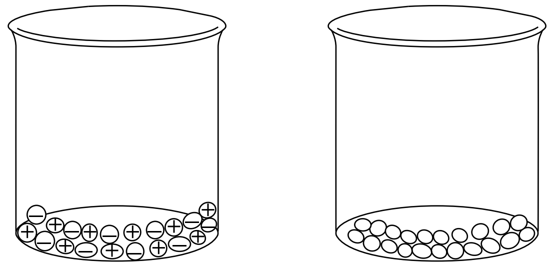
1. Small cubes.
2. The particle at the lattice points for sugar is a molecule of sugar; in the sodium chloride crystal the particles are sodium ions and chloride ions.
3. To suspend the crystal so that it has a greater opportunity to serve as a growth site, and to minimize crystal distortion by resting in the bottom of the beaker.

Answers to Implications and Applications

1\.



2\.



3. As water evaporates, the solution becomes saturated and crystals begin to form.

Post-Laboratory Activities

After the crystals begin to grow, a discussion of equilibrium would be appropriate if this topic was previously introduced. The six crystal systems (Figure 4) and examples from the mineral world may be introduced.

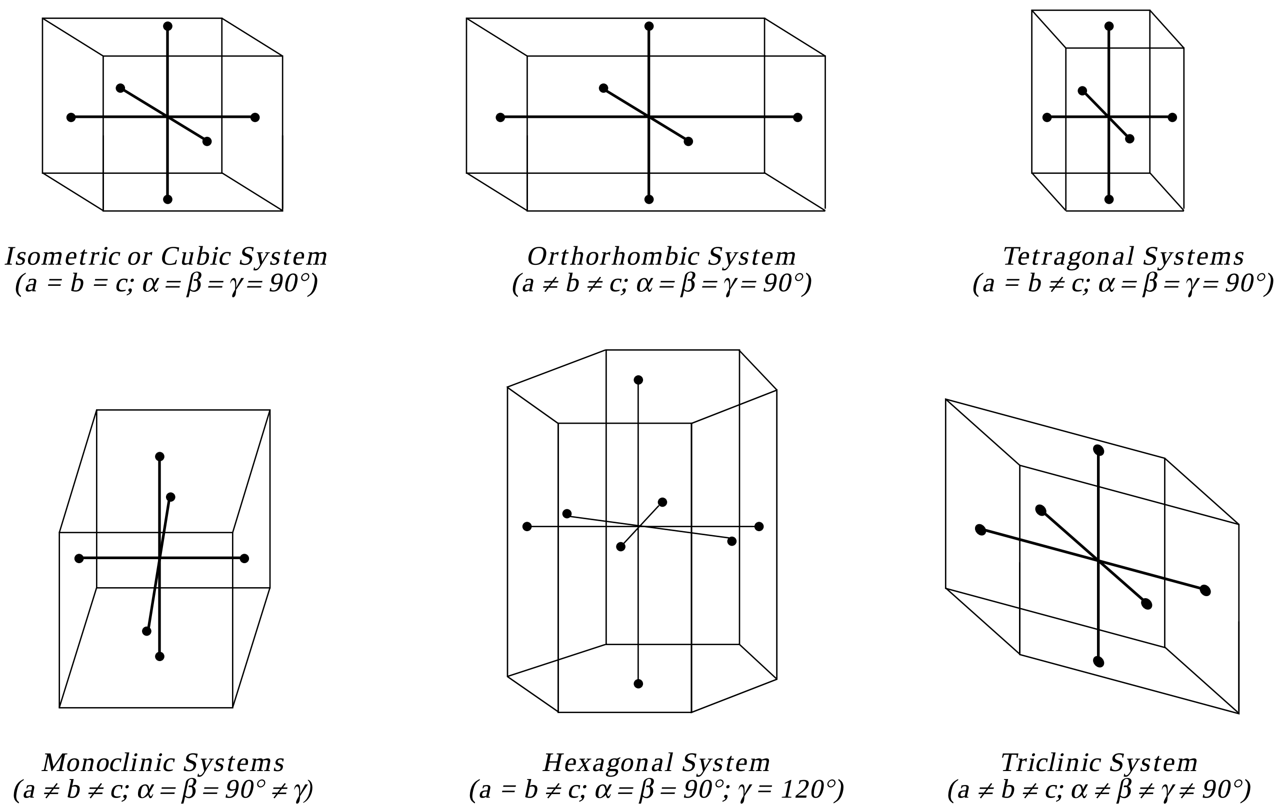


Figure 4. Six basic crystal systems: isometric or cubic, orthorhombic, tetragonal, monoclinic, hexagonal, triclinic; a, b, c = edge lengths; α, β, γ = internal angles.

Extensions

1. Students may wish to continue crystal growing with other types of compounds, *e.g.*, copper sulfate, alum, and Epsom salts. If students wish to keep the crystals they make, cover them with clear nail polish to prevent reaction with the atmosphere.
2. Have students compare the basic crystal systems and show how they differ from one another.

LABORATORY ACTIVITY: STUDENT VERSION

Activity 2: Identification of Minerals by Borax Bead Tests and Flame Tests

Introduction

Two simple tests that can be used to identify the metal ion in minerals are flame tests and borax bead tests. Both use only simple equipment and require a short amount of time. Borax beads can be made in different colors depending on whether a reducing or an oxidizing flame is used.

Purpose

To identify metal ions through flame tests and borax bead tests.

Safety

Wear protective goggles throughout the laboratory activity.

Procedure

Prepare a data table to record your results.

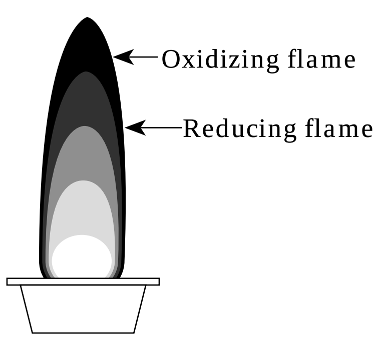
Part 1. Flame Tests

1. Place pea-sized amounts of the salts KCl, NaCl, LiCl, and $CuCl_2$ in separate watch glasses.
2. Adjust the burner so that a distinct blue cone is present.
3. Clean a platinum wire by dipping it into 6 M HCl and then holding it in the flame until no color is produced.
4. Dip the platinum wire in the KCl, and hold it in the flame. Record the color.
5. Clean the wire as before, and repeat the tests with the other salts.

Part II. Borax Bead Tests

1. Twist the end of the platinum wire to form a loop as shown.

2. Place about 1 gram of $CuCl_{2,}$ $CoCl_{2,}$ $Fe(NO_3)_3$ MnO_2, and borax in separate watch glasses.
3. Heat wire first in flame and then dip the loop of the wire in the borax, picking up a small amount. Heat it until a glassy bead is formed.



4. Dip the bead in the $CuCl_{2,}$ and return to the flame's outer core (oxidizing portion). This portion of the flame is inside the luminous part of the flame about a centimeter above the inner blue cone. Record the color, and repeat the process in the reducing portion of the flame. This region is at the tip of the inner blue cone.
5. Crush the bead from the platinum wire, and clean the wire with 6 M HCl as described above.
6. Bring a magnet close to the bead. Observe for attraction.

7. Repeat the bead test with the remaining solids.
8. Obtain an unknown from your teacher. Perform flame tests and bead tests.
9. Thoroughly wash your hands before leaving the laboratory.

Data Analysis and Concept Development

Use your data table to determine the identity of your unknown.

Implications and Applications

Can a mineral be identified by flame and bead tests alone? Why or why not?

Laboratory Activity: Teacher Notes

Activity 2: Identification of Minerals by Borax Bead Tests and Flame Tests

Major Chemical Concept

Metal ions can be identified by flame and borax bead tests.

Expected Student Background

Students should be able to:

1. use a burner safely.
2. make a data table.
3. interpret data in a table.

Time

45 min

Safety

Remind students about hazards of operating burners and using 6 M HCl.

Materials (For 24 students working in pairs)

Nonconsumables

12 Burners and tubing
12 Platinum wires in glass or nichrome wires attached to balsa wood
60 Watch glasses
12 Test tubes, 13- x 100-mm
12 Stirring rods or spatulas (for crushing the borax bead)

Consumables

Sodium chloride, NaCl, 1.2 g
Potassium chloride, KCl, 1.2 g
Lithium chloride, LiCl, 1.2 g
Copper(II) chloride, $CuCl_2$, 1.2 g
Cobalt(II) chloride, $CoCl_2$, 1.2 g
Manganese oxide, MnO_2, 1.2 g
Iron(III) nitrate, $Fe(NO_3)_3$, 1.2 g
Borax, 6.0 g
6 M Hydrochloric acid, HCl, 150 mL (76 mL conc. HCl diluted to 150 mL)
Cobalt glass *[OPTIONAL: This glass is sometimes helpful in observing the potassium flame test by elminating the interference of the sodium orange-yellow flame.]*

Advance Preparation

Prepare 6 M hydrochloric acid. Be sure to add acid to water.

As the wire deteriorates with use, cut off a portion to get a fresh sample.

Prepare unknowns from samples used.

Pre-Laboratory Discussion

Remind students of safety hazards. Demonstrate the oxidizing and reducing portions of the flame.

Teacher-Student Interaction

Students sometimes need to be reminded to make observations as quickly as possible after the wire has been put into the flame. When the wire becomes red hot, the flame will appear orange regardless of the substance being tested.

Anticipated Student Results

Flame Tests	
KCl	Lavender (difficult to see)
NaCl	Yellow-orange
LiCl	Red
$CuCl_2$	Green

Borax Bead Tests		
	Oxidizing color	**Reducing color**
$CuCl_2$	Green	Red
$CoCl_2$	Blue	Blue
$Fe(NO_3)_3$	Yellow	Green
MnO_2	Red	White

Answers to Data Analysis

Will depend on identity of student's unknown.

Answers to Implications and Applications

These tests identify only the metal ion. Other tests such as density, color, cleavage, and scratch test will give further information to help in identification (see MECC computer simulation in *Media*).

Post-Laboratory Discussion

Relate these tests to similar tests that might be made on minerals.

Extension

If time permits, obtain mineral samples from the geology or earth science teacher and allow students to perform the tests with them. Check any minerals for possible hazards.

Assessing Laboratory Learning

The extension may be used for assessment. If you do not wish to use actual minerals, prepare unknowns from the salts used in the activity.

DEMONSTRATIONS

CAUTION: Use appropriate safety guidelines in performing demonstrations.

Demonstration 1: Growing Crystals in Gels

Description

In nature minerals are often found crystallized in bands. Large, nearly perfect specimens are occasionally found. These phenomena can be simulated by preparing a gel from water glass (a solution of Na_2SiO_3) to represent the silicate rock. Small quantities of other compounds are introduced, and crystals are formed by precipitation or oxidation reduction reactions. A solution of one of the ions of the desired crystal is added to an acidified solution of water glass. This mixture is allowed to stand. When the other reactant is added to the top of the solution the ions diffuse downward, and the reaction takes place. The longer these crystals are permitted to grow, the more beautiful they become.

Materials

Beaker, 400-mL
4 Test tube, 16- x 150-mm
4 Stoppers
Parafilm™
1.0 M Copper(II) chloride, $CuCl_2$, 100 mL (17.0 g $CuCl_2 \cdot 2H_2O$ per 100 mL solution)
1.0 M Lead acetate, $Pb(C_2H_3O_2)_2$, 100 mL (32.5 g $Pb(C_2H_3O_2)_2$ per 100 mL solution)
1.0 M Potassium iodide, KI, 100 mL (16.6 g KI per 100 mL solution)
1.0 M Copper(II) sulfate, $CuSO_4$, 100 mL (25.0 g $CuSO_4 \cdot 5H_2O$ per 100 mL solution)
1.0 M Sodium chromate, 100 mL (23.4 g $Na_2CrO_4 \cdot 4\,H_2O$ per 100 mL solution)
1 Iron nail
1 Zinc strip
1.0 M Acetic acid, $HC_2H_3O_2$, 100 mL (mix 6 mL glacial acetic acid per 100 mL solution)
Hot plate
Sodium silicate solution, 100 mL (15 mL of saturated solution diluted to 100 mL). The saturated solution can be purchased in hobby shops or pharmacies as water glass. If not available locally, Aldrich Chemical Co., (800) 558-9160, will send 1 liter (Cat. No. 33, 844-3) for $12.60 plus shipping charges.

Safety

Dispose of solutions according to local codes.

Procedure

Preparation of acidified gel.

1. Prepare a hot water bath by half filling a 400-mL beaker and placing it on a hot plate.
2. Put 25 mL 1.0 M acetic acid in a test tube. *(NOTE: The concentration of acetic acid and the sodium silicate solution are critical for gelling.)*
3. Add the specified amount of the first reactant (see following table) to the acetic acid in the test tube, and mix well. This may be done by stoppering the test tube and gently turning it upside down several times.
4. Add 25 mL sodium silicate solution to the acid mixture. Mix well as above, and cover with Parafilm (with a pinhole) or a stopper.
5. The gel will set in minutes if put into very hot water.
6. Add the metal or solution listed for specific systems (see following table), stopper, and display.
7. Observe daily.

Specific Systems:

To produce	First reactant (Step 3)	Then add (Step 6)
Copper tree	5 mL 1.0 M $CuCl_2$	Iron nail + 1.0 mL 1.0 M NaCl
Lead tree	1 mL 1.0 M $Pb(C_2H_3O_2)_2$	Zn strip + 4 mL water
Lead iodide	4 mL 1.0 M $Pb(C_2H_3O_2)_2$	10 mL 1.0 M KI
Copper chromate	4 mL 1.0 M Na_2CrO_4	4 mL 1.0 M $CuSO_4$

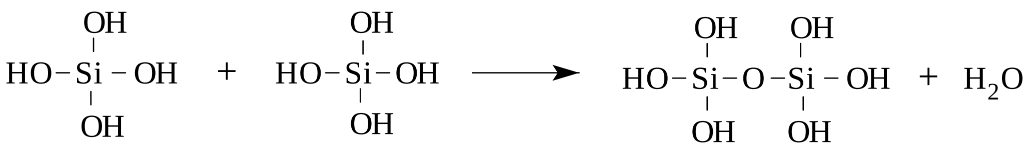
Demonstration 2: An Inorganic Polymerization Demonstration

Description

Silicates polymerize in acid solution according to the following equation:

$$Na_2SiO_3(aq) + 2HCl(aq) + H_2O(l) \rightarrow Si(OH)_4(aq) + 2NaCl(aq)$$

Although the product is represented by the formula $Si(OH)_4$, it consists of a complex mixture of polymeric acids formed by condensation.



The $Si(OH)_4$ cannot be isolated from the mixture. If the gelatinous mixture is heated, the reaction is reversible. If the NaCl(aq) is removed by washing, the reaction is not reversible. On heating, the unwashed silica becomes a solid, and the washed product is a powder that can absorb a large amount of water.

Materials

1 M Hydrochloric acid, HCl, 100 mL (8.4 mL conc. HCl diluted to 100 mL. Be sure to *add acid to water*.)

17% Sodium metasilicate, Na_2SiO_3, 100 mL (water glass, described in demonstration. 17 g Na_2SiO_3 is mixed with 83 g H_2O.)

Beaker, 250-mL

2 Petri dishes

Drying oven or microwave oven

0.05 M Silver nitrate, $AgNO_3$, 10 drops (0.02 g in 2 mL distilled H_2O)

Distilled or deionized water

Procedure

1. Add 100 mL 1 M HCl to 100 mL 17% Na_2SiO_3 in a weighed 250-mL beaker. Decant supernatant liquid.
2. Find the mass of the gel. Divide the gel into 2 equal parts.
3. Place half in a weighed Petri dish, and weigh again.
4. Wash the remaining gel in the beaker with distilled water until no cloudiness appears when a few drops of $AgNO_3$ is added to the decanted wash water.
5. Heat both gels in a drying oven at 105 °C for 1.5 hr or in a microwave oven for 15 min.
6. Reweigh the samples.

Data Analysis

1. Describe the differences in the two samples.
2. Students can calculate the number of grams of water absorbed by one gram of gel for each sample.
3. Explain the differences in structure that can account for the results in Question 2.
4. Which of the samples would be most likely to be packed with cameras and electronic equipment for use as a drying agent?

Demonstration 3: Supersaturated Solution

Description

The action of heat and pressure on water beneath the surface of the earth sometimes creates supersaturated solutions. This demonstration shows how such solutions could produce crystals.

Materials

Sodium acetate trihydrate, $NaC_2H_3O_2 \cdot 3H_2O$, 160 g
Distilled water, 30 mL
Tap water for water bath
Erlenmeyer flask, 500-mL
Beaker, 1-L or greater for water bath
Parafilm™ or 100-mL beaker to cover the Erlenmeyer flask
Graduated cylinder, 50- or 100-mL
Glass stirring rod
Wash bottle with distilled water
Balance, triple beam
Hot plate, laboratory burner or alcohol burner
Ringstand set up, if using burner
Heat-resistant gloves or tongs
Goggles and apron

Procedure

1. Weigh 160 g of sodium acetate trihydrate in a 500-mL Erlenmeyer flask.
2. Add 30 mL distilled water to the flask.
3. Heat the mixture in a hot water bath stirring occasionally until all of the solid is dissolved. (This may take 15 min or so.)
4. Remove all crystals from the sides of the flask by rinsing them down with small squirts of water from the wash bottle.
5. Cover the flask with Parafilm or the inverted 100-mL beaker.
6. Allow the solution to cool to room temperature undisturbed, or to speed up the cooling process, run cold water over the sides of the flask making sure no tap water gets into the flask and contaminates the solution.
7. While holding a single crystal of sodium acetate over the open mouth of the flask, snap your fingers, and allow the crystal to drop into the flask. The single crystal should start crystallization.
8. After crystallization is complete turn the flask upside down, and nothing should fall out.
9. The sides of the flask should be warm since this is an exothermic process.
10. The solution may be used over and over again by reheating it to redissolve the sodium acetate.

Remarks

The addition of too much water will result in leftover liquid after recrystallization.

Variations of this demonstration include placing a single crystal of sodium acetate in a shallow container and pouring the solution described above on the crystal to produce a “stalagmite” of sodium acetate. A buret may also be used to add the solution to the crystal.

Demonstration 4: Precipitation and Redissolution of Calcium Carbonate

Description

$CaCO_3$ is the major chemical component of many minerals and natural products. These minerals include marble, calcite, aragonite, coral, sea shells, stalactites, stalagmites. Precipitation of $CaCO_3$ forms these substances. Dissolution of $CaCO_3$ allows the raw materials to be transported.

$$Ca^{2+}(aq) + CO_3^{2-}(aq) \rightleftharpoons CaCO_3(s)$$

This demonstration illustrates how sensitive the direction of this equilibrium expression is to reaction conditions (pH, carbonate concentration, temperature).

Materials

1 L Saturated $Ca(OH)_2$ (limewater) [Boil 1 L distilled water, cover, and allow to cool overnight. This removes CO_2 from the water. Add 1.8 g $Ca(OH)_2$, mix well, and allow to settle. Filter if cloudy at the time of use.]
Carbon dioxide, CO_2 (either dry ice (solid CO_2) or a cylinder of compressed CO_2)
4 Straws (or 25-cm lengths of 6- to 8-mm glass tubing, fire polished)
Gloves or towels to handle dry ice
Hot plate with magnetic stirrer and stirring bar
2 Beakers, 500-mL

Safety

The $Ca(OH)_2$ solution is basic with a pH = 12.4. It can irritate eyes and skin. In case of ingestion, give copious drinks of water to dilute the limewater in the stomach, and seek medical advice.

Procedure

1. Place 150-250 mL of clear, saturated $Ca(OH)_2$ in a 500-mL beaker. Have a volunteer blow gently through a straw or glass tube into the solution. Caution: because $Ca(OH)_2$ is a strong base, warn the volunteer to not get any of the liquid into the mouth (see *Safety* above). A white precipitate of $CaCO_3$ will form.

2. Place a second sample of $Ca(OH)_2$ in a second beaker. Bubble pure CO_2 through the solution by dropping in a piece of dry ice or by using the compressed gas. Initially, a white precipitate of $CaCO_3$ will form. However, the precipitate will slowly dissolve eventually giving a clear solution.

3. Have your volunteer return to try to redissolve the first sample of $CaCO_3$ by blowing again into the sample. No amount of blowing will redissolve the precipitate.

4. Put the solution from Step 2 on a hot plate with stirring. The carbon dioxide gas is less soluble in hot water and is removed. Near the boiling temperature, the solid begins to reform. When the solution cools, the appearance of suspended solid will be quite pronounced. (Adding pure CO_2 to this final solution will not redissolve the $CaCO_3$.)

Explanations

Step 1. Although H_2CO_3 is not stable, it is useful to view CO_2 dissolving in water to form carbonic acid.

$$CO_2(g) + H_2O(l) \rightleftharpoons H_2CO_3(aq) \qquad \text{(a)}$$

The acid is immediately neutralized by hydroxide forming carbonate ion that in turn reacts with the calcium ion forming insoluble $CaCO_3$.

$$H_2CO_3(aq) + 2OH^-(aq) \rightleftharpoons 2H_2O(l) + CO_3^{2-}(aq) \quad \text{(b)}$$

$$Ca^{2+}(aq) + CO_3^{2-}(aq) \rightleftharpoons CaCO_3(s) \quad \text{(c)}$$

Step 2. When pure CO_2 is being added, its concentration increases until all the hydroxide originally in the solution is consumed. Thus, any excess dissolved CO_2 is unneutralized carbonic acid. Some hydrogen ions dissociate and dissolve the precipitate converting the carbonate to bicarbonate. ($CaHCO_3$ is soluble.)

$$H_2CO_3(aq) \rightleftharpoons H^+(aq) + HCO_3^-(aq) \quad \text{(d)}$$

$$H^+(aq) + CaCO_3(s) \rightleftharpoons Ca^{2+} + HCO_3^-(aq) \quad \text{(e)}$$

Step 3. Exhaled breath is only 4% CO_2. By contrast, the gas obtained from dry ice is 100% CO_2. Blowing into the solution never provides a concentration of carbonic acid high enough to exceed the available hydroxide. Think of all the reactions as reversible. Thus, in each, the reactants and products are in a state of balance. When the pressure of $CO_2(g)$ in reaction (a) cannot get very high, reaction (b) cannot be forced to consume all the OH^-. Thus the effect of the last two reactions cannot be seen. That is, the equilibrium in reaction (d) and (e) lies far to the left.

Step 4. Heating the solution decreases the solubility of CO_2 in water. Thus reaction (a) is forced to the left. This in turn forces reactions (d) then (e) to the left and $CaCO_3$ reforms.

Demonstration 5: Pot-O-Gold

Purpose

This demonstration should precede a discussion on solubility. Solubility and precipitation are important in understanding the occurrence of minerals. This demonstration catches the attention of students who watch the platelets swirling and catching the light.

Materials

Nonconsumables

Beaker, 1-L
Florence flask, 500-mL, with stopper
Burner
Funnel

Consumables

0.20 M Lead nitrate, $Pb(NO_3)_2$, 50 mL (3.3 g $Pb(NO_3)_2$ per 50 mL solution)
0.20 M Sodium iodide, NaI, 50 mL (1.5 g NaI per 50 mL solution)
Filter paper

Safety

Both lead and iodide ions are listed as hazards. Students should not handle these chemicals. Normal precautions should be followed. Excess solid lead iodide should be stored in a lead-waste container. The filtrate is used as part of the second solution.

Procedure

1. Mix the lead nitrate and sodium iodide solutions. A yellow precipitate of lead iodide will form.
2. Filter the supernatant liquid into 1-L beaker and add enough distilled water for a total volume of 300 mL.

3. Heat solution containing the filtrate to boiling.
4. Add enough solid lead iodide to make a saturated solution at 100 °C.
5. Pour the saturated solution, while hot, into a 500-mL Florence flask.
6. Let the solution cool slowly to room temperature. The lead iodide will precipitate out as shiny platelets that look like gold.
7. Stopper the flask securely. The mixture can be kept in a stoppered flask for several years.

Group and Discussion Activities

Key Questions

1. What happens on a particle level when crystals form from evaporation of a saturated solution? *[As water slowly evaporates, the ions deposit on the crystal because the saturated solution cannot dissolve more solute.]*
2. How can flame tests and borax bead tests be used in mineral identification? What are the limitations of these tests? *[Both flame tests and borax bead tests are used to identify the positive ion of the mineral. Sometimes the colors are very similar and these tests cannot identify the negative ion.]*
3. What is the basic unit common to all silicate minerals? What is its geometry? *[The SiO_4^{4-} ion. It is tetrahedral.]*
4. How are crystals formed from a supersaturated solution? *[A single crystal is added to disturb the solution and then many crystals form rapidly.]*
5. What factors are characteristic of minerals that are classified as gemstones? *[Color, transparency, and luster or brilliance.]*
6. Compounds of the transition elements often exhibit color. To what can this color be attributed? *[If the transition element forms a compound in which its d orbitals do not all have the same energy, the result is an energy gap that matches the energy of photons of visible light. When white light strikes the compounds, those photons are absorbed. The color we see is the result of the colors that are not absorbed.]* (See *Transition Elements* module.)
7. How is a gemstone different from a mineral? *[A gemstone, generally, 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.]*

Counterintuitive Examples

Salol (phenyl salicylate), a solid at room temperature, is a substance that supercools readily. Supercooling is the process of cooling a liquid below its freezing point without changing to a solid. Prepare microscope slides that have two “globs” of salol as shown here. Have students melt the larger glob by holding a match under it. After melting the glob place the slide on the desk top to allow it to cool to room temperature. Ask how the solid and liquid can both exist at the same temperature. Then use a spatula or stirring rod to break off a crystal from the smaller glob and move it to the puddle formed from the larger glob. The slow crystallization holds the interest of students.

Analogies and Metaphors

Fruit is frequently stacked in supermarkets in a pattern analogous to cubic close packing.

Pictures in the Mind

Making Models of Silicate Minerals

Introduction

Students sometimes have great difficulty visualizing in three dimensions. This activity gives them hands-on experience imagining various silicate ions. Commercial chemistry models can be used by declaring that the ball that usually represents the carbon atom represents a silicon atom. However, gum drops and tooth picks are better because students will have to decide the appropriate angles.

Materials

Model kits or gum drops of two colors and tooth picks.

Procedure

1. Require students to work in groups of two or three.
2. Explain that silicon has four covalent bonds and the bonds need to be as far apart as possible. Remind them to consider three dimensions.
3. Direct students to make an SiO_4^{4-} ion, and draw a projection on paper. Circulate through the room correcting those insisting on using only two dimensions.
4. Make models and drawings of:
   a. $Si_2O_7^{6-}$
   b. chains of $(SiO_3^{2-})_n$ and double chains of $(Si_4O_{11}^{6-})_n$
   c. planar sheet of atoms where each Si atom shares oxygen atoms with three other silicons
   d. a three-dimensional structure of empirical formula SiO_2.
5. Have students describe the properties of minerals that would have each of the structures they made. *Tips for the Teacher* and the *Transparency Masters* will be useful in interpreting students' drawings and providing examples. If samples of minerals with each type of structure—chains, sheets, and three-dimensional—are available, they will add to the understanding of the relationship between structure and properties.

TIPS FOR THE TEACHER

Language of Chemistry

crystal substance in which the atoms, ions, or molecules are arranged in an orderly, repeating three-dimensional pattern called a crystal lattice.

lithosphere the upper portion of the earth's crust.

mineral inorganic solid of definite composition found in the earth's crust.

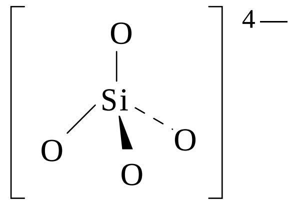
silicates minerals with crystal structure containing silicon-oxygen tetrahedra.

supercooling process of cooling a liquid below its freezing point without changing to a solid.

Silica and **silicates** are compounds made primarily of silicon and oxygen atoms. They can be discussed to make three important points:

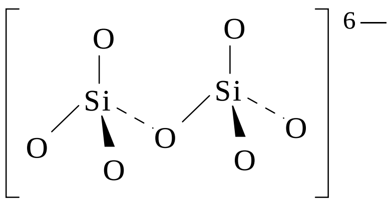
1. Many minerals are silicate based.
2. Lewis structure pictures can be used to classify minerals.
3. Lewis structure pictures can help explain physical properties of minerals.

All silicate minerals contain Si atoms bonded to four O atoms in a tetrahedral arrangement. The simplest involve the orthosilicate ion (SiO_4^{4-}).



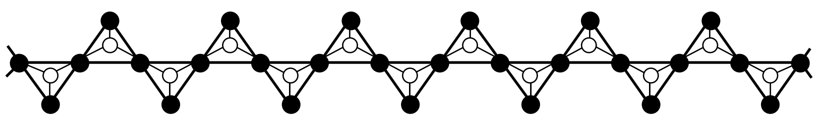
Each oxygen is bonded to only one Si and has a residual negative charge. Examples of orthosilicate minerals are zircon ($ZrSiO_4$) and forsterite (Mg_2SiO_4).

When an oxygen atom is shared by two Si atoms, the pyrosilicate anion ($Si_2O_7^{6-}$) is obtained.

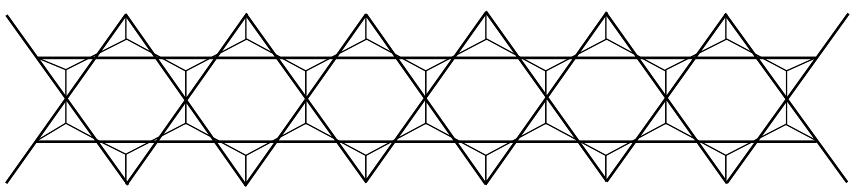


The Lewis structure shows single bonds, octets on each atom, and a tetrahedral geometry around the Si atom. Some pyrosilicate minerals are akermanite ($Ca_2MgSi_2O_7$), lawsonite ($CaAl_2Si_2O_7(OH)_2$), and hemimorphite ($Zn_4(OH)_2Si_2O_7$).

The silicate units can continue to link through sharing oxygen atoms to form long single chains of the general formula SiO_3^{2-}

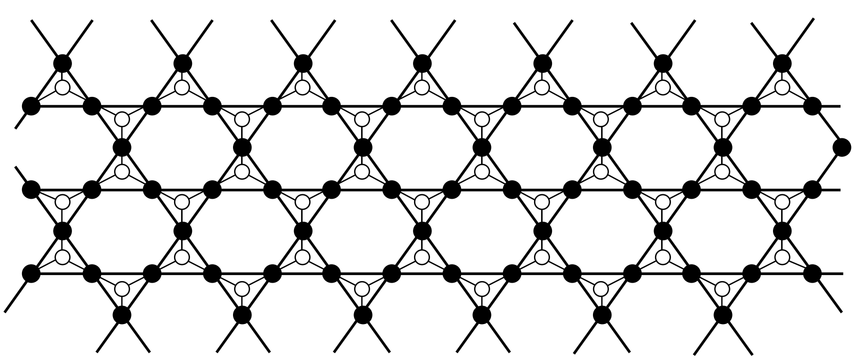


or long double chains having the formula $Si_4O_{11}^{6-}$.



Examples of some of SiO_3^{2-} minerals are enstatite ($MgSiO_3$) and spodumene ($LiAl(SiO_3)_2$). Tremolite ($Ca_2Mg_5Si_8O_{22}(OH)_2$) is an example of a mineral with double chains.

SiO_x tetrahedra can also link into two-dimensional planar sheets of atoms, where each Si atom shares oxygen atoms with three other silicons. These minerals have the general formula $Si_4O_{10}^{4-}$ and are called sheet silicates. Chrysolite ($Mg_6Si_4O_{10}(OH)_8$) is an example. In micas one Si is replaced by an Al, for example, muscovite ($KAl_2AlSi_3O_{10}(OH)_2$).



A logical extension of this build-up of tetrahedra is to have all four oxygens in a tetrahedral silicate unit shared by Si atoms in adjacent units. The result is quartz, with an empirical formula of SiO_2. The quartz structure can be imagined by viewing the three-dimensional linked structure of diamond. SiO_2 would have Si's where each C is in the diamond structure; the oxygen atoms are then midway between each pair of Si atoms.

The one-, two-, or three-dimensional links of SiO_x units lead to their physical properties. Asbestos is mixed minerals of the long, double-chain type. Thus, they are needle-like, which may account for some of the damage they do to living tissue. Micas are slippery due to two-dimensional sheets of SiO_x units that can slide over each other. Quartz has structural strength because of its three-dimensional covalent linking of SiO_x units.

Problem Solving

Many common minerals contain oxygen as a major component. Some of these are easily collected and identified. This problem-solving activity shows the variation of that oxygen content. Problem: Calculate the oxygen content of flint or quartz (SiO_2).

Find the molar mass of the compound:

$$\begin{aligned} \text{1 mol Si} &= 28.1 \text{ g} \\ \text{2 mol O} &= \underline{32.0} \text{ g} \\ \text{molar mass} &= 60.1 \text{ g} \end{aligned}$$

The part of the molar mass due to oxygen can be calculated as a percentage of the whole:

Sample Problems: Calculate the percent oxygen in the minerals:

1. Calcite, $CaCO_3$ *[48.0%]*
2. Corundum, Al_2O_3 *[47.1%]*
3. Gypsum, $CaSO_4 \cdot 2H_2O$ *[59.2%]*
4. Hematite, Fe_2O_3 *[30.1%]*
5. Orthoclase (K-feldspar), $K(AlSi_3O_8)$ *[50.1%]*

Humor: On the Fun Side

1. **CHEMTOON**

   S: "You have a glassy look." SiO_2

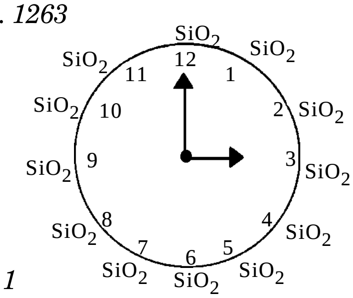
   Chem 13 NEWS, February 1985, p. 16

2. **MNEMONIC DEVICE**

   Osaic—The five most abundant crustal elements of the earth (oxygen, sulfur, aluminum, iron, calcium.

   CHEM 13 NEWS, November 1977, p. 1263

3. This is a HARD one! What is it?



Answer: Rock around the clock!

CHEM 13 NEWS, February 1982, p. 1

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

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

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

1. Silicates are compounds made primarily of oxygen and this element.
2. A gem whose basic mineral is Al_2O_3 with Cr(III) as an impurity.
3. This property of gemstones is characterized by presence of transition elements as impurities.
4. This gemstone is an allotrope of carbon.
5. Most abundant element in the earth's crust, by mass.
6. Inorganic solid of definite composition found in the crust.
7. Silicates have this geometrical arrangement.
8. Rock candy is this organic compound.
9. One of the six basic crystal systems.
10. A lavender flame test identifies this element.

Answers: 1. SILICON 2. RUBY 3. COLOR 4. DIAMOND 5. OXYGEN 6. MINERAL 7. TETRAHEDRAL 8. SUCROSE 9. MONOCLINIC 10. POTASSIUM

5. See cartoons at end of module.

MEDIA

1. The *World of Chemistry* (high school version) videotapes. WINGS for Learning/ SUNBURST, 101 Castleton Street, Pleasantville, NY 10570; (800) 321-7511; (914) 747-3310; (914) 747-4109 (FAX).

   a. "The Chemistry of Earth": reinforcing chemistry topics through examples from geology—solubility, precipitation, equilibrium, and acid-base chemistry applied in explaining mineral deposition and world-wide distribution of ores and silicate minerals; the relationship between chemical structure and macroscopic properties—cave formation and stalactite and stalagmite development; limestone.

   b. "The Atmosphere": Common theory on formation of the atmosphere; the composition today—highlights of some environmental concerns: contaminants being added to the atmosphere, the greenhouse effect, the hole in the ozone layer, the commercial use of CFC's.

   c. "Chemical Bonds": Ionic and covalent bonds defined through graphic illustration—

a comparison of their relative strength in ionic crystals (sodium chloride) and network covalent solids (diamond)—molecular solids; the difference between the strong intramolecular covalent bonds between atoms in a molecule and the weaker intermolecular attractions, such as hydrogen bonds, between molecules.

2. MECC (Minnesota Educational Computer Consortium, St. Paul, MN 55165): "Murphy's Minerals," a computer game to practice skills learned in identifying minerals. (612) 569-1500.

3. Planet Earth Series: A seven-part video series that was first shown on the Public Broadcasting Service in 1986. This series is a rich and exciting investigation of the earth sciences today, a vivid panorama of the planet we call home. Produced by WQED/Pittsburgh, in association with the National Academy of Sciences, this series includes the episodes: "The Living Machine," "The Blue Planet," "The Climate Puzzle," "Tales from Other Worlds," "Gifts from the Earth," "The Solar Sea," and "Fate of the Earth."

   The episode most useful with this topic is "Gifts from the Earth." This program acquaints students with the breadth and variety of the world's natural resources through a story spanning millions of years. Included are segments explaining how mineral-saturated hydrothermal vents on the sea floor ultimately became gold and copper mines on land; about the slow accumulation of fossil fuels; of the ingenious scientists who seek out the secrets of the earth. The formation of metallic elements, minerals—both precious and common—are explored, as well as how these resources influence civilization. One of the handouts, "Minerals in Our Lives," is particularly interesting as it lists 60 common elements and compounds readily available from the earth's crust and describes uses of each. Available from: PBS Video, 1320 Braddock Place, Alexandria, VA 22314. Telephone: (703) 739-5000.

   The episode "The Blue Planet" deals primarily with the influence of liquid water on the surface of the earth, and could also be used in this module.

4. "Gemstones of America," STS Film & Video Productions, P.O. Box 27477, Salt Lake City, UT 84127. A Smithsonian Project, 1991. (801) 263-3959.

5. 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.

6. 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: AP 807

   b. For IBM PS/2 PC-compatible computers: PC 3702

5. Videodiscs 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. "Earth's Atmosphere," "Acid Rain and Limestone" and "Silicates," three chapters on *The World of Chemistry: Selected Demonstrations and Animations*: Disc II (double sided, 60 min.), Special Issue 4.

   b. *The Periodic Table Videodisc* (single side, 30 min.). Special Issue 1.

6. *Gems and Minerals: The Ultimate Rock Video,* available from Smithsonian Laserdisc Collection, Smithsonian Institution, Washington, DC; (202) 357-1300.

Links/Connections

Within Chemistry

Chemical bonding. The study of rocks and minerals reinforces the importance of structure and geometry in determining properties of network substances.

Equilibrium. Equilibrium can be reviewed through study of the crystallization process.

Solubility and precipitation. Growing crystals, particularly in gels, is a vivid illustration of properties of solutions and precipitation phenomena.

Transition elements. Transition elements are frequently responsible for color that makes minerals valuable as gemstones.

Between Chemistry and Other Disciplines

There is a strong connection between the topic of this module and geology.

Gemstones

Gemstones are minerals valued for their beauty including color, transparency, and luster or brilliance. Color is sometimes dependent on crystal structure and bond type, but it most frequently is related to chemical composition. Color is often characterized by the presence of transition elements either directly related to the composition, such as the blue or green of copper-containing minerals or as impurities that impart color to colorless minerals such as quartz.

The basic structures of minerals are frequently silicon oxides, which have already been discussed, or a form of Al_2O_3, corundum. It is a hexagonal closest packed arrangement of O^{2-} ions with Al^{3+} ions in two-thirds of the octahedral holes. The oxide ions are stacked in the A-B-A-B arrangement, and the aluminum ions fall into those holes that allow them to touch six oxide anions. Examples of the gemstones formed are shown below.

Gem	Color	Basic Mineral	Impurity
Ruby	Red	Al_2O_3	Cr^{3+}
Amethyst	Purple	SiO_2	Mn^{3+} or Ti^{2+}
Topaz	Yellow	$Al_2SiO_4(F,OH)_2$	
Blue sapphire	Blue	Al_2O_3	V^{3+} or Co^{3+}
Emerald	Green	$Be_3Al_2Si_6O_{18}$	
Opal	White or colorless	$SiO_2 \cdot nH_2O$	
Jade	Green	$Ca_2Si_8O_{22}(OH)_2$	Mg^{2+} or Fe^{2+}

To the Contemporary World

Personal (including careers)

Study of rocks, minerals and gems will be interesting to those who are interested in careers as geochemists as well as those who pursue "rock hounding" as a hobby.

One area that will almost certainly be emphasized in the future is materials science—extracting and modifying earth materials for practical uses (see *Materials Science* module).

Community

Field Trips

In areas where possible, a trip to a working mine would be valuable. Many cities have rock and mineral displays in museums.

Knowledgeable Individuals

The earth science or geology teacher or local college professor
Rock hobbyists
Members of the local geological society
Lapidarist—a collector or dealer in gems

Other

1. A little item that can be purchased in a toy store and uses the crystallization concept is called the Magic Tree. It uses a cardboard three-dimensional tree and a powdery compound (like copper sulfate) to make crystals grow from an evaporating solution. It is manufactured by New Tomorrow, 7251 Garden Grove Blvd. #E, Garden Grove, CA 92641.
2. An article in *ChemMatters* (published by the Education Division of the American Chemical Society) entitled "Growing Diamonds" (April, 1990, pp. 10-13) describes the crystalline nature of diamond as it relates to graphite and presents some interesting comparisons between the two. In this same issue, the feature "Back Burner" also uses diamonds as its theme.
3. An essay in Aldo Leopold's Sand County Almanac (1966) New York: Oxford University Press is especially fascinating as it describes the way in which an atom, called "X," cycles through the biosphere as a part of a much larger mineral cycle. The essay "Odyssey" is found in Part 2 (pp. 104-108).
4. The October 5, 1990 issue of *Science* (pp. 25-26) has a interesting article about the production of isotopically pure diamond—the best room temperature heat conductor ever made. Controversy between an amateur scientist and General Electric about the origin of the idea is described.
5. Mica is a sheet silicate that can be cleaved to make large translucent sheets. These sheets were used as window closures prior to the advent of plate glass.
6. The brilliance of gemstones depends largely on their high refractive index. Because diamond's refractive index is so large, light rays exhibit such small angles of refraction that the rays often fail to leave the material, but will be reflected back into it. This phenomenon is known as total reflection. It can be achieved in a diamond if the stone is properly cut. When a diamond exhibits total reflection, none of the light entering the face of the stone will be able to escape out the back, but will be totally reflected back to the face, imparting a brilliance and sparkle to diamond that has only been matched recently by synthetic gems of almost equally high refractive index.

Extensions

1. Long-term growth of crystals and comparison of crystal shapes.
2. Have students do a written or oral report on their birthstone. Identify its composition and the origin of the stone's color (see *References*). Discuss the crystal system to which the stone belongs (see Figure 4). (Idea from Angie Matamoros.)
3. Concrete can be made in the laboratory and provides excellent practice in controlling variables. It is, however, a messy procedure, and students must be cautioned about spilling the ingredients on equipment and clothing and about pouring cement containing wastes in sinks. A convenient ratio is 14.5 g cement, 41 g sand, 57 g gravel, and 11.5 g water. Use disposable containers such as paper cups or coffee cans. The materials must be stirred while mixing and allowed to stand several days. The concrete can be analyzed, and other combinations may be tried. More complete instructions are available in the written materials accompanying "Chemical Kinetics" (Program 7) The World of Chemistry, High School Version, Wings for Learning, 1600 Green Hills Road, P.O. Box 660002, Scotts Valley, CA 95067-0002.
4. **A Chemist's Map of the United States**

   Examine "A Chemist's Map of the United States" (see the transparency master in the *Appendix*). List all cities that describe the solid state.
5. **A Chemist's Map of Your State**

   Refer to a detailed Atlas of the United States, selecting your state map. Find and make a list of site names associated with chemistry. Prepare an outline sketch of your state map, situating the sites at appropriate points on the map.

References

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

Aereszko, L. S. (1987). Rock candy in a cellophane bag. *Journal of Chemical Education, 64*, 804.

Baer, C. D. (1990). The growth of large single crystals. *Journal of Chemical Education, 67*(5), 410-412.

General instructions and discussion for easy growing of crystals. Tables of suggested chemicals and of crystal systems.

Bartlett, D., and Aguila, E. (1987). Teaching the concepts of metallurgy through the use of postage stamps. *Journal of Chemical Education*, *64,* 526-528.

Booth, M., and Lamb, W. (1983, October). Crystal growing [Experimenter's notebook]. *ChemMatters, 1*(3), 12.

Detailed recipe for making Rock Candy.

Davenport, D. (1990). Burning diamonds and squeezing peanuts [Back burner]. *ChemMatters, (8)*2, 14-15.

A historical perspective on diamond synthesis.

Davenport, D. (1983, October). Brooklyn bridge, the structure of metals, and footprints in the sand [Back burner]. *ChemMatters, 1*(3), 14-15.

A fascinating discussion of atomic packing in crystals and its consequences. This issue is filled with crystal articles.

Finkbeiner, A. (1984). Starborn: The origin of elements. *ChemMatters, 2*(3), 6-7.

A nice review of cosmology, tracing the nuclear reactions to convert hydrogen, eventually, into all of the elements.

Holden, A., and Singer, P. (1960). *Crystals and crystal growing*. Garden City, NY: Doubleday.

Holtzman, D. (1987, October). Superconductivity. *ChemMatters, 5*(3), 18-21.

An introductory historical and theoretical discussion of superconductivity.

Hostettler, J. D. (1985). Geochemistry for chemists. *Journal of Chemical Education*, *62*, 823-831.

Kilday, C. (1987, October). Super-student conductors. *ChemMatters, 5*(3), 22-23.

Report of and recipe for high school laboratory synthesis of $YBa_2Cu_3O_7$ superconductor.

Lamb, W. (1984, April). Liquid crystal displays. *ChemMatters, 2*(2), 10-11.

A discussion of the design of LCD's and the molecule that makes them "tick."

Leopold, A. (1966). *Sand County almanac*. New York, NY: Ballantine Books.

Loeffler, B. M., and Burns, R. G. (1976, November-December). Shedding light on the color of gems and minerals. *American Scientist*, *64,* 636-647.

A discussion to how the absorption of light gives minerals their distinctive hues.

Marshall, E. (1990, October). GE's cool diamonds prompt warm words. *Science*, (250), 25-26.

Meadows, R. (1988, April). Fossil molecules. *ChemMatters, 6*(2), 4-7.

The article details the use of radioimmunoassay to compare fossil bone collagen in order to make evolutionary links and authenticate fossil remains.

Noguchi, T. T. (1985, December). The wrong knife, mystery matters. *ChemMatters, 3*(3), 14.

A brief account of how a medical examiner prepares a cast of a knife wound to recreate the weapon.

Phillips, D. B. (1988). A rapidly growing silicate crystal. *Journal of Chemical Education, 65,* 453–454.

Reese, K. M. (1990, October 22). Radar used to seek bodies. *Chemical and Engineering News, 68,* 68.

Ground Probing Radar can be used to map underground rock strata and find buried bodies.

Robson, D. (1983, December). Liquid crystals. *ChemMatters, 1*(4), 8-11.

A general review of classifications, theory and applications of liquid crystals, especially Kevlar polymer.

Seib, S. L. (1985). Crystal growth in gels. *Journal of Chemical Education, 62,* 81-82.

Sharbaugh, A. H., III, and Sharbaugh, A. H., Jr. (1989). Crystal growth in silica gel, an experimental study of the Liesengang phenomena. *Journal of Chemical Education, 66,* 589–594.

Sinkankas, J. (1964). *Mineralogy* (currently in 12th printing). New York, NY: Van Nostrand Reinhold Co., Inc.

Tanis, D. (1984, February). Underground sculpture. *ChemMatters, 2*(1), 10-11.

The chemistry and mechanism of stalactite formation is outlined.

Viola, V. E. (1990). Formation of the chemical elements and the evolution of our universe. *Journal of Chemical Education, 67,* 723–730.

Walker, L., and Lee, P. J. (1990). The rocky road to chemistry. *Journal of Chemical Education, 67,* 325–326.

Yamana, S. (1987). Cubic close packed structure model. *Journal of Chemical Education, 64,* 1040.

Zaug, H. (1990). Growing diamonds. *ChemMatters, (8)*2, 10-13.

Discusses the structure of diamond, the history of its synthesis and details of new techniques for low pressure growth.

Some periodicals of interest for rockhounds and earth science teachers (suggested by Leonard Himes):

Lapidary Journal. Devon Office Center, Suite 201, 60 Chestnut Avenue, Devon, PA 19333-1312.

General interest and hobbyist articles on jewelry, gems, minerals, fossils, and collecting localities. Calendar of mineral and gem shows (monthly).

Gems and gemology. 1660 Stewart Street, Santa Monica, CA 90404.

Discussion of state-of-the-art gemological techniques, new gemstones, and gem locality information. Written for the practicing gemologist. Many good semi-technical articles (quarterly).

Earth. 21027 Crossroads Circle, Waukesha, WI 53187.

General interest articles, written for the public, on structural and historical geology, oceanography, and meteorology as well as fossils, rocks, and minerals (monthly).

Colored stone. Devon Office Center, Suite 201, 60 Chestnut Avenue, Devon, PA 19333-1312.

Discusses new gemstones and identification problems, business trends, and reports. Some background articles on gemstone minerals and mining. Written for commercial jewelers (bimonthly).

The mineralogical record. P.O. Box 35565, Tucson, AZ 85740.

Mineralogy of worldwide localities, news of mineral collectors and museums, show reports, columns, and commentary. Written for advanced level collectors and mineralogists (bimonthly).

Rocks & minerals. 1319 Eighteenth Street, N.W., Washington, DC 20036-1802.

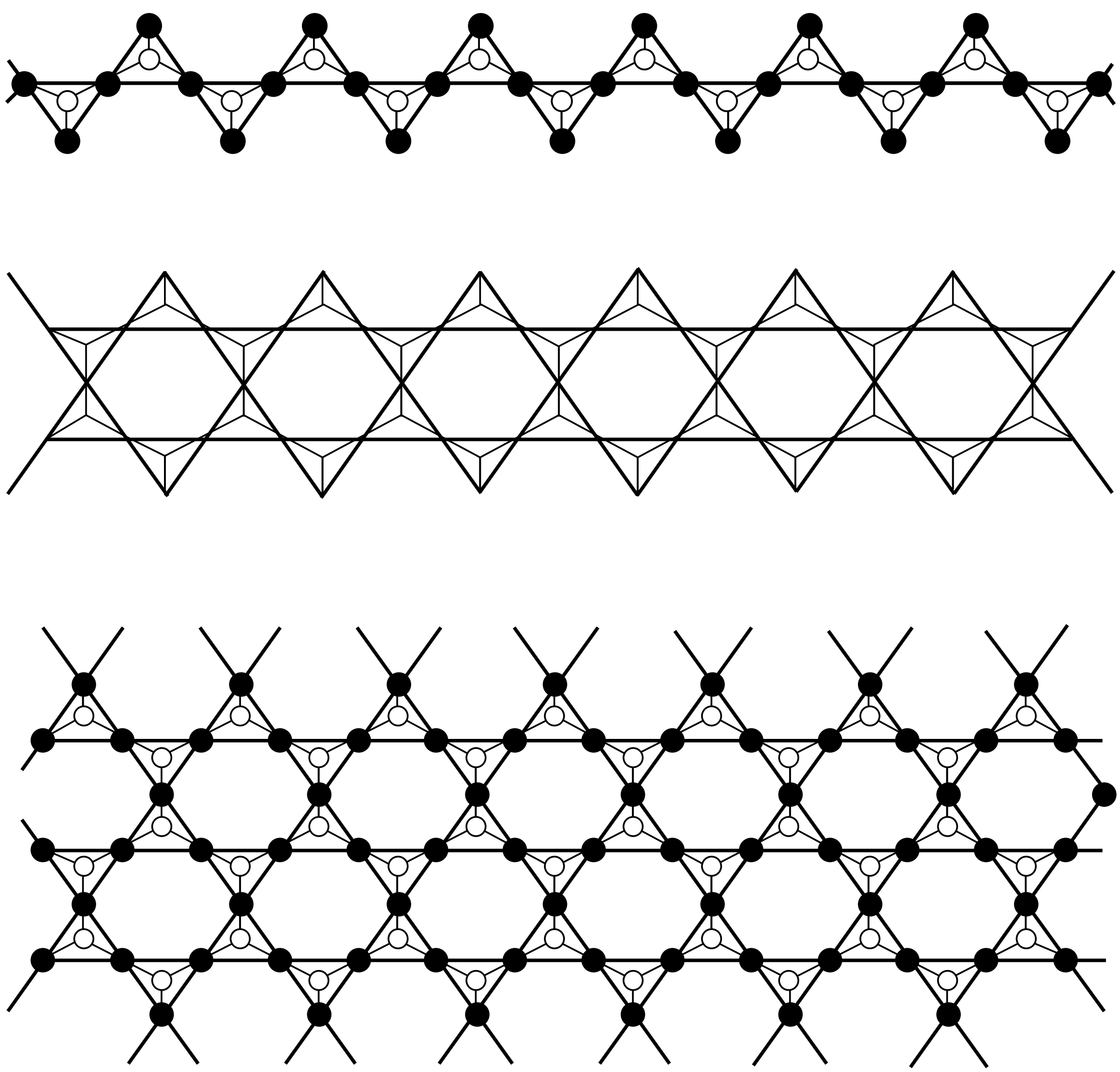
Mineralogy, paleontology, and geology oriented article and news information of interest to collectors. Includes columns and calendar of events. Education is a central theme of this publication (bimonthly).

Needless to say, there are plenty of introductory texts on mineralogy and geology, all of which would be helpful to teachers. The magazines listed above also list and review books that are (often) less technical. There are many field guides (Audubon, Peterson, *etc.*) that are available in any mall bookstore for teachers who wish to enrich their basic knowledge.

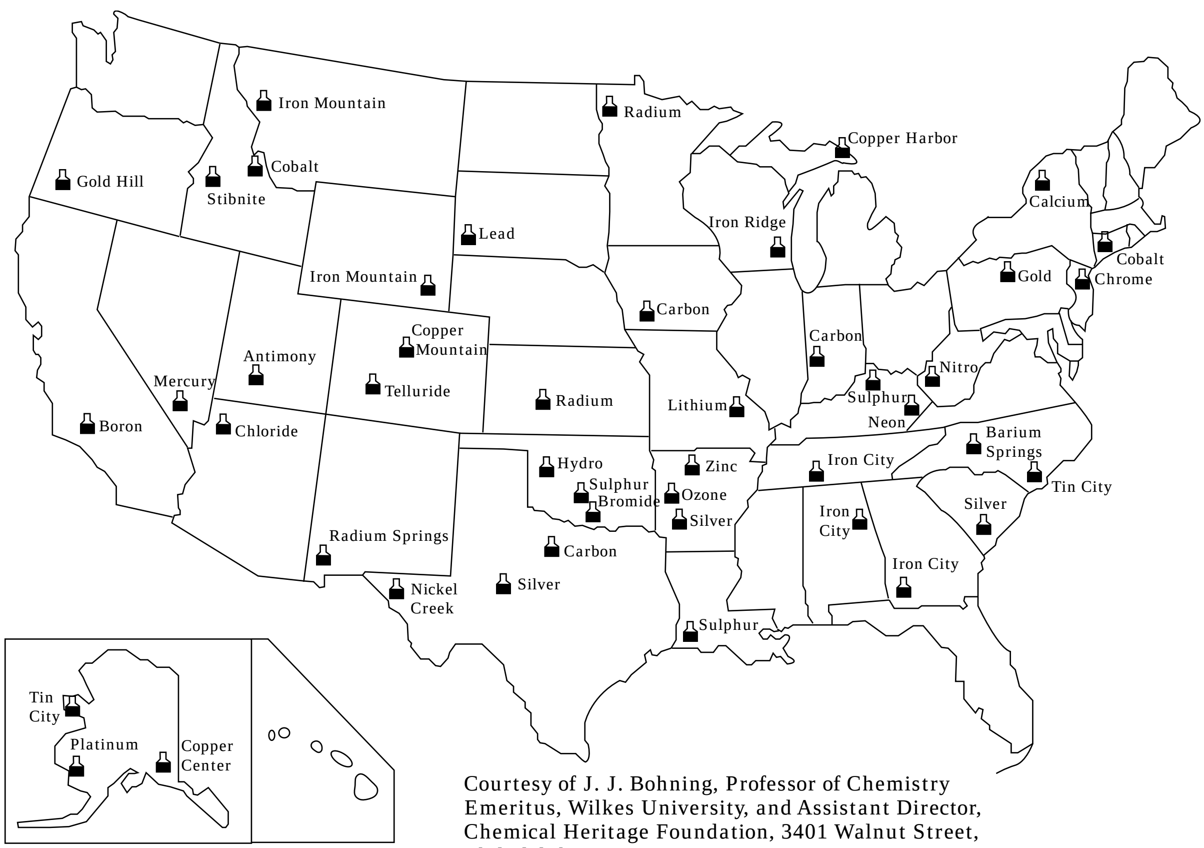
Appendix

- **Transparency Masters**
  1. Structures for SiO_3^{2-}, $Si_4O_{11}^{6-}$, and SiO_x
  2. A Geological Periodic Chart
  3. Word Search
- **Humor**

Structures for SiO_3^{2-}, $Si_4O_{11}^{6-}$, and SiO_x



A Geological Periodic Chart



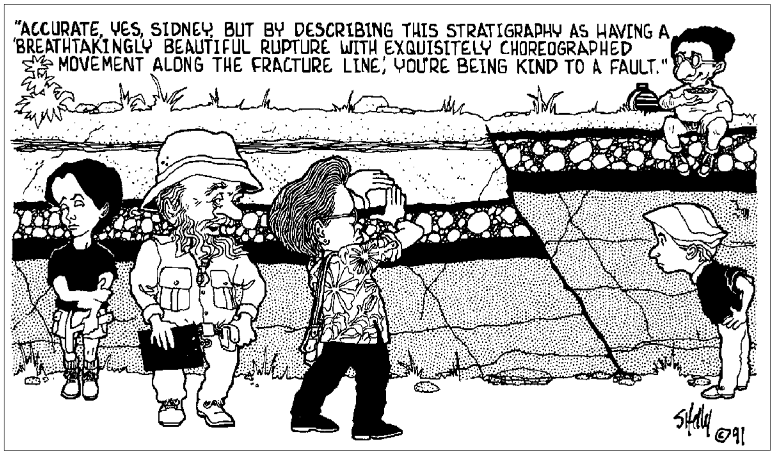
Courtesy of J. J. Bohning, Professor of Chemistry Emeritus, Wilkes University, and Assistant Director, Chemical Heritage Foundation, 3401 Walnut Street, Philadelphia, PA 19104-6228

Word Search

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

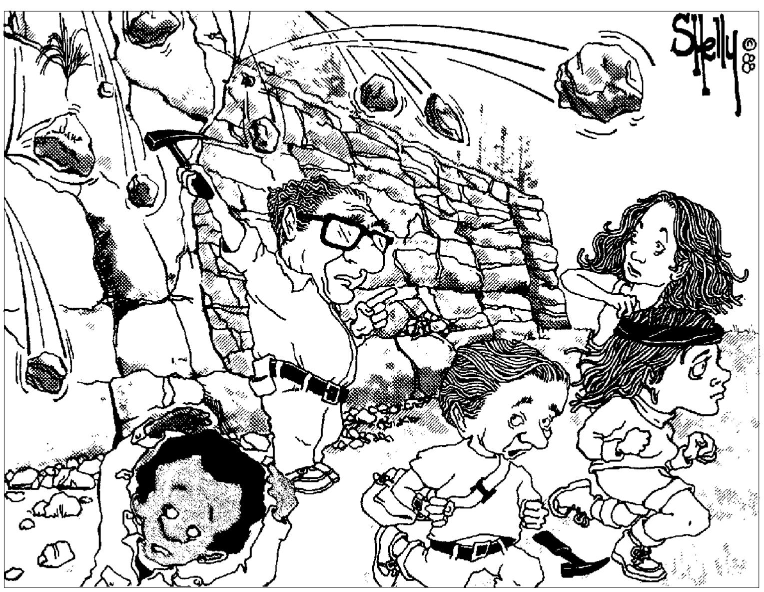
Words about concepts in this module can be obtained from the clues given. Find these words in the block of letters:

1. Silicates are compounds made primarily of oxygen and this element.
2. A gem whose basic mineral is Al_2O_3 with Cr(III) as an impurity.
3. This property of gemstones is characterized by presence of transition elements as impurities.
4. This gemstone is an allotrope of carbon.
5. Most abundant element in the earth's crust, by mass.
6. Inorganic solid of definite composition found in the crust.
7. Silicates have this geometrical arrangement.
8. Rock candy is this organic compound.
9. One of the six basic crystal systems.
10. A lavender flame test identifies this element.



Cartoon by Shelly Fischman. Reprinted with permission.

"NOW WHO CAN TELL ME IF THIS MASS WASTING IS A ROCK FALL, DEBRIS SLIDE, ROCKSLIDE, DEBRIS FALL......"



Cartoon by Shelly Fischman. Reprinted with permission.

Danylo Shepelavy, U Penn, 1993.
Reprinted with permission.