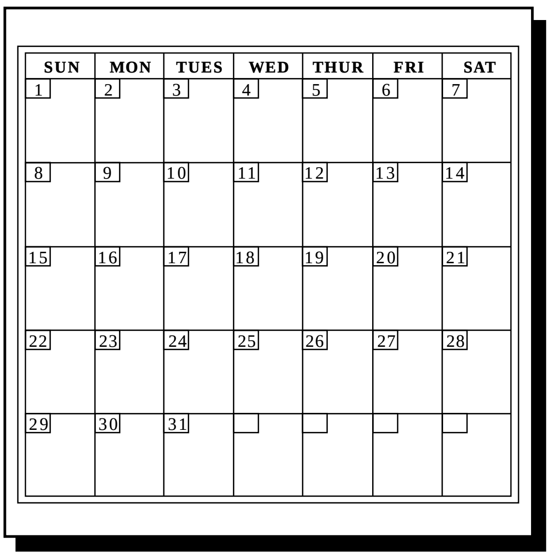
A SourceBook Module

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



PERIODICITY

ChemSource

Instructional Resources for Preservice and Inservice Chemistry Teachers

Topic Overview

Content in a Nutshell

Elements, the building blocks of everything in the universe, have a bewildering array of properties. It would be intimidating for chemists, and chemistry students to keep track of the properties of the elements and their compounds if it were not for some common characteristics allowing the elements to be grouped. Elements have periodic properties. This means if the elements are arranged in order of increasing atomic number, common properties occur at regular intervals (or cycles). The Periodic Table, found in most chemistry textbooks, is a two dimensional matrix or classification scheme based on this principle. In general, elements in the same column (or family) have similar properties. These properties vary as one goes across a row (or period) of the table. A knowledge of the format of the Periodic Table is an aid to predicting and remembering a vast amount of descriptive chemistry. This is one important reason for studying periodicity.

Two aspects in studying the Periodic Table are: (1) similarity of properties found in columns of chemical elements, and (2) trends in properties down a column or across a row of the table. Remember, however, that the concepts of periodicity are only a first approximation describing general characteristics. There are limits to periodicity. Not all properties show periodic trends, and not all families show similarities in properties. Some of the families are more representative for purposes of comparison. These are the first two and last three columns of the table. As one nears the center of the table, family characteristics become cloudy and unpredictable. This unpredictability occurs due to the complexity of electronic structure of these central elements. Consequently, linking electronic structure to chemical properties is a central emphasis of the study of periodicity. This is an important theoretical theme in chemistry and another important reason for studying periodicity.

As a classification scheme, the Periodic Table can be divided into a number of groups based on properties and electronic structure. Important ones are listed below with reference to Figure 1.

1. Hydrogen is considered as a group of one element because of its unique properties.
2. A diagonal stepped line (bold) divides the table into two unequal parts. Elements to the right of and above this line (as circled in the diagram) are **nonmetals** Elements to the left of and below the line are **metals**. Many elements adjacent to this line (*e.g.*, Si and Ge) have both metallic and nonmetallic properties (such as semiconductivity) and are called **metalloids**
3. The columns labelled p^1 through p^6 are called the *p*-block because the last valence electron enters a *p* orbital. This block contains families called the halogens (Column p^5) and the noble gases (Column p^6).
4. The columns labeled s^1 (the family named the alkali metals) and s^2 (the family named the alkaline earth metals) are called the *s*-block because the last valence electron enters an *s*-orbital. The circled Groups 3 and 4 on the diagram (the *s*- and *p*-blocks), when taken together, are called the **representative elements**
5. This is the *d*-block or **transition elements** The columns are labelled d^1 through d^{10} because the last valence electron enters a *d*-orbital.
6. This grouping is labeled the *f*-block. This block contains the **lanthanides** or rare earth elements (top row) and the **actinides** (bottom row). The columns are labeled f^1 through f^{14}. This block is sometimes grouped with transition elements.

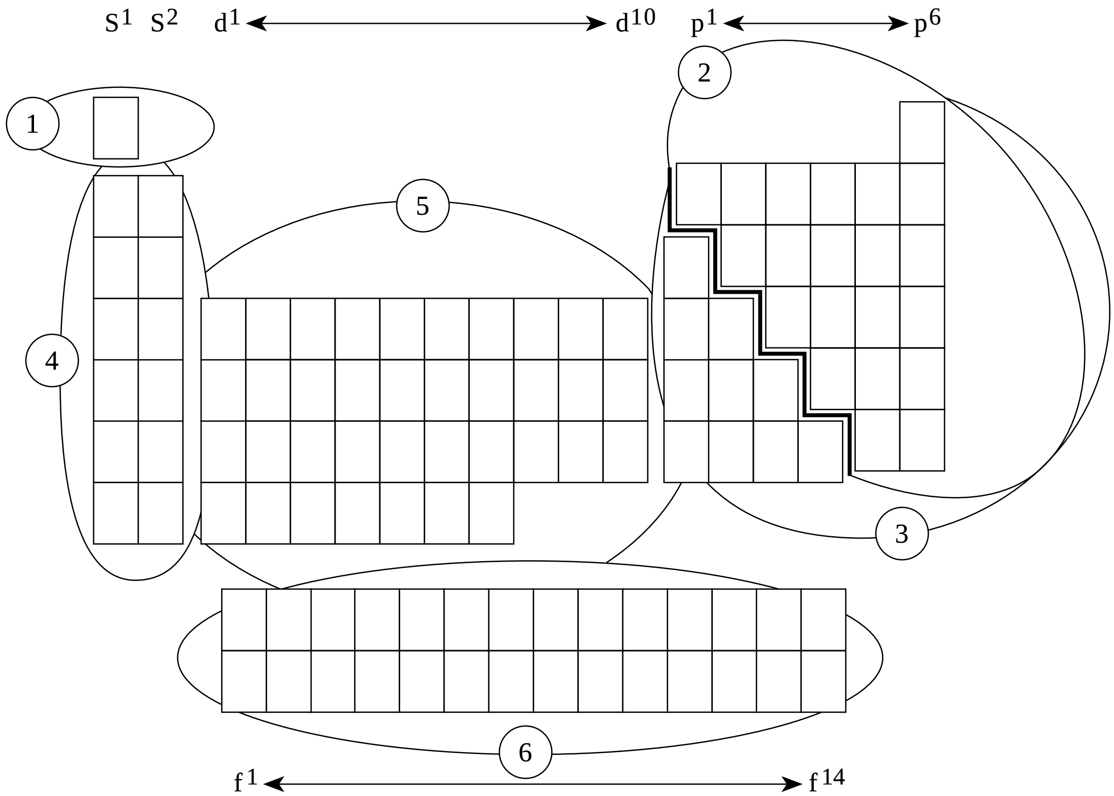


Figure 1. Divisions of the Periodic Table.

There are several ways of referring to the columns (groups or families) in the Periodic Table. In 1923, H.G. Deming published a popular chemistry text with a periodic table that eventually evolved into the long-form Periodic Table that we use today. In 1928, Merck and Company produced a convenient notebook form of the Table that was widely distributed in schools and eventually became the universally accepted Periodic Table in the United States. Deming numbered the columns of the representative elements with Roman numerals and an "A" designation. For example, he labeled the alkali metals Group IA, the alkaline earth Group IIA, the group headed by boron IIIA, *etc.* He labeled the transition elements with a "B" designation, so that the scandium group became IIIB, the titanium Group IVB, *etc.* This notation proved satisfactory to chemistry teachers for many decades because it was so easy to distinguish between the representative elements and the transition elements.

Meanwhile, European chemists adhered to a different designation for the Periodic Table columns. The Roman numerals and A and B designations were present but applied differently. European numbering simply went across the Table in sequence. Alkali metals were IA, alkaline earths were IIA, and the scandium group was IIIA. Continued numbering across the transition elements resulted in the copper group being designated IB, the zinc group IIB, and the boron group IIIB,*etc.* While Roman numerals continued to correspond to the outer electron structure of the elements within each group, the European scheme did not allow for the neat, clean distinction between the representative and transition elements. In 1970, the International Union of Pure and Applied Chemistry (IUPAC) recommended worldwide adoption of the European system. This recommendation spawned a great deal of confusion when some textbook publishers began to follow the IUPAC notation, and others continued to use the Deming notation.

In an attempt to bring some uniformity to the way in which the elemental groups were designated in the Periodic Table, the American Chemical Society (ACS) Division of Inorganic Chemistry Nomenclature Committee proposed a simple 1-18 (with a *d* designation for Groups 3-12) numbering scheme for the eighteen columns in the Periodic Table. This proposal was accepted as the official ACS form of the table in 1983. While the ACS solution eliminated ambiguity, the advantage of the group number corresponding to the number of valence electrons vanished.

American chemical educators continue to favor the Deming notation. Textbook publishers, in many instances, continue to cater to this preference. The result is a hodgepodge of Periodic Table numbering schemes. Many textbooks number the representative elements columns in the Periodic Table from 1 to 8, and don't number the transition element columns at all. The only way to really be safe is to cover all the bases and include all of the numbering schemes at the top of the Periodic Table, or to omit column numbering altogether. *SourceBook* editors have made the latter decision.

Place in the Curriculum

Periodicity and selected elements of the Periodic Table are usually taught in conjunction with and just after a consideration of the electronic structure of the atom in beginning chemistry courses. It is sometimes reintroduced in support of other subjects (especially those involving descriptive topics). Usually, representative elements are emphasized in an introductory module on periodicity because their properties are more predictable and the *s* and *p* valence electrons, which account for these properties, are easier to discuss theoretically. The properties of transition elements and the lanthanides and actinides depend in part on *d*- and *f*-electrons. Although a systematic study of these elements is usually not taught at the high school level, the *Transition Elements* module describes some of their properties.

Central Concepts

1. Elements can be organized into a two dimensional matrix (periodic table) by arranging them in order of increasing atomic number.
2. Elements in a given column (family or group) of the Periodic Table show similar (related) properties.
3. Elements in columns (families or groups) and rows (periods) of the Periodic Table show trends in chemical and physical properties.
4. Elements in families and periods of the Periodic Table show trends in atomic properties (*e.g.*, atomic size).
5. Physical and chemical properties and an element's position in the Periodic Table can be related to electronic structure.

Related Concepts

1. **Atomic Structure**
   a. Atoms are composed of a nucleus (containing protons and neutrons) and surrounding electrons. Electrons, though of little relative mass, are found in orbitals that occupy most of the atomic volume.
   b. Electrons occupy specific energy levels in an atom. Energy levels are quantized and are described by shells, subshells, and orbitals.
   c. Orbital occupancy of a multi-electron atom is given by its electron configuration.
2. **Bonding**
   a. Electrons at the highest occupied energy level in an atom in its ground state determine the atom's chemical properties and are called valence electrons.

b. Atoms may form aggregates and gain stability by sharing an electron pair between them, thus forming a covalent bond.

c. A metal atom and a nonmetal atom may form a stable structure by transferring of electrons from the metal atom to the nonmetal atom. This transfer forms oppositely charged particles called ions resulting in a structure held together by ionic bonds.

d. Valence electrons are arranged around the kernels of atoms, forming molecules. Valence electrons can be represented as dots, yielding structures (Lewis-dot structures) consistent with the octet rule.

3. **Acids and Bases** (see *Acid-Base* module)
   a. Acids and bases are chemical species that exhibit different characteristic chemical properties.
   b. Acids are characterized conceptually as releasing H^+ ions and bases as releasing OH^- ions in water solution (Arrhenius Theory).
4. **Alkali Metals**
   a. Properties of alkali metals can be generalized in terms of chemical periodicity.
   b. Chemistry of alkali metals is based on the oxidation states 0 and +1.
5. **Halogens** (see *Halogens* module)
6. **Transition Elements** (see *Transition Elements* module)

RELATED SKILLS

1. **Chemical Skills**
   Write the name and symbol of common elements.
2. **Laboratory Skills**
   a. Use tests for common gases, especially H_2(g).
   b. Use common acid/base tests.

PERFORMANCE OBJECTIVES

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

1. Explain trends and patterns in ionization energies of elements within families and periods of representative elements.
2. Explain trends and patterns in the sizes of elements within families and periods of representative elements.
3. Explain trends and patterns in the sizes of ions within families and periods of representative elements.
4. Predict relative sizes of atoms and ions in families and periods of representative elements not listed in the data tables given to students.
5. Explain the relationship between electron arrangement and location of elements in the Periodic Table.
6. Describe the nature of periods and groups (or families) in the Periodic Table.
7. Identify an element as an alkali metal, alkaline earth metal, halogen, or noble gas.
8. Identify an element as belonging to the *s*-, *p*-, *d*- or *f*-block in the Periodic Table.
9. State general and comparative reactivity trends for elements within a family of representative elements.
10. State general reactivity trends for representative elements within a given period.

Concept/Skills Development

Laboratory Activity: Student Version

Activity 1: Comparing the Reactivity of Aluminum, Calcium, Magnesium, and Sulfur with Water and Dilute Acid

Introduction

Reactivity, or the ease with which an element will react chemically, can be compared by observing reaction rates. You will experiment with several elements in combination with distilled water and then with dilute hydrochloric acid to determine the comparative reactivities of the elements. Your teacher may demonstrate the reactions of several other elements to add to those you investigated in the laboratory.

Purpose

To determine if any relationship exists between the placement of the selected elements on the Periodic Table and their chemical reactivities.

Safety

1. Wear protective goggles throughout the laboratory activity.
2. Use care in handling the solids. Pick up your samples with forceps to prevent possible chemical burns.
3. Be sure to cover beakers with watch glasses while observing the reactions.
4. Dispose of the reaction products and any remaining solid elements as your teacher directs.

Procedure

1. Pour about 5 mL of distilled water into an 18- x 150-mm test-tube. Test the water with litmus or pH paper before adding the solid, and before disposing of the test-tube contents. Add a piece of aluminum metal (Al) to the water.
2. Observe the system for 1-2 min, and record any evidence of chemical reaction. *NOTE: Heating a system sometimes speeds up a reaction. (Heating can be performed by placing your test-tube in a hot water bath.) If no change (or little change) is noticed after 1-2 min, heat the system for one minute, and record your observations.*
3. If there is evidence that a gas is being produced, test the gas with a burning splint (for H_2) or with a glowing splint (for O_2).
4. Dispose of the residue of this system as directed by your teacher.
5. Repeat Steps 1-3 separately using calcium, magnesium, and sulfur. Record your observations.
6. Perform similar tests on each of the elements using about 30 mL of dilute hydrochloric acid (HCl). Record observations of each system. Test the acid solution with litmus or pH paper before adding the solid, and before disposing of the contents.
7. Record your observations in the data tables.
8. Thoroughly wash your hands before leaving the laboratory.

Observations

Solids	Litmus or pH test before H_2O	Without heat	With heat	Test for H_2	Test for O_2	Litmus or pH test after reaction
Mg						
Ca						
Al						
S						

Solids	Litmus or pH test before HCl	Without heat	With heat	Test for H_2	Test for O_2	Test for Cl_2	Litmus or pH test after reaction
Mg							
Ca							
Al							
S							

Data Analysis and Concept Development

In interpreting the observations, the following chemical facts are needed:

H_2 gas will burn rapidly in air; O_2 and Cl_2 gas will not. O_2 gas will support burning; a glowing splint thrust into O_2 will burst into flame. Cl_2 gas has a choking odor. A burning splint thrust into H_2 gas will cause an explosion.

1. List the elements that reacted with water in order of most to least vigorous.
2. List the elements that reacted with acid in order of most to least vigorous.
3. Compare the element order in the two lists.
4. Using the reactivity position of elements on your list, deduce any patterns you find between reactivity and element position on the Periodic Table.

Implications and Applications

1. Write balanced equations for all reactions observed between elements and water.
2. Write balanced equations for all reactions observed between elements and hydrochloric acid.
3. What chemical similarities are there between reactions of elements with water and elements with acid?
4. How would you explain the difference in reactivity between an element in water and an element in acid?
5. Using the results of your activities, how would you expect the reactivity of gallium (Element 31) to compare to the reactivity of aluminum, if both elements were placed in dilute hydrochloric acid? Explain your response.
6. State how you would expect strontium metal (Element 38) to react with water. Explain your reasoning.

LABORATORY ACTIVITY: TEACHER NOTES

Activity 1: Comparing the Reactivity of Aluminum, Calcium, Magnesium, and Sulfur with Water and Dilute Acid

Major Chemical Concept

Chemical reactivity of representative elements can be related to the element's position on the Periodic Table. This relationship is shown by reactions observed between several elements with water and dilute hydrochloric acid.

Level

General and Honors

Expected Student Background

1. Experience with observational evidence for chemical change.
2. Knowledge of atomic theory, electron structures of elements, and common ions.
3. Ability to write balanced equations given the reactants for reactions observed.
4. Knowledge of alkali metal reactivity trends, if possible. Do *Demonstration 1* (The Relative Reactions of the Alkali Metals) in combination with this activity.

Time

Two full class periods will be needed to perform the activity and discuss the results, if *Data Analysis and Concept Development* and *Implications and Applications* sections are assigned as homework. If this arrangement is not feasible, three to four class periods will be required.

Safety

1. Direct students to hold test-tubes with wire test-tube holders, and set test-tubes in a rack when not holding them.
2. If students wish to test the gas emitted for flammability, direct them to point the mouth of the test-tube away from themselves and other people.

Materials (For 24 students working in pairs)

12 Test-tubes, 18- x 150-mm
12 Wire test-tube holders
12 Forceps or tongs
12 Laboratory burners, ring stands, and wire gauze
12 Beakers, 250-mL
24 Pieces of aluminum shot (large pea size) or turnings
24 Strips of magnesium ribbon, 10-cm each (large pea size, when rolled tightly)
24 Pieces of lump sulfur (large pea size)
Calcium turnings (Ca oxidizes in air. Use of "old" Ca that has not been kept in an airtight container might not react at first until the protective oxide layer has been soaked through.)
Distilled water
6 M Hydrochloric acid, HCl, 2 L (Dilute 1000 mL conc HCl to 2000 mL total volume with distilled H_2O)
12 Test-tubes, 13- x 100-mm (for gas testing)
Red and blue litmus paper and/or pH paper

Advance Preparation

1. The metals and sulfur should be prepared and placed in labeled containers. Element samples should be of comparable size and conformation. You may wish to have students make a tight coil of the magnesium ribbon samples.
2. It is advisable to perform the activity prior to the class in which students perform the activity.

Pre-Laboratory Discussion

1. Review safety guidelines.
2. Although students are expected to decide what reactions occur and what products are obtained, suggest testing solutions with litmus paper and testing any gases produced for flammability. If so, review the method for collecting and testing gases, but do not tell them what gas to expect. Demonstrate tests for oxygen, hydrogen, and carbon dioxide gases. Refer to the *Identification of Gases* table in the *Appendix*.
3. Instruct students how to dispose of residues from the systems. Remind them to clean the beakers between tests.
4. *Demonstration 1* can be done prior to this activity. Students can then include Li, Na, and K in their set of elements for analysis.

Teacher-Student Interaction

Monitor student experimentation to ensure safety and correctness of procedure. Some students will be unsure if a reaction occurs in some systems. For example, gas bubbles may appear on the surface of solids, even though a strong reaction is not observed. In such cases suggest students tap the test-tube to loosen the gas from the solid and watch to see if more bubbles form. Students, however, should be allowed to determine whether or not a reaction occurred.

Anticipated Student Results

This chart summarizes the expected results. All the observed reactions involve evolution of hydrogen gas.

	H_2O	HCl
Al	N.R.	Reacts strongly
Ca	Reacts	Reacts violently
Mg	N.R.	Reacts very strongly
S	N.R.	N.R.

Answers to Data Analysis and Concept Development

1. Calcium. (No reaction occurred with the other three elements.)
2. Calcium, magnesium, aluminum, sulfur (no reaction)
3. Calcium is the most reactive in each set of data, but comparisons of the other elements can only be made by reacting them with acid.
4. Magnesium, aluminum, and sulfur are all in Period 3 of the table. Magnesium is more reactive than aluminum, and aluminum is more reactive than sulfur when combined with dilute acid. Magnesium and calcium are in the same family (column); data show calcium is more reactive than magnesium.

Answers to Implications and Applications

1. $Ca(s) + 2H_2O(l) \rightarrow Ca(OH)_2(s) + H_2(g)$

   $Mg(s) + H_2O(l) \rightarrow$ N.R.

   $Al(s) + H_2O(l) \rightarrow$ N.R.

   $S(s) + H_2O(l) \rightarrow$ N.R.

2. $Ca(s) + 2HCl(aq) \rightarrow CaCl_2(aq) + H_2(g)$

   $Mg(s) + 2HCl(aq) \rightarrow MgCl_2(aq) + H_2(g)$

   $2Al(s) + 6HCl(aq) \rightarrow 2AlCl_3(aq) + 3H_2(g)$

   $S(s) + HCl(aq) \rightarrow$ N.R.

3. When calcium reacts with water, there is a single displacement of hydrogen from water and the formation of hydrogen gas. This is an oxidation-reduction reaction; the calcium is oxidized and the hydrogen is reduced. The reaction is exothermic. Reactions of calcium, magnesium, and aluminum with acid share all the characteristics listed for calcium and water. One interesting difference between the calcium with water and calcium with acid reactions is that calcium reacts with water, forming a precipitate, but no precipitate forms in the reaction of calcium with acid. This difference is due to the low solubility of $Ca(OH)_2$, and the high solubility of $CaCl_2$ in water.
4. In all reactions hydrogen ion is reduced. Since the concentration of the hydrogen ion is much greater in acid than in water, and since increased concentration of reactants generally increases reaction rate, the reactivity of elements with acid is greater than it is with water. Sulfur reacted with neither water nor acid.
5. Gallium is listed directly below aluminum on the Periodic Table. Calcium was more reactive than magnesium, and it is located below magnesium. Since calcium, magnesium, and aluminum react by losing electrons (that is, oxidize) in these reactions, it would be reasonable to assume a similar type of reaction by gallium with acid. Calcium's two valence electrons are in the fourth energy level, whereas the two valence electrons of magnesium are in the third energy level. The higher reactivity of calcium can be explained, if one assumes that calcium's valence electrons are attracted less strongly than magnesium's because those of calcium are farther away from the attractive force of the nucleus. There are also more inner shell electrons to shield the nucleus. Given a similar situation in the comparison of electron arrangements of aluminum and gallium, one predicts that gallium will be more reactive than aluminum.
6. Strontium reacts more vigorously with water than calcium for the same reasons.

Post-Laboratory Discussion

A class discussion of the laboratory activity is essential. You may wish to base the discussion on student responses to the *Data Analysis and Concept Development* and the *Implications and Application* sections. Students' learning will be enhanced if they generate the answers to these questions, while you lead them with oral questions related to the way students are thinking about data obtained and questions asked in the *Student Instructions*.

Extensions

1. Perform *Demonstration 1* with the class, if this demonstration has not been performed already.
2. *Activity 2: Trends in Oxy-Hydrogen Compounds of Third Period Elements* is a valuable and reasonable extension to this laboratory activity.
3. *Activity 2* in the *Halogens* module involving the comparative reactivity of the halogen elements produces an important set of data that can be used to deduce periodic trends for nonmetallic elements.
4. Included in the *Group Activities* section of this module are data that can be graphed and the graphs used to deduce periodic patterns and trends for ionization energies, atomic sizes (radii), and ionic sizes (radii) for selected elements.

Assessing Laboratory Learning

1. Based on electron arrangements and common ions formed in chemical reactions, explain how the reactivity of sodium metal would compare to the reactivity of magnesium metal. *[Sodium and magnesium both have the third energy level as their valence level. Neutral atom electron arrangements are: Na (2-8-1), and Mg (2-8-2). Since Na has one electron removed to become* Na^{+} *and Mg has two electrons removed to become* Mg^{2+}*, and the number of inner shell shielding electrons is the same for both, sodium should be more reactive. Further support for the argument is that the attraction of sodium's nucleus for electrons is caused by eleven protons, while magnesium has twelve protons in its nucleus.]*
2. What reactivity trend would you expect to find in the alkali elements, starting with lithium and going down the column? Explain your reasoning. *[The reactivity should be greater, as one goes from element to element down the column. Each of these elements reacts by having one electron removed from it. With each successive element, the distance of the valence electron from the nucleus increases by one energy level and electron shielding increases. These factors combine to make removal of the valence electron easier, and reactivity increases.]*
3. Based on your study of reactivity so far, how would you expect reactivities of lithium, beryllium, and boron to compare? Explain your reasoning. *[Lithium should be most reactive, followed by beryllium, and then boron. Lithium needs to have only one electron removed, while beryllium needs two electrons removed, and boron would have to have three electrons removed. These would be expected to follow the same pattern as their third period analogues, but should be less reactive because their valence electrons are closer to their nuclei and have less inner shell electron shielding. NOTE: This pattern is not observed as clearly, in actuality, as the pattern for the third period analogues.]*

LABORATORY ACTIVITY: STUDENT VERSION

Activity 2: Trends in Oxy-Hydrogen Compounds of Period 3 Elements

Introduction

Arrangement of elements in the Periodic Table can be used to establish interesting and important generalizations about chemical behavior. This laboratory activity will provide you with data leading to such a generalization.

Purpose

To use litmus and conductivity tests to determine properties of some oxy-hydrogen compounds of Period 3 elements.

Safety

1. Wear protective goggles throughout the laboratory activity.
2. Handle solutions with care. If you spill any solutions on your table or the floor, wipe up the spill and rinse the area with tap water.
3. If you should get any solution on your skin, flush the affected area with plenty of tap water.

Procedure

NOTE: Be sure to rinse your beaker well with tap water and then with distilled water after each test.

1. Obtain approximately 25 mL of one of the following solutions in a 50-mL beaker. Test the solution with litmus paper and with the conductivity apparatus. Record observations in the table below.

Solution	Litmus test	Conductivity test
NaOH		
MgO_2H_2		
$C_2O_2H_4$		
PO_4H_3		
SO_4H_2		

2. Repeat the procedure for each solution listed. Remember to wash your beaker between tests.
3. Thoroughly wash your hands before leaving the laboratory.

Data Analysis and Concept Development

Chemical Facts needed for data analysis:

1. An acid is a compound that releases H^+ ions in aqueous solution. A base is a compound that releases OH^- ions in aqueous solution. An amphoteric compound is one that acts either as an acid or as a base depending on with what it reacts.
2. A water-soluble acid will turn blue litmus pink, will not affect pink litmus and will give a colorless solution when phenolphthalein is added. A water-soluble base will not affect blue litmus paper, will turn pink litmus blue and will give a red solution when phenolphthalein is added. A basic compound that is insoluble in water will often dissolve in an acidic (*e.g.*, HCl) solution. An acidic compound that is insoluble in water will often dissolve in a basic (*e.g.*, NaOH) solution.

From the results of litmus and conductivity tests, write the ions contained in each solution.

Solution	Ions present
NaOH	
MgO_2H_2	
$C_2O_2H_4$	
PO_4H_3	
SO_4H_2	

Implications and Applications

1. Make a general statement concerning the acid-base properties of the oxy-hydrogen compounds of the elements going across the Periodic Table.
2. What statement could you make from your data regarding the relative ability of Period 3 elements to form H^+ ions and OH^- ions?
3. Predict a litmus test, a conductivity test, and write the ions for a solution labeled ClO_4H.

LABORATORY ACTIVITY: TEACHER NOTES

Activity 2: Trends in Oxy-Hydrogen Compounds of Period 3 Elements

Major Chemical Concept

A trend from basic to acidic properties can be observed in oxy-hydrogen compounds of representative elements in a period. This trend is observed as one goes from left to right across a period.

Level

General and Honors

Expected Student Background

1. Understanding which ions are responsible for acid or base characteristics of water solutions.
2. Knowledge of atomic theory.

Time

One class period will suffice for gathering the data. It is possible that some discussion of the data may occur in the first class period, although at least half of a second period will be required to discuss the laboratory activity.

Safety

Read the *Safety Considerations* in the *Student Version*. Use only 9-volt conductivity testers (not ones which employ 120-volt AC and bare wires). The 9-volt conductivity testers are easy to build, inexpensive to use and safer.

Materials (For 24 students working in pairs)

12 Beakers, 50-mL

Light bulb conductivity apparatus (See following note concerning construction of conductivity apparatus.)

Red and blue litmus paper

Sodium Hydroxide, NaOH, 500 mL (Dissolve two or three pellets of solid NaOH in 500 mL distilled water.)

Magnesium Hydroxide, $Mg(OH)_2$, 500 mL (Stir two spoonfuls of solid $Mg(OH)_2$ or milk of magnesia in 500 mL distilled water. Filter or allow the solid to settle and decant the supernatant solution.)

Acetic Acid, $HC_2H_3O_2$, 500 mL (Add 5-10 mL concentrated $HC_2H_3O_2$ to 500 mL distilled water.) [*NOTE: Some teachers prefer to use a sucrose solution ($C_{12}H_{22}O_{11}$ labeled "$C_{12}O_{11}H_{22}$") instead of acetic acid. This solution will not conduct electricity, nor will it give an acid or base indication.*]

Phosphoric acid, H_3PO_4, 500 mL (Add 5-10 mL concentrated H_3PO_4 to 500 mL distilled water.)

Sulfuric acid, H_2SO_4, 500 mL (Add 5-10 mL of concentrated H_2SO_4 to 500 mL of water.)

Advance Preparation

Prepare the solutions ahead of time. *NOTE: Specific concentrations of solutions are not important. You will want to be certain that all solutions, except sucrose, if used, conduct electricity and show positive litmus tests. Distilled water should be used. Since acetic acid and phosphoric acid are weak acids, they may show less conductivity than the others, indicating a transition from strong base to strong acid.*

Doing Chemistry DMEX C26 (Videodisc side C, Frame 25883 and Teacher's Manual p. C26-62) provides details for a microscale electrical conductivity demonstration. However, a simpler microscale electrical conductivity meter can be constructed from a battery and a low voltage light bulb. Either type is safer than using 120 volt electricity as the electrical circuit.

Materials

Wooden stick 18 cm long (paint stirrer cut in half) or Empty plastic film container with two holes drilled in the cap for the LED leads (a 9-V battery fits nicely in this container)
2 Pieces of 14- or 16-gauge Copper wire, each 8 cm long
Electrical tape
9V Battery
9V Battery Holder (Radio Shack #270-326A)
6-32 x 1/2" Screw with nut
9V Battery Clip (Radio Shack #270-325)
Light-emitting diode (Radio Shack #276-041)
330 ohm Resistor (Radio Shack #271-017)
Solder
Soldering iron
Drill with 1/8" and 1/4" bits
Wire stripper or pocket knife

Procedure

1. Drill a 1/8" hole in the wooden stick 6 cm from one end.
2. Drill a 1/4" hole in the wooden stick 6 cm from the other end.
3. Attach the battery holder to the wooden stick with the 6-32 screw and nut. (Use the 1/8" hole).
4. Solder one of the terminals of the light-emitting diode to one of the leads of the battery clip *[NOTE: The diode must be connected with the correct polarity. The polarity of the diode is usually indicated on the back of the package. The cathode (negative terminal) of the diode must be connected to the negative terminal of the battery clip (usually the black wire) or the anode (positive terminal) of the diode must be connected to the positive terminal of the battery clip (usually the red wire).]*
5. Solder one of the resistor terminals to the other lead of the battery clip.
6. Solder one of the copper wires to the other resistor terminal (if the copper wire is insulated, strip about 2 cm of insulation off of each end).
7. Solder the other copper wire to the remaining terminal of the diode.
8. Test the apparatus by attaching the battery clip to the battery and touching the two copper wires together.
9. Insert the battery in the battery holder and the light-emitting diode in the 1/4" hole.
10. Tape the copper wires to the wooden stick so that the wires do not touch each other.
11. A piezoelectric buzzer (Radio Shack) soldered in parallel to the diode will give a "sound and light" show as well.

Pre-Laboratory Discussion

Location of solutions and litmus paper should be stated. You should review the safety guidelines with students given in the Student Instructions.

Teacher-Student Interaction

1. Make sure students use clean beakers and conductivity apparatus electrodes are rinsed after each test.
2. Observe the results obtained by students. Discuss the activity with students, but do not reveal results of the various tests at this time.

Anticipated Student Results

Solution	Litmus test	Conductivity test
NaOH	Pink to blue	Conducts
MgO_2H_2	Pink to blue	Conducts
$C_2O_2H_4$	Blue to pink	Conducts
PO_4H_3	Blue to pink	Conducts
SO_4H_2	Blue to pink	Conducts

Answers to Data Analysis and Concept Development

Solution	Ions present
NaOH	Na^+, OH^-
MgO_2H_2	Mg^{2+}, $2OH^-$
$C_2O_2H_4$	H^+, $C_2H_3O_2^-$
PO_4H_3	$3H^+$, PO_4^{3-}
SO_4H_2	$2H^+$, SO_4^{2-}

*NOTE: The ions may not be exactly as shown. They are written for the sake of simplicity and to emphasize the presence of H^+ and OH^-. Students may have difficulty with acetic acid. Other oxy-hydrogen compounds of carbon could be used, some of which are nonconductors. Consider sugars (*e.g.*, sucrose, $C_{12}O_{11}H_{22}$, a nonconductor) or carbonic acid (CO_3H_2, a weak conductor) as substitutes.*

Answers to Implications and Applications

1. Compounds form water solutions that are basic and ionic on the left, neutral and non-ionic in the middle, and acidic and ionic on the right side of the period.
2. Elements on the left form OH^- ions and those on the right form H^+ ions.
3. ClO_4H should conduct electricity and test as an acid (blue litmus turns pink). It should dissociate forming H^+ and ClO_4^-.

Post-Laboratory Discussion

1. Initial discussion can center around laboratory results and students' answers to the questions.
2. After discussion is completed, you may wish to reveal identities for the substances in solution, along with their usual formulas.
3. Some students may ask why aluminum was omitted from the activity. Aluminum hydroxide [$Al(OH)_3$] is insoluble in water. It will, however, dissolve in acid or base solution. This makes the compound amphoteric. This concept could be demonstrated. (Refer to the *Chemical Facts* in the *Student Version*.)

Extensions

1. *Demonstration 1* in this module.
2. *Activity 2* in the *Halogens* module involves the comparative reactivity of these elements.
3. *Group Activities* included in this module of study.

Assessing Laboratory Learning

Since this activity provides a single periodic trend, it may be best to include it with other learning assessments, rather than testing over this activity alone. Questions of the type included in the *Implications and Applications* section of this activity would be good to use as an evaluative instrument.

Suggestions for Other Laboratory Activities

Relative Reactivity of Halogens and the Halides (*Activity 2* in the *Halogen* module).

DEMONSTRATIONS

CAUTION: Use appropriate safety guidelines in performing demonstrations.

Demonstration 1: Relative Reactions of Alkali Metals with Water

Introduction

This demonstration should be used along with *Activity 1*. As an alternative, consider using a videotape (see *Media*). Because of the danger of storing and handling potassium, it is recommended that a video demonstration of potassium reactivity be used along with this demonstration to extend the periodic trend.

The purpose of this demonstration-discussion activity is to show relative reactivities of alkali metals by reacting two of them (Li and Na) with water. [Use the videodisc on the Periodic Table (see *Reference*) to illustrate the reaction of potassium with water.] These activities should be performed as a demonstration rather than as a student activity because of the high reaction rates, the somewhat variable way in which the reactions occur, and the dangers involved in handling metals improperly.

This demonstration is effectively done as a step-by-step process in which students write observations, equations, and answer questions while the demonstration is being performed. The process will require one class period.

Safety

These metals should be kept in separate beakers, and the metals should be covered with dry kerosene. The beakers should be covered with watch glasses or other appropriate covers. *This demonstration should be performed before the class only after you have practiced it carefully. Observe all safety considerations including wearing safety goggles.*

Materials

Lithium metal, Li, 2 pea-sized pieces
Sodium metal, Na, 3 pea-sized pieces
Pair of forceps
Pair of crucible tongs
Test-tube, 18- x 150-mm
Square of aluminum foil, 5- x 5-cm
2 Beakers, 400-mL
2 Watch glasses (or other appropriate covers for the reaction beakers.)
Litmus paper
5% Phenolphthalein (in 95% ethanol)
Paper towels

Procedure

For convenience, a list of questions is submitted. This list may be copied on a handout so that students can answer the questions after viewing the videodisc and as the demonstration progresses.

1. Using forceps, remove one piece of sodium from the kerosene. Dry the metal by pressing it in folds of paper towel. After testing the water with litmus paper, drop the piece of sodium in the water and immediately cover beaker with a watch glass. After reaction is finished, remove the watch glass and test solution with litmus paper and with phenolphthalein.

   NOTE: Students often want to see the reaction repeated. If that is done, fresh water should be obtained for the second reaction.

2. Put another piece of dried sodium on a 5- x 5-cm square of aluminum foil, and fold the foil around it so that there is a small opening to allow gas to escape. Holding the foil with crucible tongs, submerge the foil in another beaker of water, and invert the 18- x 150-mm test-tube filled with water so that some of the gas evolved can be collected in the test-tube. The test-tube can be left inverted in the beaker until it is convenient to perform the flammability test. After students have answered Question 1,have them share their observations.

3. Test the gas for flammability. After students agree that hydrogen gas is produced, have them answer Question 2.

4. Point out the location of lithium on the Periodic Table. Ask students to predict how lithium's reaction rate will compare to that of sodium, and then perform the demonstration with lithium. (*NOTE: The handling of Li and the reaction system are the same as for Na.*) It is not essential that the class have consensus on lithium's rate before the reaction, but differing hypotheses should be supported with logical reasoning. After the first reaction with lithium, it may be necessary to use another piece of lithium in the same container in order to get a clear litmus test. Have students write a balanced equation for this reaction (Question 3).

5. Instruct students to continue answering Questions 4 and 5. These questions can be discussed until general consensus is reached.

6. Oral discussion of Question 6 should precede viewing the video of the reaction of potassium with water. Once again, consensus is not as important as reasoned hypothesis.
7. Watch the video demonstration of the reaction of potassium with water. Have students write a balanced equation for the reaction (Question 7).
8. If time permits, ask students to answer Question 8, and discuss their answers. The question may be given as a homework assignment.

Questions

1. What evidence indicates that the combination of sodium and water produced a chemical change? *[Gas produced, litmus changed to blue, phenolphthalein turned red, heat]*
2. After your teacher collects and tests the gas produced, write a balanced equation for the reaction of sodium with water.

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

3. Write a balanced equation for the reaction of lithium with water.

   $$[2Li(s) + 2H_2O(l) \rightarrow 2LiOH(aq) + H_2(g)]$$

4. How does the reactivity of lithium with water compare to that of sodium with water. *[The reaction of sodium is greater, indicating a greater reactivity for sodium.]*
5. Offer an explanation for the differing reactivities of lithium and sodium in terms of electron arrangements of the two elements. *[The electron configurations of Li and Na are: Li 2–1 and Na 2-8-1. Sodium loses its valence electron more readily than does lithium. The greater distance of sodium's valence electron from its nucleus and the additional energy level of inner shell electrons in sodium combine to make the removal of sodium's valence electron easier than the removal of lithium's valence electron.]*
6. Predict potassium reactivity in comparison to that of lithium and sodium. *[After brief discussion, the class should predict that potassium will be more reactive than the others tested.]*
7. Write a balanced equation for the reaction of potassium with water.

   $$[2K(s) + 2H_2O(l) \rightarrow 2KOH(aq) + H_2(g)]$$

8. Based on your experience with Li, Na, and K, how would you expect the reactivity of rubidium and cesium to compare with each other and with the three metals you have seen tested? *[Assuming the reactivity trend continues, for reasons argued earlier relating to electronic structure, cesium should be more reactive than rubidium, and both of these should be more reactive than the first three metals.]*

Reference

The Periodic Table Videodisc: *Reaction of the Elements* . Journal of Chemical Education: Software (Department of Chemistry, University of Wisconsin, 1101 University Avenue, Madison, WI 53706.). This is a 30-min videodisc with still shots and action shots of each element and its common reactions. It can be used with various computer programs. Several issues of this software journal have computerized databases for the Periodic Table for various computer types. For IBM: Issue IB, 1; KC? Discoverer: Exploring the Periodic Table. For Macintosh: Issue IC,1 The Periodic Table Stack. For Apple: Issue IA, 1 The One-Computer Classroom (Periodic Table Works).

Relative Reactivity of Halogens and the Halides (*Activity 2* in the *Halogen* module) can be performed as a demonstration if it is not used as a laboratory activity.

Group and Discussion Activities

Key Questions

1. What trends (*e.g.*, in atomic size and ionization potential) are shown among elements as one moves across a period of the Periodic Table? *(Because the outer electrons are held more strongly as one moves across a period of elements, atomic size would decrease and ionization potential would increase.)*
2. What trends (*e.g.*, atomic size and ionization potential) are shown among elements as one moves down a column of the Periodic Table? *(Because outer electrons are held more weakly as one moves down a column of the Periodic Table, atomic size would increase and ionization potential would decrease.)*
3. Account for the similarity of properties among families of elements in the Periodic Table. *(Identical numbers of outer electrons in the electron structure among a family of elements account for similarities in properties.)*

Counterintuitive Examples and Discrepant Events

1. Examine "non-periodic" trends in ionization energies of Period 3 elements. There are "blips" in the trend that can be explained in terms of electron structure (changes in *s* to *p* electrons, changes in p^3 to p^4 electrons). *[One might expect that ionization energies would increase steadily across a period, because of the greater number of protons with each successive element and the low electron shielding effect from adding electrons to the same energy level. With two exceptions in each period this pattern exists. It can be noted that removing an electron from a full s-sublevel provides one of the "blips," and removing an electron from a half-filled p-sublevel provides the other "blip." It can be stated, then, that filled and half-filled sublevels appear to have a higher stability, with respect to electron removal, than do other conditions.]*
2. Discuss hydrogen as an example of an alkali metal. *[Since hydrogen is a gas that exists as diatomic molecules in the elemental state, one might consider it odd that many periodic tables list hydrogen above the alkali metals. There are similarities to the alkali metals: hydrogen has one valence electron, hydrogen has positive character in many compounds, and hydrogen sometimes forms positive ions in solutions. Hydrogen's comparatively high ionization energy and electronegativity cause it to behave in some cases, as a halogen, tending to form negative ions (hydrides) in compounds. Furthermore, two of the halogens are gases at room temperature, as is hydrogen. Some forms of the Periodic Table list hydrogen with the alkali metals and halogen families.]*
3. Discuss the appearance of the Periodic Table if atomic weight rather than atomic number had been used to arrange the chart. How does one explain the Co-Ni, Ar-K, and Te-I reversals? *[In these cases of atomic weight "discrepancy" the most commonly occurring stable isotopes of Ni, K, and I are lighter than the most commonly occurring stable isotopes of Co, Ar, and Te. These reversals could be related to the observation that, of the naturally occurring stable isotopes, the most stable ones have an even number of protons and an even number of neutrons—"even, even." Next, in stability, would be "odd, even," and "even, odd." There are very few naturally occurring stable isotopes that have both an odd number of protons and an odd number of neutrons.]*

4. Examine the periodic and non-periodic behavior of some transition metal families. *[Transition metal behavior could be assigned as a project for individuals or small groups of students who are interested in pursuing possible periodic patterns beyond looking at representative elements. Graphs of 1st and 2nd ionization energies for Periods 4 and 5 show some interesting similarities, which could produce useful discussion and patterns relating to electron arrangements. Compiling common oxidation states for these elements and examining them with regard to periods and families could be constructive.]*

Metaphors and Analogies

The following activity (Xeno simulation) is taken from Dorin, Demmin and Gabel. *Concept Mastery, Chemistry: The Study of Matter*, Chapter 14, p. 385. Boston: Prentice-Hall, and from the Teacher's Guide, p. TG-212.

Have students imagine they are scientists on another world, where there is a set of elements different from Earth's. The name of the planet is Xeno. The students' job is to perform tests on the elements of Xeno, and to arrange the elements in a Periodic Table with families and periods, similar to the Periodic Table used on earth. They obtain the information in stages.

Directions

Stage 1 Testing Collect data on the physical properties of the elements. These data are given in the following table. Devise a Periodic Table based on these data. Justify your groupings.

Physical Properties of Elements on Xeno*

Element	Color	Hardness	Melting Point (˚C)
A	Turquoise	Soft	1050
B	Silvery, black	Hard	–300
C	Yellow	Soft	1000
D	Gray	Hard	400
E	Pink	Soft	1200
F	Silvery, black	Hard	–100
G	Silvery, black	Hard	–200
H	Black	Hard	300
I	Aqua	Soft	900
J	Brown	Soft	1000

*Room temperature on Xeno is –320 °C.

Stage 2 Testing Collect data on the chemical properties of the elements. Using the data listed below, modify your original periodic table. Justify your new arrangement.

Chemical Properties of Elements on Xeno

Element	Reacts with water	Reacts with acid	Reacts with oxygen	No reaction
A			X	
B	X	X	X	
C				X
D		X	X	
E				X
F	X	X	X	
G	X	X	X	
H	X	X	X	
I			X	
J		X	X	

Stage 3: Determine relative atomic masses for elements on Xeno. Using the data listed below, modify your periodic table. Justify your new arrangement.

Relative Atomic Masses of Elements on Xeno

Element	Relative atomic mass	Element	Relative atomic mass
A	5	F	15
B	3	G	9
C	1	H	14
D	7	I	1
E	10	J	6

Teaching Notes

Stage 1: The first arrangement might look like the table that follows. Notice that melting point increases across a period and down a group, whereas hardness decreases. (At this stage, it is equally valid to arrange the elements so that melting point decreases across a period or down a group.)

The elements on the left are all silvery and black; those in the middle, darkly colored; and those on the right, brightly colored. (With the given information, element J could also be put in the right group, either above or below C.)

B	–333
G	–200
F	–100

H	300
D	400
J	1000

I	900
C	1000
A	1050
E	1200

Stage 2: The table reflects similarities in chemical properties. Since B, G, and F show the same chemical properties, the left group remains intact. The middle group is split in two with H on the left because its chemical properties are identical to those of the elements in the left group. D and J do not react with water, so they are closer to the elements in the right group.

B	H	D	I	C
G		J	A	E
F				

Stage 3

C	I				B
	A	J	D		G
E				H	F

a. Notice that the brightly colored elements are now on the left side of the table.

b. Xeno's unreactive elements (C and E) are on the left side of the table, whereas earth's noble gases are on the right. Xeno's hard, silvery elements would be gases at 25 °C (earth's room temperature) and are on the right, whereas earth's metals are solid at 25 °C and are on the left side of the table.

c. This table now has 3 periods and 6 families (groups).

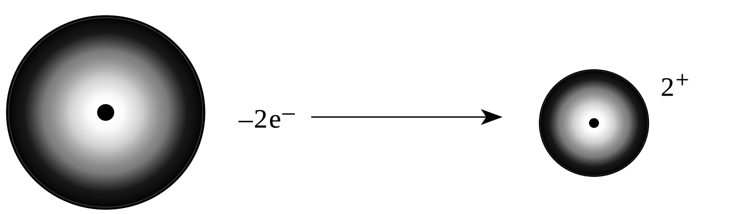
d. This table has places for 18 elements, 10 of which are known. The properties of a missing element should follow the trends in properties within its period and its group.

e. Although it is easy to record the physical properties given in Stage 1, these properties by themselves do not give enough information to build a periodic table. The chemical properties from Stage 2 are very useful, but the best information is the relative atomic masses from Stage 3.

Notice the similarties between this process of building your table for elements on Xeno and the historical development of the Periodic Table on Earth.

Pictures in the Mind

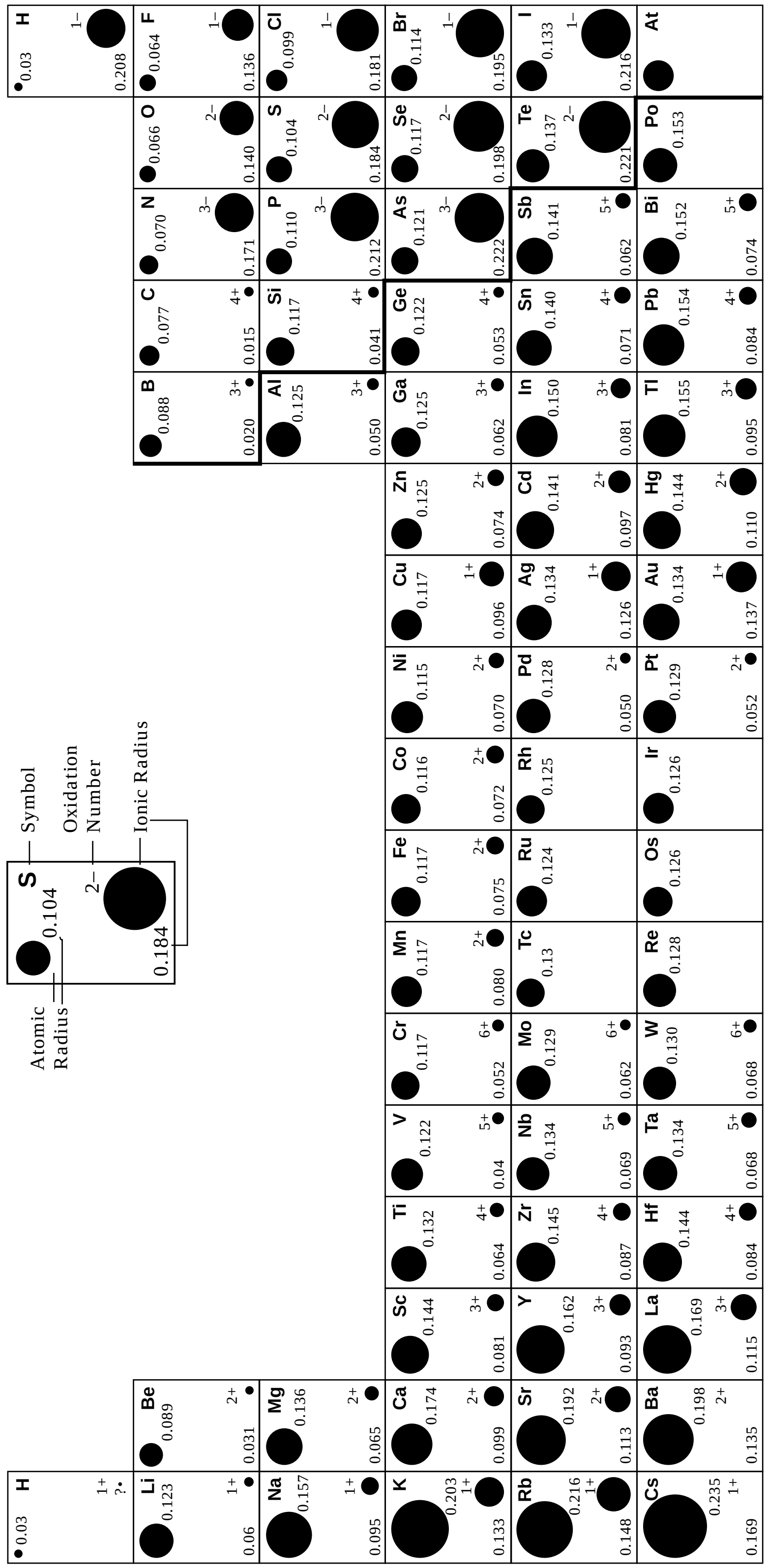
1. Have students draw circles to represent relative sizes of atoms in selected families and periods of the Periodic Table.
2. Have students draw circles to represent relative sizes of atoms and ions of selected elements. [See *Appendix* from Dorin, Gabel, and Dennmin. (1989). *Chemistry: The study of matter* . Prentice-Hall, pp. 376-377, 379.]



Magnesium atom, Mg
radius 0.136 nm

Magnesium ion, Mg^{2+}
radius 0.065 nm

Figure 2. Relative sizes of Mg and Mg^{2+}.



Adapted from Dorin, H., Demmin, P., and Gabel, D. (1989). *Chemistry: The study of matter*. Prentice Hall, Inc.

Figure 3. Covalent Atomic radii and ionic radii.

Other Activities

1. What country has been named for an element? (*HINT*: It must be an "old" element and a "new" country. Why?) *[Although many elements are named after a country, only one country, Argentina, is named after an element silver. The name for silver is from the Latin argentum.]*

2. Periodic Chart Puzzles based on the game Hang-Man or Wheel of Fortune. Examples that follow are taken from Stafford, D. G. *et al.* (1987). *Top chem: The Oklahoma project: Chemistry*. Oklahoma City: Oklahoma State Department of Education.

   The primary purpose of the Periodic Chart Puzzles is to provide an opportunity to reason with concepts, patterns, and models. This is the essence of scientific thinking. The patterns that you will be using are the trends of property, size, periods (rows) and groups (columns). These patterns and model constitute an important part of the structure of chemistry. If you can solve these puzzles, you have a good grasp of some of the important basic building blocks of chemistry.

   The concepts and patterns could relate to many concepts discussed in this module and in others: *s*, *p*, *d*, *f* elements, electron configuration, orbital diagram, ionization potential, electronegativity, atomic size, isoelectronic series, relative atomic weight, orbital diagram, metal, nonmetal, period, group, family, isotope, valence electron, ionic size, quantum numbers, atomic number, unpaired electrons, empirical formula and metalloid.

   The puzzles should be fun to do! As each puzzle is worked try to see the concept or pattern clearly in your mind. It is in this way that you will gain most from the activity. Get help only if you cannot reason out the answer for yourself.

   An activity that can be even more fun is creating puzzles of your own. Make a puzzle and exchange it with one made by someone else. This can be a very educational activity. The creative aspect of logical thinking is very important in science.

   In many cases, both letters in the symbol are used. When that is the case, the numbers in the adjacent blocks are the same. For example, if the word is *Site*, then the four blocks would be:

1	1	2	2

For the elemental symbols

<u>Si</u> <u>Te</u>

"Thing" by Don Stafford

Clues:

1	2	3	4	5	5	6	6	7	8	8	9

1. Boron family, Period 3, first letter
2. Atomic Number 5
3. Oxygen family, Period 3
4. Oxygen family, Period 2
5. Atomic Number 71
6. Oxygen family, Period 5
7. Atomic Number 40, first letter
8. Atomic Number 68
9. Atomic Number 8

Answer: ABSOLUTE ZERO

"Thing" by Connie Sloan

1	1	2	3	4	5		6	7	8		9	10	10	11

Clues:

1. 84 protons
2. 53 protons
3. 16 protons
4. Atomic Number 8
5. Z = 7
6. Z = 53
7. Z = 23
8. Z = 39
9. Atomic mass = 183.85
10. Atomic mass = 26.98
11. Atomic mass = 39.10

Answer: POISON IVY WALK

"Phrase" by Donna Deen

1	2		3	4	4		5	6	7		8	8	9	10	10

6	9		11	11	12	12	13		14	6		15	15

9	16	17	17	3		6	9		18	6	3		19	19

20	20	1	3

Answer: BE THE JOB LARGE OR SMALL DO IT RIGHT OR NOT AT ALL

Clues:

1. Boron family, Period 2
2. Atomic Number 4, second letter
3. Atomic mass 232, first letter
4. Lightest noble gas.
5. Tenth letter in the alphabet.
6. Atomic mass of 15.999
7. Atomic Number 5
8. Element for which Lanthanide series is named.
9. *spdf* configuration of $1s^2 2s^2 2p^6 3s^2 3p^6$ second letter
10. Element that contains 32 electrons.
11. At. No. = 62
12. Period 3, oxidation number of +3
13. Atomic Number 3, first letter
14. Atomic Number 101, second letter
15. Atomic Number 22, reversed
16. A solid halogen mistakenly thought of as a liquid.
17. Element known as quicksilver, reversed.
18. Heaviest noble gas, second letter.
19. Halogen family element with lowest electronegativity.
20. Boron family, $3p^1$ element

"PERIODICALLY PUZZLING"

[Nelson, B. J. (1985, December). ChemMatters, p. 16.]

Here are some questions about the elements, their properties, and periodicity. In each case, the correct answer is the name of an element (one of the two given). Write the answer in the appropriate space at right, placing the first letter in the first blank. There are more than enough blanks to fit either element name, so the number of letters in the name cannot be used as a clue. When the puzzle is complete, the Periodic Law will be displayed in the shaded column.

1. More outer electrons, phosphorus or silicon?
2. Liquid at room temperature, cobalt or mercury?
3. Produces a yellow flame test, barium or sodium?
4. Can be cut with a knife, dysprosium, or chromium?
5. Part of the lanthanide series, cerium or thorium?
6. Larger atoms, carbon or fluorine?
7. Very high ionization energy, krypton, or potassium?
8. Less dense, strontium or lithium?
9. A 1^+ or 1^- charge, hydrogen or rubidium?
10. Named after the theorizer of relativity, curium or einsteinium?
11. Configuration ends in $3p^1$, aluminum or sulfur?
12. Gives a yellow-green flame test, potassium, or barium?
13. Named after an Eastern Hemisphere continent, americium, or europium?
14. Has a dot diagram of X·, calcium or potassium?
15. Forms a hexafluoride, argon or xenon?
16. A metal used in jewelry, sodium, or rhodium?
17. Isolated by Madame Curie, radium or rhenium?
18. Its crystals sublime as violet gas, iodine or bromine?
19. Brass mimics this metal, copper, or gold?
20. One of the two most dense metals, osmium, or magnesium?
21. Used to disinfect water, boron or chlorine?
22. Compounds of this are used in toothpaste, lithium or fluorine?
23. Named after the inventor of dynamite, lawrencium or nobelium?
24. Has a higher ionization energy, antimony, or bismuth?
25. Has the higher oxidation state, scandium, or calcium?
26. Is smaller, titanium or zirconium?
27. Reacts with H_2O to produce H_2, calcium, or copper?
28. Atomic number 5, boron or nitrogen?
29. Used in the breeder reactor, uranium, or plutonium?
30. Used to make computer chips, krypton or silicon?
31. Aqueous solutions are blue, copper or nickel?
32. Low melting point, francium or platinum?
33. A poison; carbon or arsenic?
34. Forms a 2^+ ion, strontium or boron?
35. Configuration ends in $6p^6$, radium or radon?
36. Known for heavy metal poisoning, cadmium or magnesium?
37. Becomes rust, iron or nickel?
38. Deep blue compounds, cobalt or zinc?
39. Aqueous solutions are green, nickel or sodium?
40. A yellow element, selenium or sulfur?
41. Atomic weight 165, terbium or holmium?
42. Alkali metal, period 5, rubidium or strontium?
43. Used as light bulb filaments, platinum, or tungsten?
44. Reactor fuel, uranium or nobelium?

1
2
3
4
5
6
7
8
9
10

11
12
13

14
15
16
17
18
19
20
21

22
23
24
25
26
27
28
29
30

31
32

33
34
35
36
37
38

39
40
41
42
43
44

Answer to "Periodically Puzzling": Properties are periodic functions of atomic number.

1		P	HOSPHORUS
2	ME	R	CURY
3	S	O	DIUM
4	DYS	P	ROSIUM
5	C	E	RIUM
6	CA	R	BON
7	KRYP	T	ON
8	L	I	THIUM
9	HYDROG	E	N
10	EIN	S	TEINIUM
11		A	LUMINUM
12	BA	R	IUM
13		E	UROPIUM
14		P	OTASSIUM
15	X	E	NON
16		R	HODIUM
17	RAD	I	UM
18	I	O	DINE
19	GOL	D	
20	OSM	I	UM
21		C	HLORINE
22		F	LUORINE
23	NOBELI	U	M
24	A	N	TIMONY
25	S	C	ANDIUM
26	TI	T	ANIUM
27	CALC	I	UM
28	B	O	RON
29	PLUTO	N	IUM
30		S	ILICON
31	C	O	PPER
32		F	RANCIUM
33		A	RSENIC
34	S	T	RONTIUM
35	RAD	O	N
36	CAD	M	IUM
37		I	RON
38		C	OBALT
39		N	ICKEL
40	S	U	LFUR
41	HOL	M	IUM
42	RU	B	IDIUM
43	TUNGST	E	N
44	U	R	ANIUM

"IT'S ELEMENTAL"

[Lowery, J. O. (1982, December). ChemMatters, p. 16.]

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

Find the full name of the elements identified below by their chemical symbols. Names can be backwards, in rows, in columns and diagonally. Circle each as you find it.

Ag	Al	Am	Ar	As	At	Au	B(2)Ba		Be	Bi
Bk	Br	C	Ca	Cd	Ce	Cl	Cm	Co	Cr	Cs
Cu	Er	Es	F	Fe	Fm	Ga	Ge	H	He	Hf
Hg	Ho	I	In	K	Kr	La	Li	Lr	Md	Mg
Mn	Mo	N	Na	Nb	Ne	Ni	No	Np	O	Os
P	Pa	Pb	Po	Pt	Pu	Ra	Rb	Re	Rh	Rn
Ru	S	Sb	Se	Si	Sn	Ta	Th	Ti	Tl	U
W	Xe	Y	Zn							

Answer key to "It's Elemental":

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

"FAMILY RESEMBLANCE"

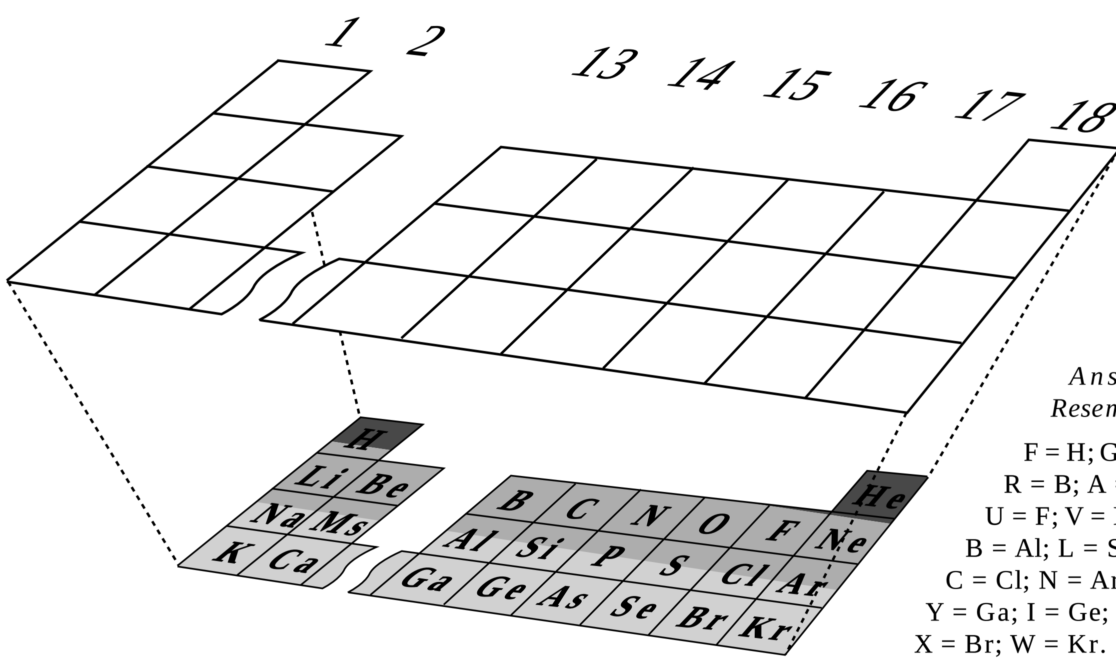
[Wolfgram, D. (1987, December). *ChemMatters,* p. 16.]

Can you place these elements in their proper positions on the Periodic Table without knowing their identity? Instead of the usual chemical symbol, each element is represented by a code letter, and some clues to the element's identity are listed below. In addition, the elements fall into these families or groups:

JKQ, WNVG, IAL, EPFZ, YBR, ODS, CXU, THM

Place each code letter in its proper space in the table below, then indicate the actual chemical symbol that corresponds to each letter.

- W is an inert gas.
- P is an alkali metal.
- X is a halogen.
- D is an element that needs three electrons to become stable.
- K is an atom that readily yields a 2+ ion.
- M is an element found in the group to the right of S.
- B would probably form a 3+ ion.
- A has six protons in its nucleus.
- R has an atomic number one less than A.
- O has an atomic number one more than A.
- S has 18 more protons in its nucleus than has D.
- F has only one proton in each atom.
- Y has atoms that are larger than the atoms of B.
- I has the largest atomic number in its group.
- T is found in the fourth period (or row).
- C has atoms that are larger than those of U, but smaller than those of X.
- V has one more proton in its nucleus than U.
- H has the smallest atomic number in its group.
- G has two protons in each atom.
- N is a third period element.
- J is a second period element.
- Q has an atomic mass greater than that of J and less than that of K.
- E has an atomic number less than that of Z but greater than that of P.
- Z has more protons than other elements in its group.
- U is found in the second period.

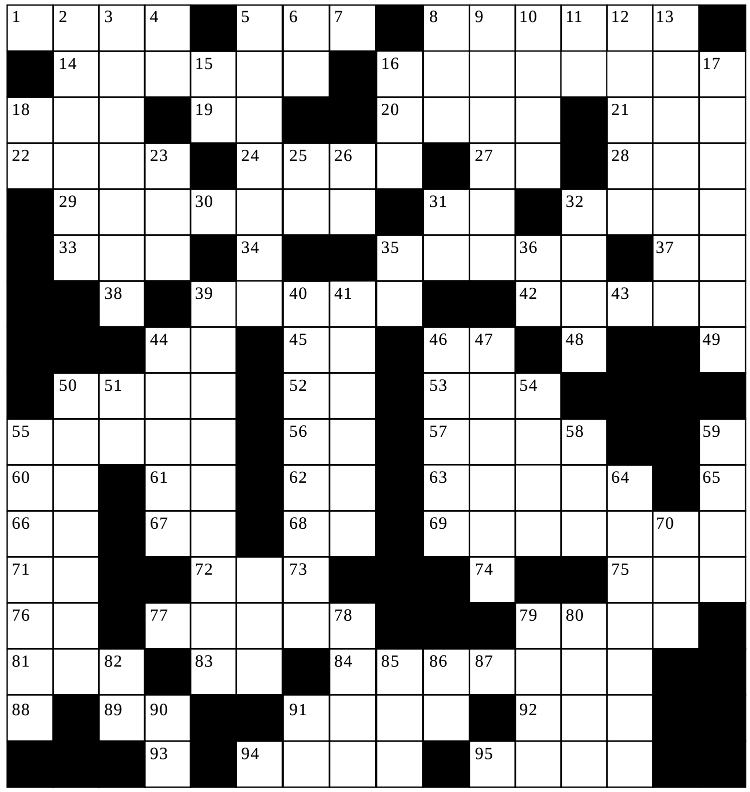


Answers to Family Resemblance:

F = H; G = He; P = Li; J = Be;
R = B; A = C; O = N; H = O;
U = F; V = Ne; E = Na; Q = Mg;
B = Al; L = Si; D = P; M = S;
C = Cl; N = Ar; Z = K; K = Ca;
Y = Ga; I = Ge; S = As; T = Se;
X = Br; W = Kr.

"IT'S ELEMENTARY"

[Landon, L. (1989, February). *ChemMatters,* p. 16.]



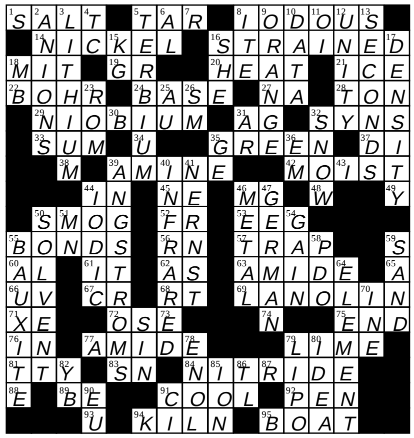
Across

1. Product of an acid and base.
5. Black mixture of hydrocarbons.
8. HIO_2 is ____ acid.
14. Element used in coins.
16. Bond angles too large or too small.
18. Massachussetts Institute of Technology, abbr.
19. 1/1000 of 15 down, var.
20. Given off by an exothermic reaction.
21. Solid phase of water.
22. Danish atomic theorist, Niels ____.
24. A substance that produces hydroxide ions in water.
27. Element; ancient name natrium.
28. 2000 lbs.
29. Element formerly named columbium; renamed after daughter of Tantalus.
31. Element; ancient name, argentum.
32. Synthetics, abbr.
33. Total.
34. Chemical symbol for element number 92.
35. See 9 down.
37. Chemical prefix denoting two.
38. Meter.
39. An organic compound containing $–NH_2$ group.
41. Noble gas used in advertising.
42. Humid.
44. Element named after brilliant indigo line in its spectrum.
45. See 41 across.
46. Eighth most abundant element in earth's crust.
48. Element once called wolfram.
49. ____ axis.
50. Smoke and fog.
52. Heaviest of the alkali metals.
53. Electroencephalogram.
55. Can be covalent or ionic.
56. Noble gas, not 31 down or 45 across.
57. Catches vacuum filtrate or animals.
59. Symbol often used to denote entropy.
60. Most abundant metal in earth's crust.
61. Institute of Technology, abbr.
62. Element forms poisonous compounds.
63. compound with $–CONH_2$ group.
65. Angstrom.
66. Portion of the electromagnetic spectrum.
67. Element named after Greek word for color.
68. Room temperature, abbr.
69. Component of many soaps and salves.
71. See 31 down.
72. Suffix meaning a carbohydrate.
74. Moles, in universal gas equation.
75. Not the beginning.
76. See 44 across.
77. See 63 across.
79. Common name for calcium oxide.
81. Teletype, abbr.
83. Element used to plate cans to prevent corrosion.
84. Name for monatomic ion formed by nitrogen.
88. Energy, abbr.
89. Element in emeralds.
91. Not warm.
92. Writing implement.
93. See 34 across.
94. High-temperature oven.
95. Possible shape of cyclohexane ring.

Down

1. Element known in ancient days as brimstone.
2. Negatively charged ions.
3. Lightest metal.
4. The only one of the first 83 elements not found in nature.
5. One of four elements named after Swedish town.
6. See 60 across.
7. Symbol commonly used for ideal gas law constant.
8. Chemical suffix.
9. Part of ROY G BIV.
10. Information gathered in laboratory experiment.
11. Two-digit binary code for Number 1.
12. One.
13. SI time units.
15. SI unit of mass.
16. Standard hydrogen electrode, abbr.
17. Physical property related by mass and volume.
18. Megabyte.
23. Read only memory.
25. Element; ancient name aurum.
26. Symbol for samarium.
30. Element makes pyrotechnics green.
31. Chemical symbol for a noble gas.
32. Crystalline form of water.
36. Electromagnetic.
39. A unit used to define bond lengths.
40. Portion of the electromagnetic spectrum.
41. German scientist known for an equation used in electrochemistry.
43. Element that is purple in the gas phase.
44. HIO_3 is ____ acid.
46. Examples: Fe, Ag.
47. Nationality of Wilhelm Roentgen.
50. Substance that dissolves a solute.
51. Element that gives the purple color to amethyst.
54. Opposite of loss.
55. Aluminum ore.
58. Partial differential overlap, abbr.
59. A starting material in the manufacture of glass.
64. Building block of compounds.
70. Chemical suffix.
73. Vice or wrong-doing.
77. See 65 across.
78. Organic compound has –OH next to C=C.
79. Prefix for fatty.
80. Innovative thought.
82. Like 5 down, but another town.
85. Charged atom.
86. Element has green spectral line and Greek name for green twig.
87. See 7 down.
90. Element named after a continent.
91. Roman numeral 101.
94. Element makes flame violet.
95. See 30 down.

Answer to It's Elementary:



3. Have students graph relative ionization energy vs. atomic number (from data tables provided) and discuss patterns and trends. Data for this activity and suggestions for discussion follow.

   This activity has been effective when the first ionization energies are graphed and discussed prior to the graphing of second and higher ionization energies. A brief discussion of the definition of ionization energy (or ionization potential) will be helpful. (First ionization energy is the amount of energy required to remove one electron from a neutral atom that is in the gaseous state. Second ionization energy measures removal of one electron from an ion with a 1+ charge, and so forth).

   Graphs are made by plotting atomic number (Z) on the horizontal axis of the graph and relative ionization energy on the vertical axis of the graph. If students are to plot all five ionization energies on the same graph, the relative ionization energy coordinate will need to be 100 units high. Relative ionization energy is used because it allows for the use of smaller numbers. Ionization energies are all made relative to rubidium's first ionization energy so they can all be compared on the same graph. There is no need to skip ten spaces on the atomic number coordinate between 20 and 31 or between 38 and 49.

   The larger number of elements plotted on the first ionization energy graph is intended to allow students to observe the trends and patterns for more periods of elements and to see that the general trends and patterns remain the same. Of course, these data are graphed only for the representative elements.

   Suggested discussion questions follow.

First Ionization Energies

a. What patterns can you observe in the first ionization energies of elements? *[A repeating pattern of peaks and valleys defines the values of ionization energies.]*

b. How do patterns you observed relate to the placement of elements on the Periodic Table? *[Peaks represent the last element in a row of the table, the valleys represent the first element in a row.]*

c. Which elements have consistently high values and which ones are consistently low? *[Alkali metals are low, the noble gases are high.]*

d. How can these values (Question 3) be interpreted in terms of how strongly an atom holds electrons? *[It is easier to remove an electron from an alkali metal because it is not strongly held.]*

e. How would you predict the first ionization energy of cesium compares to that of sodium? (This question can be carried on to other families of elements, as well.) *[It should be easier to remove a valence electron, and therefore, have a smaller ionization energy.]*

f. How do the two irregularities in the data for the second and third periods relate to the electron arrangements of the element pairs involved? *[The dips correspond to an* s *to* p *electron and a half filled* p *to doubled up* p *configuration.]*

g. How would you expect a graph of second ionization energies to compare to your graph of first ionization energies? *[See section on second ionization energies.]*

Second Ionization Energies

a. Why was there no second ionization energy for hydrogen? *[Hydrogen only has one electron.]*

b. What similarities do you see between the first and second ionization energy graphs? *[A pattern of rising and falling peaks and valleys.]*

c. What differences do you see between the two graphs? *[The peaks represent the alkali metals.]*

d. How much higher are the second ionization energies than the first ionization energies? (Encourage students to make ratios of second to first ionization energies for the various elements.) *[They are 2-3 times as high except for the alkali metals that are ten times as high.]*

e. Which elements have highest second ionization energies? *[The alkali metals.]*

f. Are the irregularities of data within a period caused by electron arrangements similar to the ones that caused the irregularities in the first ionization energies? *[Yes; that is,* $s \rightarrow p$ *and* $p^3 \rightarrow p^4$*.]*

g. What explanation can be given for the huge jump in second ionization energies for the alkali metal elements? *[The second electron comes from a lower energy level.]*

h. What patterns would you expect to see in graphs of higher ionization energies – third, fourth, and fifth? *[Similar patterns, but with peaks moved over one element.]*

All ionization energy data are adapted from: Emsley, J. (1991). *The elements, 2nd ed*. Oxford:Clarendon Press. Values given in parentheses do not have a high degree of reliability.

$$I_1 \quad M \rightarrow M^+ + e^-$$
$$I_2 \quad M^+ \rightarrow M^{2+} + e^-$$
$$I_3 \quad M^{2+} \rightarrow M^{3+} + e^-$$
$$I_4 \quad M^{3+} \rightarrow M^{4+} + e^-$$
$$I_5 \quad M^{4+} \rightarrow M^{5+} + e^-$$

I_1 = First ionization energy, I_2 = second ionization energy, *etc.*

R_I = Relative ionization energies based upon the element in the list with lowest ionization energy (Rb). This choice will yield an ordinate ~100 units in length.

Ionization Energies and Relative Ionization Energies (based on Rb) for Selected Elements

Z	Symbol	I_1	RI_1	I_2	RI_2	I_3	RI_3	I_4	RI_4	I_5	RI_5
1	H	1312	3.26	-------		-------		-------		-------	
2	He	2372	5.89	5250	13.03	-------		-------		-------	
3	Li	513	1.27	7298	18.11	11815	29.32	-------		-------	
4	Be	899	2.23	1757	4.36	14848	36.84	21006	52.12	-------	
5	B	801	1.99	2427	6.02	3660	9.08	25025	62.10	32822	81.44
6	C	1086	2.69	2352	5.84	4620	11.46	6222	15.44	37827	93.86
7	N	1402	3.48	2856	7.09	4578	11.36	7475	18.55	9440	23.42
8	O	1314	3.26	3388	8.41	5300	13.15	7469	18.53	10989	27.27
9	F	1681	4.17	3374	8.37	6050	15.01	8408	20.86	11023	27.35
10	Ne	2081	5.16	3952	9.81	6122	15.19	9370	23.25	12177	30.22
11	Na	496	1.23	4562	11.32	6912	17.15	9543	23.68	13353	33.13
12	Mg	738	1.83	1451	3.60	7733	19.19	10540	26.15	13630	33.82
13	Al	577	1.43	1817	4.51	2745	3.14	11575	28.72	14839	36.82
14	Si	787	1.95	1577	3.91	3231	8.02	4356	10.81	16091	39.93
15	P	1012	2.51	1903	4.72	2912	7.23	4956	12.30	6273	15.57
16	S	1000	2.48	2251	5.59	3361	8.34	4564	11.33	7013	17.40
17	Cl	1251	3.10	2297	5.70	3826	9.49	5158	12.80	6540	16.23
18	Ar	1520	3.77	2665	6.61	3928	9.75	5770	14.32	7238	17.96
19	K	419	1.04	3051	7.57	4411	10.95	5877	14.58	7975	19.79
20	Ca	590	1.46	1145	2.84	4910	12.18	6474	16.06	8144	20.21
31	Ga	579	1.44	1979	4.91	2963	7.35	6200	15.38	(8700)	21.59
32	Ge	762	1.89	1537	3.81	3302	8.19	4410	10.94	9020	22.38
33	As	947	2.35	1798	4.46	2735	6.79	4837	12.00	6042	14.99
34	Se	941	2.33	2044	5.07	2974	7.38	4144	10.28	6590	16.35
35	Br	1140	2.83	2104	5.22	3500	8.68	4560	11.32	5760	14.29
36	Kr	1351	3.35	2350	5.83	3565	8.85	5070	12.58	6240	15.48
37	Rb	403	1.00	2632	6.53	3900	9.68	5080	12.61	6850	17.00
38	Sr	550	1.36	1064	2.64	4210	10.45	5500	13.65	6910	17.15
49	In	558	1.38	1821	4.52	2704	6.71	5200	12.90	(7400)	18.36
50	Sn	709	1.76	1412	3.50	2943	7.30	3930	9.75	6974	17.31
51	Sb	834	2.07	1794	4.45	2443	6.06	4260	10.57	5400	13.40
52	Te	869	2.16	1795	4.45	2698	6.69	3610	8.96	5668	14.06
53	I	1008	2.50	1846	4.58	3200	7.94	(4100)	10.17	(5000)	12.41
54	Xe	1170	2.90	2046	5.08	3097	7.68	(4300)	10.67	(5500)	13.65

4. Have students plot atomic radius *vs.* atomic number (from data table provided) and discuss patterns and trends. Data for this activity and suggestions for discussion follow.

   The number of data points in this graphing activity is limited. This is purposely done to force students to make generalizations from smaller amounts of information. If they have been through the analysis of ionization energy graphs, they have seen the way patterns repeat and have begun accounting for these patterns in terms of their understanding of atomic theory. This activity, as well as the one on ionic sizes, should enhance the learning from the ionization energy activity.

Graphs are plotted with atomic number on the horizontal axis, but the vertical axis will be atomic radius measured in picometers (1pm = 1 x 10^{-12} m). It is helpful to spread the atomic number coordinate so that the graph is larger and easier to interpret.

Suggestions for Discussion Questions

a. What trends and patterns do you see in the graph of these data?

b. Offer an explanation for the relationship between atomic number and atomic radius going from left to right in a period.

c. How would the atomic radii of lithium and beryllium compare to each other? Explain your answer.

d. How would the atomic radii of lithium and beryllium compare to the radii of the remaining elements of the second period? Explain your answer.

e. How would the sizes of the radii of the elements in the fourth period (K, Ca, Ga, *etc.*) compare to the sizes of the corresponding elements in the third period (Na, Mg, Al, *etc.*)? Offer an explanation for the differences in radii of the elements in these two periods.

Atomic and Ionic Radii for Some Representative Elements

Element	Atomic number (Z)	Atomic radius (pm)	Ionic charge	Ionic radius (pm)
Boron	5	88	3+	20
Carbon	6	77	4+	15
Nitrogen	7	70	3–	171
Oxygen	8	66	2–	140
Fluorine	9	64	1–	136
Sodium	11	157	1+	95
Magnesium	12	136	2+	65
Aluminum	13	125	3+	50
Silicon	14	117	4+	41
Phosphorus	15	110	3–	212
Sulfur	16	104	2–	184
Chlorine	17	99	1–	181

f. Have students analyze and discuss ionic size related to family, ionic charge, and atomic numbering, deriving information on ionic sizes from the data table provided. Data for this activity and suggestions for discussion follow.

5. This activity is performed similarly to the atomic radii activity, using the same elements' ions. The same questions from the other activity can be adapted to fit this activity.

6. Have students generate electron configurations for selected families and/or periods of the Periodic Table and discuss similarities and/or trends in the electronic structures. Relate and justify these trends with physical properties. There must be hundreds of examples of alternative periodic tables, some humorous and others serious. There are also periodic tables used in the textbooks of countries that don't use an English alphabet. These are interesting and make good displays. A few examples of alternative periodic tables are included here.

7. The first ionization energy data (see *Other Activities 4*) can be used to construct three dimensional graphs that illustrate periodic trends. Glue a periodic table to a board and drill small holes through each box representing the elements. Use medical swab sticks cut to scale into lengths representing the relative ionization energies. A 96-well plate can also be used. Straws that fit into the holes can be cut to scale. The periodic trends of other chemical and physical properties can be explored in this manner.

8. The "Great Periodic Table Race" is a board game using dice, game pieces, and "discovery cards." Game was developed by Richard Rodin and distributed by Science Kit.

9. "Understanding the Periodic Table" is an analogy puzzle published by Hubbard Scientific Co., 1952-T Raymond Drive, Northbrook, IL 60620. (708) 272-7810 or FAX (708) 272-9894.

10. Have students generate a concept list during a class brainstorming session at the end of the discussion of periodicity. Put concepts on cards and generate a map (in groups of two). In groups of four, have students develop a consensus map. Develop a consensus (total class) map during a teacher led discussion.

11. Many types of alternative periodic charts have been proposed. Obtain copies of these charts and discuss the pros and cons of the format of the elements.

    Five alternatives have appeared together on a poster [*Chemistry Currents,* (1). Fall 1986—CentCom, Ltd., 60 East 42nd Street, New York, NY 10165; (212) 976-9660.] and separately in *Journal of Chemical Education.*

    a. Octagonal prismatic periodic table [Kow, T. W. (1972). *49*, 59].

    b. Pyramidal format [Fernelius, W. C., and Powell, W. H. (1982). *59*, 504].

    c. Three-dimensional form consisting of two concentric helices [Quam, G. N., and Quam, M. B. (1934). *11*, 288].

    d. Fan-shaped table [Quam, G. N., and Quam, M. B. (1934). *11*, 288].

    e. Circular format [Strong, F. C. III. (1985). *62*, 456].

    Three alternatives (two reproduced in the *Appendix*) have appeared on calendars published by Instruments for Research and Industry (I^2R), Inc., 108 Franklin Avenue, Box 159, Cheltenham, PA 19012.

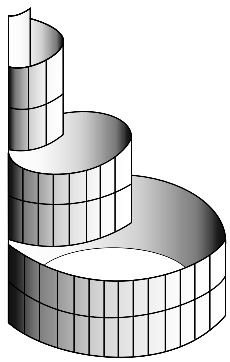
    f. Spiral Periodic Chart (September 1982)

    g. Periodic Pyramid (September 1984)

    h. 3-D Periodic Chart (September 1983)

12. Construct your own Periodic Spiral.

Several years before Mendeleev's Table, A.-É. Beguyer de Chancourtois published the first spiral periodic table in 1863. Spiral periodic tables are especially useful for showing the continuity of the elements, as well as the relationships between the *main group elements,* the *transition elements,* and the *lanthanides* and *actinides.*



This spiral three-dimensional table is based on a 1914 design by Ingo Hackh. The flat periodic chart in the *Appendix* should be used to construct the spiral version. Copy on heavy stock paper. Use a coloring pencil and color the main group elements blue; the transition elements, orange; and the lanthanides and actinides, brown. To assemble your spiral periodic table, cut along the heavy black lines. With the printing facing out, bend into three circles of different diameters. Position the elements Li, Na, K, Rb, Cs, and Fr so that they overlap the corresponding symbols on the tab. Glue in place.

Figure 4. Periodic spiral.

TIPS FOR THE TEACHER

Language of Chemistry

alkali metals elements in group headed by Li.

alkaline earth metals elements in group headed by Be.

atomic radius half the distance of a single bond between two atoms of an element.

electronegativity a measure of attraction of an atom for a pair of shared electrons.

first ionization energy energy required to remove the most loosely held electron from the outer energy level of an atom in the gas phase.

group or **family** a vertical column in the Periodic Table.

halogens elements in group headed by F.

noble gases elements in group headed by He.

period horizontal row in the Periodic Table.

periodic law chemical and physical properties of elements are periodic functions of their atomic number.

transition element any *d*-block element of the Periodic Table.

Common Student Misconceptions

1. **"The radius of an atom increases in a period with the addition of electrons."**

   From the data given on atomic radii, we see that with the addition of electrons, the atomic radii decrease within a period. This is due to the increase in the positive charge of the nucleus and its attraction for the electrons in the atom. Although the number of electrons in the atom increases as one goes across a period and although the electrons repel each other potentially causing the atoms to grow in size, this effect is more than opposed by the increase in the number of protons attracting these electrons. Since these electrons are added to the same shell, the number of protons attracting them causes the size of the atoms to decrease.

2. **"All properties show periodic characteristics."**
   There are deviations in all periods.
3. **"Elements are arranged according to atomic weight."**
   While this is true in general, the periodic properties are characteristic of atomic numbers.

History: On the Human Side

Origins of the Periodic Table are rooted in the idea of elementary substances first proposed by the ancient Greeks. In 450 B.C., Empedocles proposed the existence of four elementary substances: earth, air, fire, and water. These were later adopted by Plato and Aristotle (who added a fifth, *quinta essentia*, crystalline spheres of the heavens). The history of elements paralleled that of atoms until 1700 when atoms were becoming well established while the idea of four elements was questioned. A clearly defined working concept of elements was proposed by John Dalton in 1808. In 1817, Johann Wolfgang Döbereiner pointed out that elements could be grouped in triads of related substances (Li-Na-K; Cl-Br-I; Ca-Sr-Ba; S-Se-Te; As-Sb-Bi). He found that when these triads of elements were arranged in order of increasing mass, a series emerges in which the intermediate atomic mass was close to the arithmetic average of the other two. Properties such as density, melting point, and boiling point behaved similarly.

The time was ripe for a classification according to similarities. Taxonomy was beginning to be a common practice in biology, and it was felt that chemistry also needed a taxonomy. What was lacking was a set of reliable atomic masses on which to base the taxonomy. This fact was established in 1860 at an international conference in Karlsruhe, Germany. Both Dmitri Mendeleev and Lothar Meyer attended this conference.

Alexandre-Émile Beguyer de Chancourtois (1820-1886), a French geologist, arranged elements in a three dimensional spiral in order of increasing atomic mass. Elements with similar properties fell into vertical columns. John Newlands (1827-1898) proposed a law of octaves when he noticed that every known eighth element, in order of increasing atomic mass, repeated properties. The stage was set for Mendeleev and Meyer.

Dmitri Mendeleev (1834-1907) was a Russian born in Siberia, the youngest of 13, 14, 17, or 18 children depending upon the historical source. When his father died, his mother took him on a 1000 mile journey by horse cart to Moscow and then to St. Petersburg, where he was educated. His hot temper led him to quarrel with an important minister of education, and he was unable to obtain a university position. As a consequence, he was briefly a high school teacher and then after continuing his education, did research in Paris and Heidelberg. Returning to Russia, he was appointed Professor of Chemistry at the Technological Institute of St. Petersburg.

In 1869, Mendeleev was writing his textbook, *Principles of Chemistry*. As part of the project he was searching for a way of organizing the vast amount of information concerning the elements as an aid to his students' understanding. On February 17, 1869, he was arranging a stack of cards on which he had written the name, symbol, and atomic mass of each element. He laid out the cards in rows in order of increasing mass and noticed what others before him had—the elements fall into families. He published his table listing 63 known elements, leaving spaces for 31 more. Mendeleev not only predicted the existence of unknown elements; he predicted their properties. His most successful predictions were for the elements scandium, gallium, and germanium, which were later discovered. In addition, he suggested corrections for atomic masses on purely theoretical grounds; these suggestions also later proved to be accurate. These predictions showed the power of his periodic table.

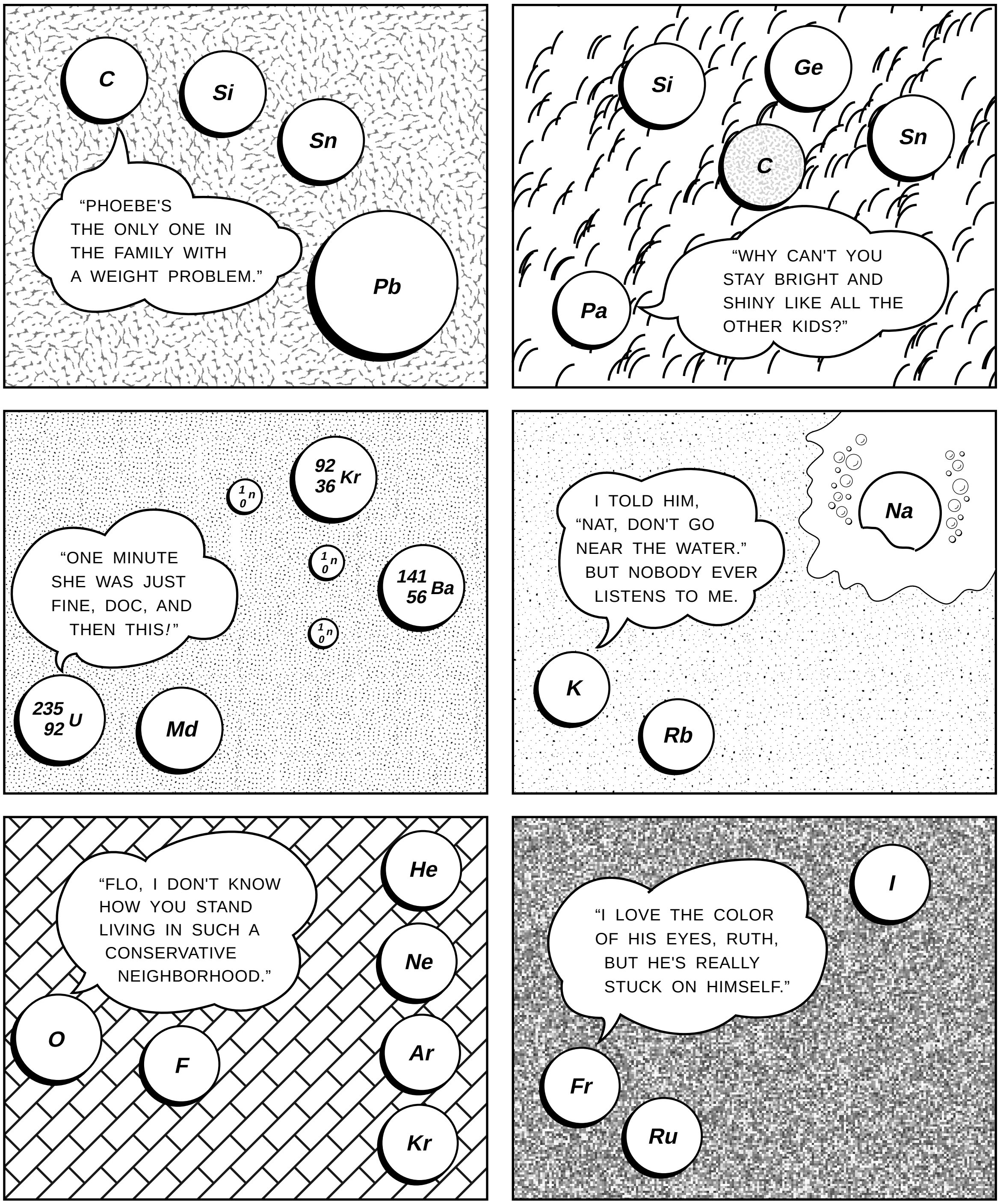
Mendeleev had a hot temper and strong democratic leanings, which got him into trouble in Czarist Russia. For the most part, he was tolerated by his country's officials because of his fame and importance as an internationally known chemist. However, in 1890, he was forced to resign his university position in a policy dispute with the administration over oppression of students. At this time, he took over as Director of the Bureau of Weights and Measures.

Lothar Meyer (1830-1895), a German chemist, proposed an arrangement independent of and similar to that of Mendeleev. His arrangement emphasized the periodicity of physical properties. He made graphs of atomic volume versus atomic weights that showed a line which rose and fell into cycles or periods with minima and maxima defining chemical families. Meyer, like Mendeleev, made his proposal as a result of writing a textbook. He did not publish his findings until 1870, one year after Mendeleev had. He and Mendeleev engaged in an unfortunate quarrel over priority. He later admitted that he lacked the courage to predict the existence of undiscovered elements as Mendeleev had.

Daniel Morris (see *References*) suggests a connection between music and the development of ideas of elements.

HUMOR: ON THE FUN SIDE

1. What elements think of each other, a conversation between elements. Ihde, J. (1986, February). Puzzle page. *Chem Matters* , p. 20. Washington: American Chemical Society.



John Ihde, chemistry teacher at Wausau West High School, Wausau, WI captured some rare conversation between the elements.

2. **Fantastic New Compounds** Clues given on elements to make compounds. Russell, F., *et al.* (1986, October). Puzzle page. *Chem Matters*, p. 1, 16. Washington: American Chemical Society.

ChemMatters magazine has obtained a bizarre research report describing a previously unknown class of compounds made by a new principle of chemical synthesis. One newly discovered compound, which contains the elements *indium* (In) and *potassium* (K), can be used in ballpoint pens. Remarkably, its formula is *InK*! The formulas of the other compounds were not revealed, but can be derived from their chemical composition. Can you write the formulas?

a. A pen to hold the ink can be made of a compound containing one part bismuth and one part carbon.

b. A compound with equal parts tin, oxygen, and boron does not mix with other substances.

c. One part phosphorus and nine parts potassium make up this compound that was recently isolated from dog urine.

d. A very absorbent material of equal parts sulfur, phosphorus, oxygen, nitrogen, and germanium has multiple uses.

e. A mineral of the three elements aluminum, sulfur, and phosphorus is found in a major mountain range.

f. The compound containing lithium, phosphorus, and sulfur forms a structure that enables you to smooch.

g. This chemical, sometimes found in rabbits' feet, contains one part lutetium, one part carbon, and one part potassium.

h. A compound that's helpful when you're studying for a test contains one part chromium and one part americium.

i. Bromine, iodine, carbon, and potassium are found in this material that is used to build houses.

j. This compound, which was banned by the church, contains one part nitrogen and one part silicon.

k. Discovered in automobiles, this compound contains one part sulfur and one part gallium.

l. A substance one part boron, one part oxygen, and one part astatine floats on water.

m. This compound—one part aluminum, one part molybdenum, and one part neodymium—makes a very nutty substance.

n. A compound of one part potassium, one part nickel, and one part iron penetrates many other substances.

o. Tungsten, rhenium, nitrogen, carbon, and hydrogen in equal parts can form a useful tool.

p. Equal parts of carbon, oxygen, calcium, cobalt, and lanthanum will make a tasty beverage.

q. A substance that's one part cobalt, one part radon, and one part yttrium is similar to many of these examples.

Answers:

1. BIC 2. SNOB 3. K_9P 4. SPONGE 5. ALPS 6. LIPS 7. LUCK 8. CRAM 9. BRICK 10. SIN 11. GAS 12. BOAT 13. ALMOND 14. KNIFE 15. WRENCH 16. COCA COLA 17. CORNY

3. **Periodic Puns**

   Some very uncommon elements (see *Appendix*) from Huheey, J. (1978). *Diversity and periodicity: An inorganic chemistry module.* New York: Harper & Row.

   a. When people leave, they ___. *[Argon]*
   b. What you do with dead people. *[Barium]*
   c. Old McDonald put the sow in the field and the ___ the porch. Eeii, Eeii, Ooo. *[Boron]*
   d. One who follows a golfer around the course. *[Cadmium]*
   e. An early morning "snap, crackle, and pop!" *[Cerium]*
   f. A salt water chemical. *[Cesium]*
   g. People are always doing this to their hair on a windy day. *[Chromium]*
   h. What country is known for Paris, perfume and profound leaders? *[Francium]*
   i. How does one purchase gasoline (by the ___)? *[Gallium]*
   j. "On your mark...Get set...___!" *[Gold]*
   k. Romeo fell head over ___ with Juliet. *[Helium]*
   l. "Oh! Give me a ___ where the buffalo roam..." *[Holmium]*
   m. Water and gin combo. *[Hydrogen]*
   n. What you do with wrinkled clothes. *[Iron]*
   o. A dead person lies in a ___ a hill in the cemetery. *[Krypton]*
   p. To scrub the floor, you must get down and put your ___ it. *[Neon]*
   q. Who was the main character in the television show "Have Gun Will Travel"? *[Paladium]*
   r. ___ your boots before you to go work and take them off when you get home. *[Polonium]*
   s. Those who hold wild parties find that the police will eventually ___. *[Radium]*
   t. A cool dude might exclaim this in response to a perfect test score. *[Radon]*
   u. To answer these awful puns is to ___! *[Sulfur]*
   v. A person in a bank who deposits your money for you. *[Tellurium]*
   w. An apologetic lisping child says this. *[Thorium]*
   x. A truck driver's farewell (___ –4 Good Buddy!) *[Tin]*
   y. If you yawn near a beehive, you might get your ___. *[Tungsten]*
   z. A boat with a hole in the bottom will ___. *[Zinc]*

4. Tom Lehrer's *An Evening Wasted with Tom Lehrer* contains a cut called "Element Song" in which the element names are sung to Sir Arthur Sullivan's "Mighty Major General." Available on CD (Warner #6199). Contact local tape/CD store.

5. **Cartoon** Knights of the Periodic Table. Sources: Siromoski, R. *Discover,* May 1990, p. 93 (see *Appendix* for cartoon).

6. A Dear John letter from Francium. Source: Ratzlaff, B. (December 1985). *ChemMatters*, p. 13.

Dear John,

I'm writing to tell you that I can't marry you—I'm breaking our engagement. I guess you want to know why, so let me explain. I'll start at the beginning...

It all started when I was born the daughter of Actinium-227 by alpha emission. I not only grew up unstable, but my psychiatrist recently diagnosed me as a paranoid schizophrenic and said she has trouble telling my 20 isotopes apart. The sad truth is that ^{223}Fr *(my longest lived isotope) has a half-life of only 21 min, after which I decay into that awful* ^{223}Ra*! And my* ^{221}Fr *has a half-life of only 4.8 min.! So you see, there's no use continuing our relationship when I won't be around long.*

I was a quiet child. When my existence was finally discovered in 1939 by Marguerite Perey at the Curie Institute in Paris, I was thrilled! They named me Francium after the country in which I was discovered. They introduced me to my sisters: Lithium, Sodium, Potassium, Rubidium, and Cesium. Soon I learned that, as members of the Alkali metal family, we had a lot in common. We all had a valence of one, tarnished in air, had low melting points, and reacted with water. Not only that, we generally had soft crystals and were commonly found as halides and as aluminosilicates and combined vigorously with other elements.

Father said that the strong similarity between my sisters and me was the arrangement of the electrons in our atoms. But then, Father always had an explanation for everything. I asked him once why he liked Lithium best. He said he loved us all equally and that I was only being my unstable self. But I keep bugging him, and finally he admitted that he liked Lithium best because she was used in the treatment of steel parts and was making something of her life. He said I had no meaningful purpose that he could see. Then he looked me up and down and grunted that I ought to do something about my atomic weight. I ran to my room in tears and looked in the mirror. My atomic weight was around 223, more than anyone else in my Alkali metal family. John, I just can't bear it! You saw how futile my attempts to diet were.

Sitting in the earth's crust the way I do in tiny amounts (never more than one ounce), I have a lot of time to think. It isn't so bad having a melting point of 27 °C, and my changes of phase add some excitement to my life. But something has been bothering me. Even though I was discovered more than 30 years ago, my sisters still leave me out of everything. The Alkali family has always been famous, but nobody knows the real *me! Why, I remember that in* Inorganic Chemistry, *R.T. Sanderson said, 'Relatively little is known of this element except that a close resemblance to Cesium has been recognized.'*

Cesium! He compared me with Cesium—my sister who hangs out in a mineral called pollucite. No one would ever catch a weighable amount of me *in that trash! I'm sorry—there I go being unstable again.*

Hey, did you hear that people are actually cloning me? It's true! What they do is bombard thorium with protons, and they've got instant artificially made Francium. Neat, isn't it? Who knows? Maybe some day, good old atomic number 87 will find her niche in society, and I will be accepted for what I am! But until then, I know we could never be right for each other.

John, I am really sorry. Please try to understand. I will always love you and will never forget our half-lives together.

Love always,

Francium Alkali

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

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

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

1. Half the distance of a single bond between two atoms of an element (2 words).
2. Measure of the attraction of an atom for a pair of shared electrons.
3. Energy required to remove the most loosely held electron of an atom in the gas phase (2 words).
4. Helium is one (2 words).
5. Astatine is one.
6. Elements in the first group (2 words).
7. Another name for group.
8. A horizontal row on the periodic chart.
9. Transition elements are in this section of the periodic chart.
10. ______ states that chemical and physical properties of the elements are periodic functions of their atomic number (2 words).

Answers: 1. ATOMIC RADIUS 2. ELECTRONEGATIVITY 3. IONIZATION ENERGY 4. NOBLE GAS 5. HALOGEN 6. ALKALI METALS 7. FAMILY 8. PERIOD 9. D-BLOCK 10. PERIODIC LAW

MEDIA

1. The *World of Chemistry* videotape “Number 7: The Periodic Table.” 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. Other films and videos.

a. *The Periodic Table*. Presents the history, terminology and structure of the Periodic Table and explains the relationship between electron configuration and preiodicity. 24 min. video. The Media Guild, 11526 Sorrento Valley Road, Suite J, San Diego, CA 92121; (619) 755-9191; (800) 886-9191.

b. *Chemical Families*, A CHEM Study Film. Ward's Natural Science Establishment, Inc., 5100 West Henrietta Road, P.O. Box 92912, Rochester, NY 14692-9012; (716) 359-2502; (800) 962-2660; (716) 334-6174 (FAX).

c. *Ascent of Man Part 10: World Within World* , KCET Video, 4401 Sunset Blvd., Los Angeles, CA 90027; (800) 328-7271.

d. *Updating the Periodic Table*. Videotape address by Glenn Seaborg. Item Number DC 5800. Lawrence Hall of Science Discovery Corner, University of California at Berkeley, Berkeley, CA 94720; (510) 642-1929.

e. "Periodic Classification of the Elements" and "Periodic Properties of the Elements," two chapters from the Chem 101 Series, Learning Center, Department of Chemistry, University of Illinois at Urbana-Champaign, Urbana, IL 61801; (217) 333-2998.

3. Software published by JC*E:* Software, a publication of the *Journal of Chemical Education*, Department of Chemistry, University of Wisconsin-Madison, 1101 University Avenue. Madison, Wl 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. *Aufbau*, by Dale Jensen, one of the programs in *The One-Computer Classroom: Periodic TableWorks*, Vol. I A, No. 1 for the Apple II computer.

4. Software published by Project SERAPHIM, Department of Chemistry, University of Wisconsin-Madison, 1101 University Avenue. Madison, Wl 53706-1396: (608) 263-2837 (voice) or (608) 262-0381 (FAX).

For the Apple II computer:

AP 207, *The Periodic Table as a Database*. The Periodic Table is used as a graphical database to display chemical and physical properties. Various display modes, including 3-D, are accessible.

AP 209, AP 310

5. Other Software.

   a. *Astro Stack* HC17. Each element has its own valuable information. HyperCard program for Macintosh. The Public Domain Exchange, 2074C Walsh Avenue, Dept. 644, Santa Clara, CA 95050; (408) 955-0292.

   b. *MacMendeleev*. A computerized Periodic Table database for the Macintosh. Trinity Software, P.O. Box 960, Campton, NH 03223; (603) 726-4641.

6. Videodiscs published by *JCE:* Software, a publication of the *Journal of Chemical Education*, Department of Chemistry, University of Wisconsin-Madison, 1101 University Avenue. Madison, Wl 53706-1396: (608) 262-5153 (voice) or (608) 262-0381 (FAX).

   a. "Electron Clouds" and "The Aufbau Principle," two chapters on The World of Chemistry: Selected Demonstrations and Animations: Disc II (double sided, 60 min.), Special Issue 4.

   b. "Similarities and Trends in Groups I – Noble Gases" and "Similarities and Trends in Groups II – Alkali Metals," two chapters on *The World of Chemistry: Selected Demonstrations and Animations*: Disc I (double sided, 60 min.), Special Issue 3.

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

Links/Connections

Within Chemistry

1. Periodicity is a central organizing feature of chemistry. Consequently, it is linked to many major concepts in chemistry—electronic structure, atomic structure, and bonding. It is related to the atomic properties of elements (*e.g.*, electronegativity) and to their empirical properties (*e.g.*, reactivity).
2. The spectra of a family of elements such as the alkali metals can be correlated with electron transitions from the excited states to lower energy states. The collective transitions give rise to characteristic colored flames, lithium (red), sodium (yellow), potassium (lilac), rubidium (purple), and cesium (blue). The brilliant display of color in fireworks, flares, and aerial rockets takes place when chemical changes supply sufficient thermal energy to the salts of alkali metals so that the metal ions are promoted to excited states, and radiate the energy as characteristic colors during the relaxation process to lower energy states.

Between Chemistry and Other Disciplines

The Periodic Table classifies and organizes knowledge in chemistry. As such, it is parallel to classification systems in other disciplines—for example, to taxonomic classification in biology and Library of Congress or Dewey Decimal systems in libraries (see *Metaphors and Analogies).*

To the Contemporary World

Personal

Students may relate some elements of the Periodic Table to everyday life. Examples are:

1. **Fluoridation.** Fluorine is beneficial in preventing cavities.
2. **Calcium.** Calcium is a mineral needed for strong bones and teeth.
3. **Lead.** The issue of lead poisoning.
4. **Aluminum.** The issue of recycling resources.
5. **Chlorine.** The use of chlorine in water to prevent disease.
6. **Helium.** Use in balloons. Non-toxic but may asphyxiate. Sources: Natural gas may contain as much as 7% helium. Can you give some reasons why? What might be the origin of He in the earth's crust? Relate to *Nuclear Chemistry* module.
7. **Germanium and Silicon.** Role in semiconductors.
8. **Titanium.** Use in "white out" materials such as Liquid Paper™. Use in paints.

Community

1. **Field trips.** Mining or manufacturing involving elemental substances in your area.
2. **Knowledgeable individuals.** An M.D. with an interest in environmental or public health might be an excellent resource to discuss the presence of elemental substances such as mercury or lead in our environment.

3. The prevalence of lead poisoning among inner-city children. Causes, prevention; chemical antidotes for lead poisoning.
4. **Nitrogen** Role as a fertilizer; liquid NH_3; nitrogen fixation.
5. **Role of metals in society.** Metallurgy. Extraction of metals from their ores. Alloys. The role of steel in our lives. Large structures demanding great strength would not be possible without the use of steel (*e.g.*, skyscrapers and superhighways).
6. **Zinc.** Galvanization (placing a protective coating of zinc on iron). Use of zinc in dry cells (ordinary flashlight batteries). Use of zinc oxide as a topical ointment.
7. **Tin**. Uses in tin plate for canned foods. Also used in many important alloys, including solder and pewter.
8. Role of certain elements in materials science (see *Materials Science* module).
9. **Transuranium elements.** Can we predict the properties of elements that have not yet been synthesized? What role do some of the transuranium elements play in our lives?

Extensions

1. Have students do written and/or oral reports on the discovery, physical and chemical properties and common uses of selected elements.
2. Have students obtain data on ionization energies, atomic sizes and ionic sizes for the transition elements in Periods 4 and 5. Discuss patterns (or lack of patterns) relating to these data. (Data are given in *Appendix* of *Transition Elements* module.)
3. Have students explore density data for elements to see if density could be considered a periodic property.
4. Have students obtain electronegativity data for elements and graph them to ascertain periodic trends for this property.
5. Primo Levi's collection of short stories *The Periodic Table* (see *References*) provides good extension topics for discussion. Have different students read the various stories and give book reports on them.

References

Module drafted by Michael Abraham, Donna Coshow, and William Fix, the Oklahoma team.

Ball, D. W. (1985). Elemental etymology: What's in a name? *Journal of Chemical Education, 62*(9), 787-788.

How the elements were named.

Brooks, D. W. (Producer). (1989). Doing chemistry [Videodiscs, computer program, and supporting written materials]. Washington, DC: American Chemical Society.

Cotton, F. A., and Wilkinson, G. (1988). *Advanced inorganic chemistry* (5th Ed.). Wiley: New York.

An advanced college text filled with descriptive information concerning the elements and their compounds.

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

A comprehensive compilation of data on the elements. Very handy reference book.

Fernelius, W. C., and Powell, W. H. (1982). Some confusion in the Periodic Table of the elements. *Journal of Chemical Education, 59,* 504-508.

A historical review of the group numbering system in the Periodic Table.

Holden, N. E. (1984). *A history of the Periodic Table: SIRS science series* . Boca Raton, FL: Social Issues Resources Series, Inc.

This will augment your knowledge of historical information concerning the Periodic Table.

Levi, P. (1984). *The Periodic Table*. New York, NY: Random-Pantheon-Schocken.

A work of fiction with essays, short stories, and biographical remembrances organized around elements in the Periodic Table. This book was written by a distinguished Italian chemist/writer.

Loening, K. L. (1984). Recommended format for the Periodic Table of the elements. *Journal of Chemical Education, 61,* 136.

A note on the ACS-recommended format for the Periodic Table.

Morris, D. (1969). Music of the new spheres. *Chemistry, 42* (11), 10-12.

The author suggests a connection between music and the development of ideas of elements.

Nelson, B. J. (1984, April). Elements and their organization. *Chem Matters* .

Nelson, B. J. (1985, December). Periodically Puzzling. *Chem Matters* , p. 16.

Orna, M. V. (1982). On naming the elements with atomic number greater than 100. *Journal of Chemical Education, 59,* 123.

A review of the origin and meaning of the three-letter symbols of the elements above atomic number 100.

Partners for a noble element. (1987, November 21). *Science News* .

Roberts, R. M. (1989). *Serendipity: Accidental discoveries in science*. New York, NY: Wiley.

Chapter 7 of this book is on "Discoveries of Chemical Elements" and discusses oxygen, iodine, helium, and the noble gases.

Rochow, E. G. (1977). *Modern descriptive chemistry*. Philadelphia, PA: Saunders.

More details than can be obtained in most beginning college chemistry texts.

Sanderson, R. T. (1960). *Chemical periodicity*. New York, NY: Reinholt.

A classic text on periodicity.

Weast, R. C. (Ed.). (1992). *Handbook of chemistry and physics* (any edition). Cleveland, OH: CRC Press.

The source of data about everything chemical including the elements and their compounds.

Appendix

- **Transparency Masters**
  1. Divided Periodic Table
  2. Densities of the Elements (see text by Sanderson in *References*)
  3. Melting Points of the Elements (see text by Sanderson in *References*)
  4. Word Search
- **Tables**
  1. Identification of Selected Substances
- **Other(° C)**
  1. I^2R Periodic Chart: The Periodic Pyramid
  2. I^2R Periodic chart: Non Scientist's Concept of the Periodic Chart of the Elements
  3. Spiral Periodic Chart Cut-Out
- **Humor**

DIVIDED PERIODIC TABLE

H																	He
Li	Be											B	C	N	O	F	Ne
Na	Mg											Al	Si	P	S	Cl	Ar
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
Cs	Ba	La	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn
Fr	Ra	Ac															

Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr

DENSITIES OF THE ELEMENTS

(g/cm^3) or (g/L) with *
gr = graphite
w = white
g = gas
l = liquid

1	*H (g) 0.09																*H (g) 0.09	*He (g) 0.18
2	Li 0.53	Be 1.85											B 2.4	C (gr) 2.26	*N (g) 1.25	*O (g) 1.43	*F (g) 1.69	*Ne (g) 0.90
3	Na 0.97	Mg 1.74											Al 2.70	Si 2.3	P (w) 1.82	S 2.07	*Cl (g) 3.2	*Ar (g) 1.78
4	K 0.86	Ca 1.55	Sc 2.99	Ti 4.5	V 5.96	Cr 7.1	Mn 7.2	Fe 7.86	Co 8.9	Ni 8.90	Cu 8.92	Zn 7.14	Ga 5.91	Ge 5.36	As 5.7	Se 4.8	Br (l) 3.11	*Kr (g) 3.74
5	Rb 1.53	Sr 2.6	Y 5.51	Zr 6.5	Nb 8.6	Mo 10.2	Tc 11.5	Ru 12.2	Rh 12.5	Pd 11.4	Ag 10.5	Cd 8.6	In 7.3	Sn 7.28	Sb 6.7	Te 6.2	I 4.93	*Xe (g) 5.89
6	Cs 1.90	Ba 3.5	La 6.15	Hf 13.3	Ta 16.6	W 19.3	Re 20.5	Os 22.48	Ir 22.4	Pt 21.45	Au 19.3	Hg (l) 13.55	Tl 11.85	Pb 11.34	Bi 9.8	Po 9.4	At	*Rn (g) 9.73

MELTING POINTS OF THE ELEMENTS

(ºC)

1	H −259.2																H −259.2	He −269.7
2	Li 180.5	Be 1283											B 2027	C	N −210.1	O −218.8	F −219.6	Ne −248.6
3	Na 98	Mg 650											Al 660	Si 1423	P 44.2	S 119	Cl −101	Ar −189.4
4	K 63.2	Ca 850	Sc 1423	Ti 1677	V 1917	Cr 1900	Mn 1244	Fe 1539	Co 1495	Ni 1455	Cu 1083	Zn 419.5	Ga 29.78	Ge 960	As 817	Se 217.4	Br −7.2	Kr −157.2
5	Rb 38.8	Sr 770	Y 1500	Zr 1852	Nb 2487	Mo 2610	Tc 2127	Ru 2427	Rh 1966	Pd 1550	Ag 960.8	Cd 320.9	In 156.2	Sn 231.9	Sb 630.5	Te 450	I 113.6	Xe −111.9
6	Cs 28.6	Ba 710	La 920	Hf 2222	Ta 2997	W 3380	Re 3180	Os 2727	Ir 2454	Pt 1769.3	Au 1063	Hg −38.87	Tl 303.6	Pb 327.4	Bi 271.3	Po 254	At	Rn −71

Word Search

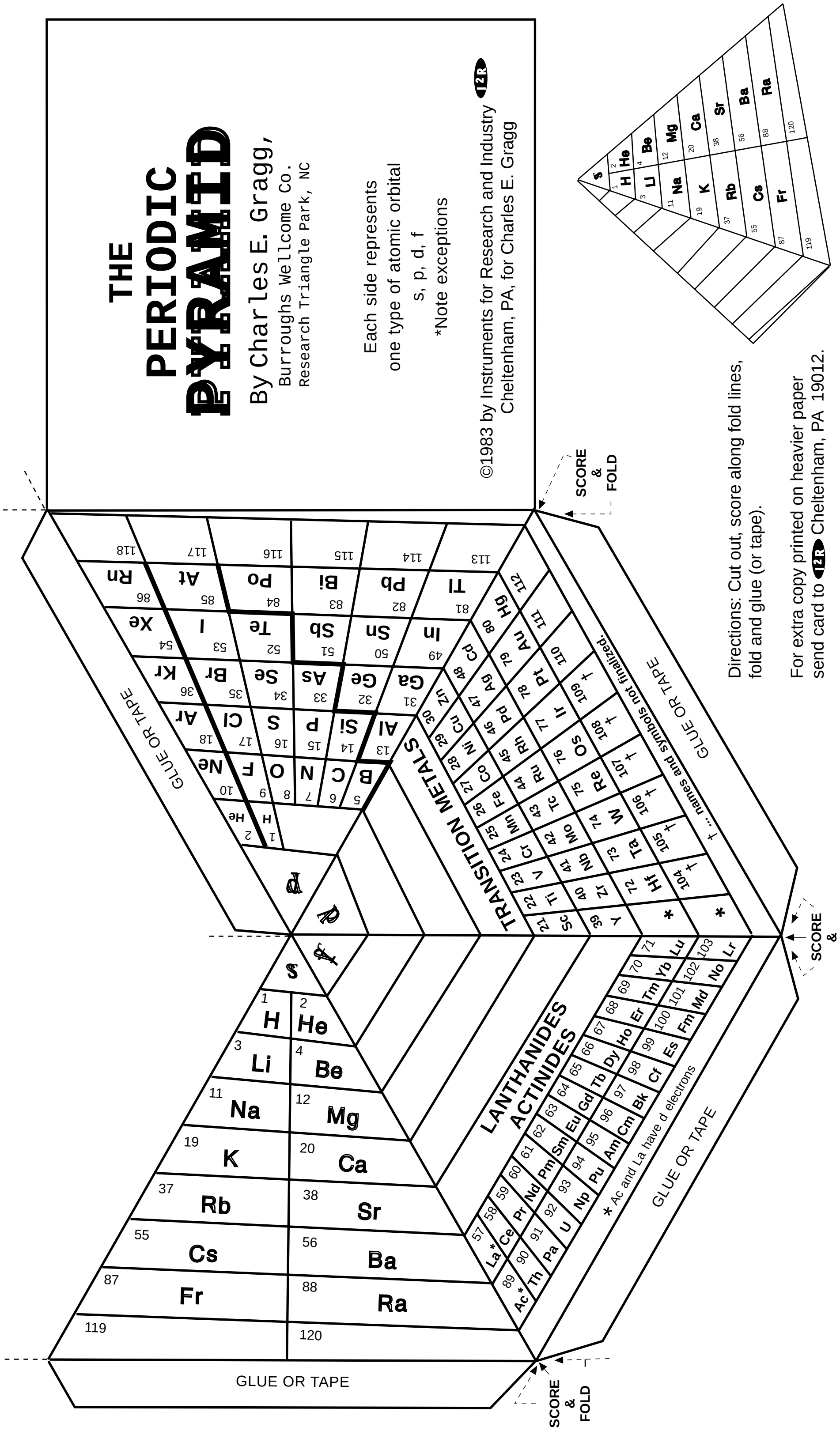
```
Y T I V I T A G E N O R T C E L E
L T B Q W A L C I D O I R E P B A
R A N Q Y Y S C F I Q A L T H B L
T B V O Y I Y W M J B W W T N G K
J A S R B G M L S A K U Q J F P A
Z Q R R R L Q E Q N C A D O E A L
Y Z N A B H E W E P O J T R D G I
X L U D Z N K G N N L L I H Q A M
Y W I H R Q O B A S B O S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

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

1. Half the distance of a single bond between two atoms of an element (2 words).
2. Measure of the attraction of an atom for a pair of shared electrons.
3. Energy required to remove the most loosely held electron of an atom in the gas phase (2 words).
4. Helium is one (2 words).
5. Astatine is one.
6. Elements in the first group (2 words).
7. Another name for group.
8. A horizontal row on the periodic chart.
9. Transition elements are in this section of the periodic chart.
10. ______ states that chemical and physical properties of the elements are periodic functions of their atomic number (2 words).

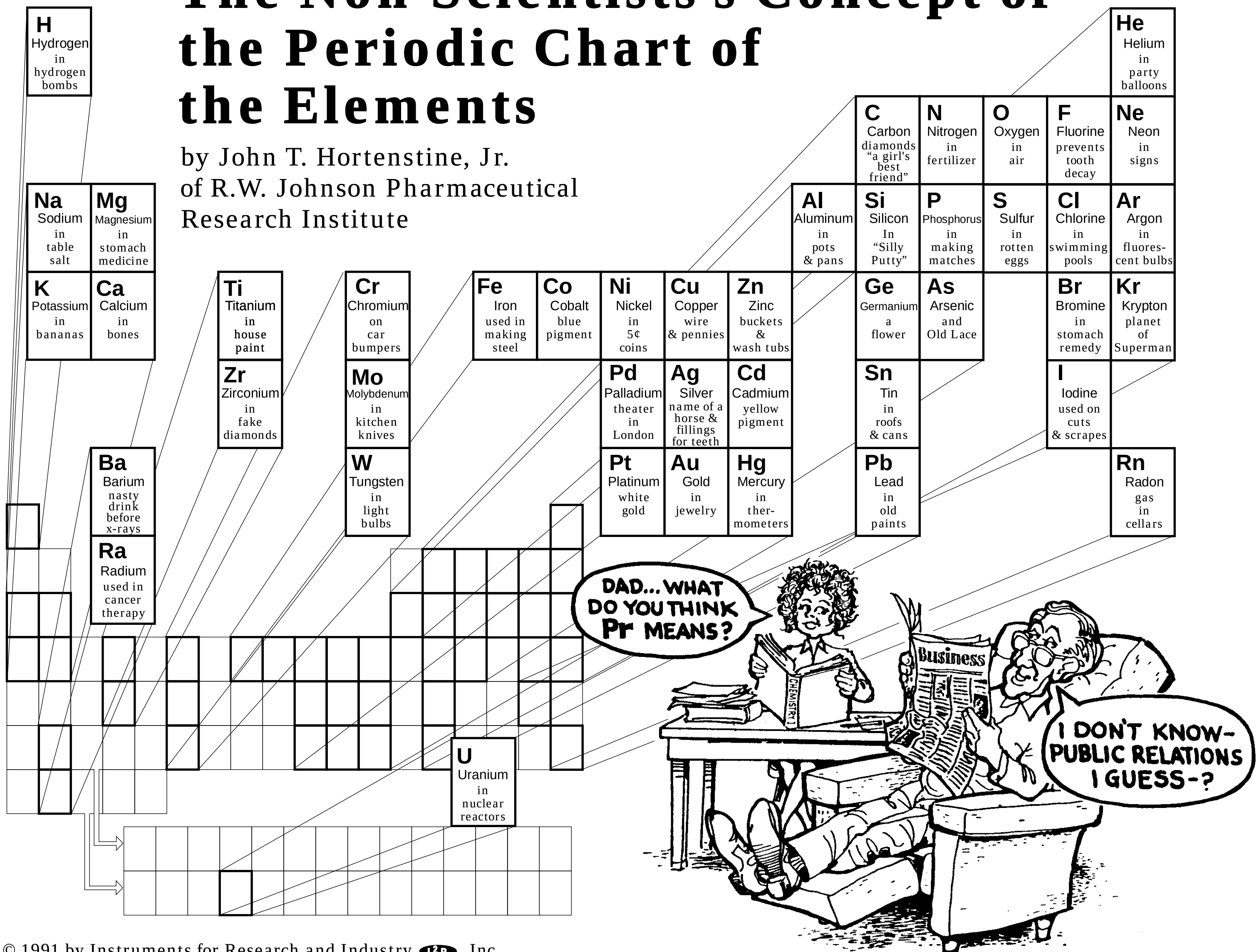
Identification of Selected Substances

Name	Formula	Color	Odor	Combustion	Mixes w/ water	Specific Test
Hydrogen	H_2	None	None	Burns	No	Burns explosively
Oxygen	O_2	None	None	Supports burning	No	Glowing splint flames
Carbon dioxide	CO_2	None	None	No	Yes	Turns lime-water milky
Nitrogen dioxide	NO_2	Brown	Choking	No	Yes	Mixed with water turns litmus red
Bromine	Br_2	Brown	Choking	No	Yes	Liquid at room temperature
Chlorine	Cl_2	Pale green	Choking	No	Yes	Forms yellow mixture with water
Ammonia	NH_3	None	Ammonia water	No	Yes	Mixed with water turns litmus blue
Sulfur dioxide	SO_2	None	Suffocating	No	Yes	Mixed with water turns litmus red
Hydrogen sulfide	H_2S	None	Rotten eggs	No	Yes	—
Hydrogen chloride	HCl	None	Choking	No	Yes	Mixed with water turns litmus red
Water vapor	H_2O	None	None	No	Yes	Cobalt chloride paper turns pink

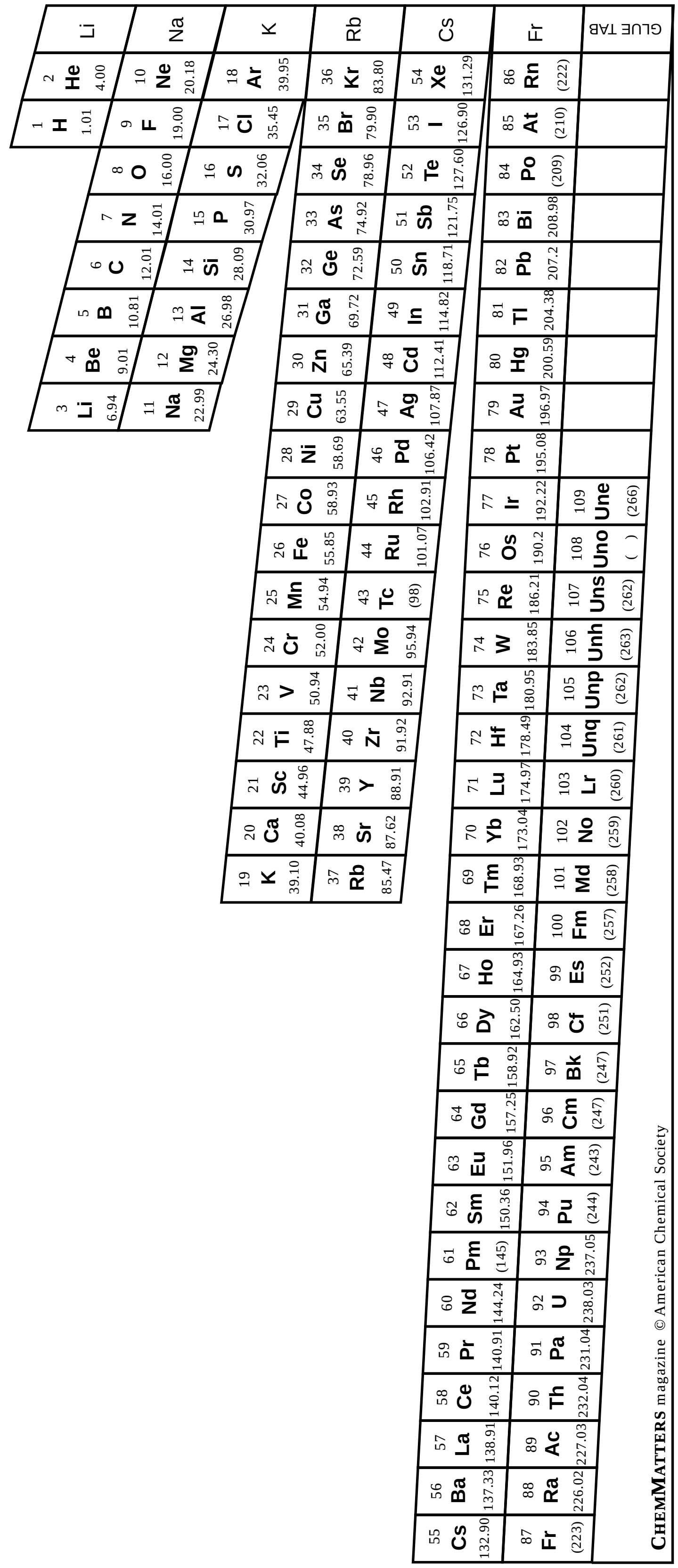

THE PERIODIC PYRAMID
By Charles E. Gragg,
Burroughs Wellcome Co.
Research Triangle Park, NC
Each side represents one type of atomic orbital
s, p, d, f
*Note exceptions
©1983 by Instruments for Research and Industry
Cheltenham, PA, for Charles E. Gragg
Directions: Cut out, score along fold lines, fold and glue (or tape).
For extra copy printed on heavier paper send card to I²R Cheltenham, PA 19012.
SCORE & FOLD
GLUE OR TAPE
TRANSITION METALS
LANTHANIDES
ACTINIDES
* Ac and La have d electrons
† ... names and symbols not finalized.

The Non-Scientists's Concept of the Periodic Chart of the Elements

by John T. Hortenstine, Jr.
of R.W. Johnson Pharmaceutical
Research Institute

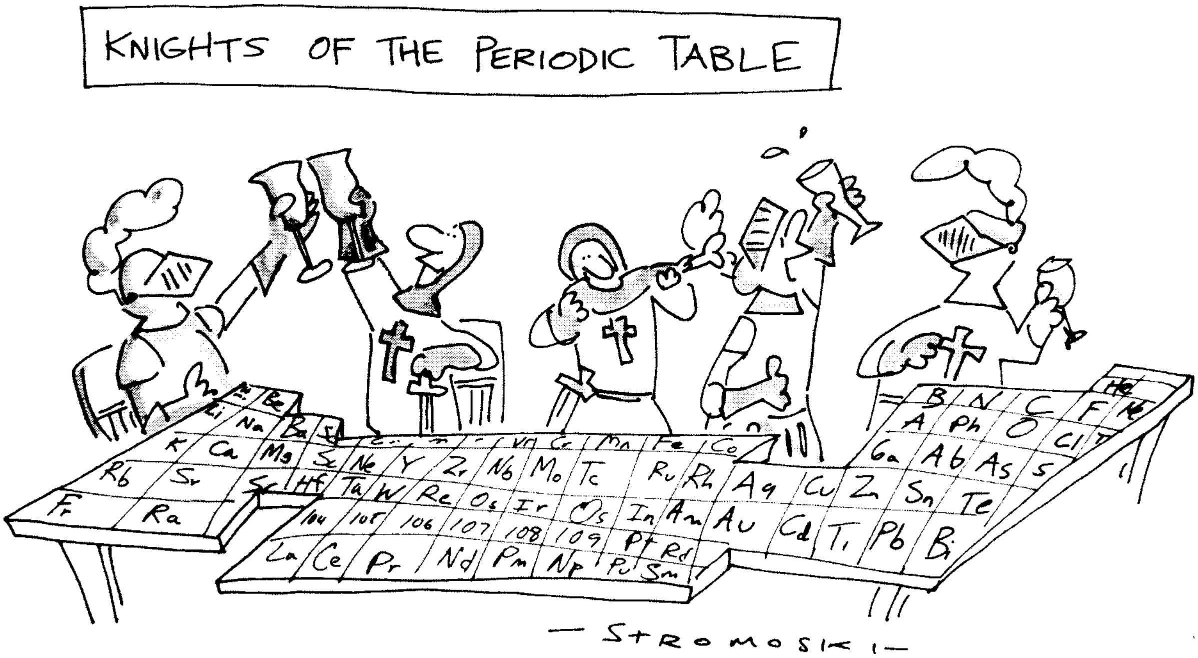


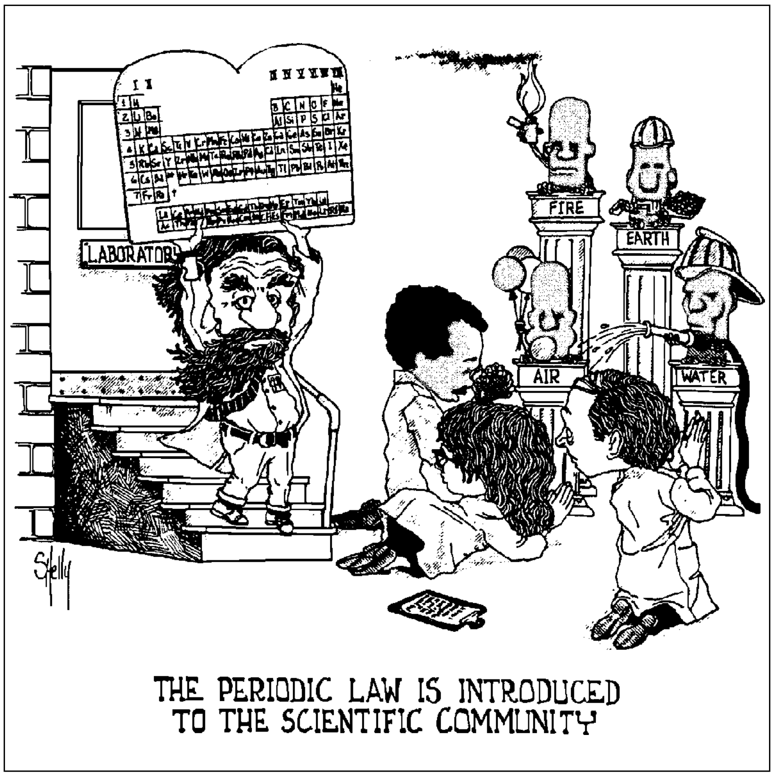
Spiral Periodic Chart Cut-Out



Some Very Uncommon Elements

Used by permission of Veritex Publishing Co.


KNIGHTS OF THE PERIODIC TABLE
— STROMOSKI —



Used with permission of McGraw-Hill Book Company.

Used with permission of Veritex Publishing Co.

Used with permission of Veritex Publishing Co.