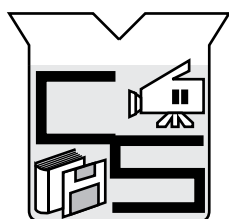
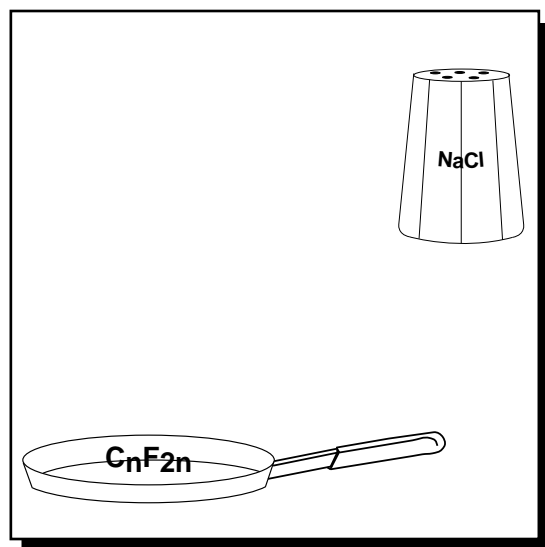


A SourceBook Module

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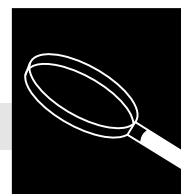


ChemSource

*Instructional Resources for Preservice and
Inservice Chemistry Teachers*

HALOGENS

Topic Overview

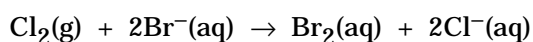


CONTENT IN A NUTSHELL

The elements fluorine, chlorine, bromine, iodine, and astatine form a group or family in the Periodic Table known as the *halogens* (salt formers). As a group, these elements are unique in several ways. All three states of matter are represented by halogens at room temperature and one atmosphere pressure: fluorine and chlorine are gases, bromine is a liquid, and iodine and astatine are solids. As elements, all exist as diatomic molecules. Because of their high reactivity, halogens are not found free in nature, but are usually produced from halide salts.

When considering the halogens, particularly during laboratory activities and demonstrations, one usually concentrates on chlorine, bromine, and iodine. There is a good reason for this. All known isotopes of naturally occurring astatine are radioactive with relatively short half-lives. It is estimated that only a few milligrams of astatine exist at the earth's surface at any particular time. Fluorine, on the other hand, has a single stable isotope and is the second most abundant of the halogens at the earth's surface—if the hydrosphere and lithosphere are combined; chlorine is most abundant. But fluorine is the most reactive of all elements, reacting with all other elements except the noble gases helium, neon, and argon. Fluorine, which is prepared by electrolysis, cannot be used for reactions in water solution because it oxidizes water, but can be stored in stainless steel vessels because protective fluoride coatings are formed.

The most obvious chemical property of halogen elements is their ability to act as oxidizing agents. The relative oxidizing ability of halogens corresponds to their order in the Periodic Table, $F_2 > Cl_2 > Br_2 > I_2$. This trend can be amply shown by a student laboratory activity and/or teacher demonstration and correlated to trends in atomic size, electron affinity, and electronegativity. Commercially, Cl_2 is obtained by the electrolysis of NaCl solution; Br_2 and I_2 are, in turn, produced by Cl_2 oxidation of Br^- and I^- , respectively. For example:



A major use of Cl_2 is in water treatment, where its action on pathogens has led to enormous improvement in the public's general health. All halogens are extensively used in the synthesis of organic compounds where properties may be tailored by replacing hydrogen atoms with halogen atoms. Of particular note are Freons and halogen-containing polymers such as polyvinyl chloride (PVC) and fluorine-containing Teflons. Many of these halogenated hydrocarbons have been found to be highly toxic, potential carcinogens or, as in the case of Freons, environmentally unsound and so have been or are being removed from general use.

All halogens, with the exception of fluorine, exhibit oxidation states of -1 , 0 , $+1$, $+3$, $+5$, and $+7$ (F exhibits only -1 and 0). The most common state is the halide or -1 state; crystalline metallic halides are common compounds. The iodide ion is a reasonably good reducing agent and can cause the reduction of metallic ions such as Fe^{3+} to Fe^{2+} and Cu^{2+} to Cu^+ . A clear distinction must be made between elemental halogens and halide ions during the study of "halogens."

Oxoanions and oxyacids of halogens are themselves potent oxidizing agents that, in the form of "bleaches," "cleaners," or pool additives, find their way into consumer products. Common liquid "chlorine" bleaches are not chlorine water solutions, but rather sodium or calcium hypochlorite solutions; the hypochlorite ion does the bleaching. *It should be emphasized that chlorine bleaches and ammonia-containing cleansers should never be mixed, since they react to form very toxic chloramine (NH_2Cl).*

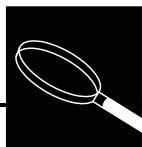
The importance of halogens to human history is detailed later, as are links between halogen chemistry and issues of importance to our everyday lives.

This descriptive module can be used in the first-year chemistry in a variety of places, either as a free-standing module taking cognizance of the related concepts and skills noted below, or selected parts of the module can be used in two or more parts of course(s) in multi-year chemistry/science curricula. For example, much of the material can be integrated into study of oxidation-reduction. Also, chemical and physical properties of halogens can be used as a part of a unit of study on the Periodic Table.

PLACE IN THE CURRICULUM

CENTRAL CONCEPTS

1. Halogens comprise a highly reactive family of elements that do not exist in the free state in nature but can be prepared electrochemically or chemically from halide melts or halide solutions (see *Laboratory Activity 1* and *Demonstration 1*).
2. Free halogen atoms (seven outer valence electrons) are one electron short of an eight-electron noble gas configuration. The atoms dimerize ($2X \rightarrow X_2$) or act as very strong oxidants ($X + e^- \rightarrow X^-$) to complete the octet of electrons.
3. Diatomic halogens are fairly strong oxidants ($X_2 + 2e^- \rightarrow 2X^-$; with $F_2 > Cl_2 > Br_2 > I_2 > At_2$). The reverse reaction can be obtained electrochemically or by stronger oxidizing agents. These reactive elements have characteristic properties, *e.g.*, at room temperature they exist as gases (fluorine and chlorine), a liquid (bromine), and solids (iodine and astatine) with colors ranging from light and medium yellow-greens for fluorine and chlorine through deep red for bromine to almost black with a metallic luster for iodine—although its vapor is a rich violet color (see *Laboratory Activity 2* and *Demonstrations 1b, 4*).
4. Halide ions (X^-) have noble gas electron configurations and are found in nature as stable crystalline solids (salts), that, with few exceptions, are soluble in water, are colorless unless colored by the cation component, and are used to form strong acids (except fluoride).
5. Halogens, except fluorine, form oxoanions (XO_n^-) that are highly reactive and can serve as bleaching agents and disinfectants similar to the elements themselves. Oxyhalogen ions provide another way for electron octet formation. These anions formally contain halogen atoms in positive oxidation states, which have even fewer valence electrons per halogen atom than in the free element. This is consistent with the fact that they are even stronger oxidants than are halogens.
6. Organic halogen compounds are rare in nature, although many useful and stable ones have been synthesized. They can be solids, liquids, or gases; some form very stable polymers. Halogens in these organics are covalently bonded to carbon, making organic halogen compounds inert, except in the presence of irradiation, heat, or catalysts. Unfortunately, many are highly toxic, and the stability of others is causing environmental problems.
7. Halogen elements provide trends that can be extended elsewhere in the Periodic Table. These include, but are not limited to, trends in oxidizing strength, atomic and ionic sizes, completion of the octet of electrons by sharing electrons or forming anions or oxoanions, and trends in electronegativities (see *Laboratory Activity 2* and *Demonstration 2*).



RELATED CONCEPTS

1. Redox (Oxidation-reduction concepts can be taught concurrently with this descriptive module.)
2. Acids and bases
3. Atomic structure, including ions
4. Bonding (electron-pair sharing and ionic aggregates in salts—the gas-to-solid trend can also be used in considering van der Waals or London dispersion forces)
5. Formula writing (nomenclature)
6. Equation writing and balancing
7. Electrochemistry (specifically, electron donation at the cathode and electron removal at the anode)
8. Solutions (one species dispersed in another as well as salts dissolved as solvated ions)
9. Periodicity

RELATED SKILLS

1. Ability to read carefully and follow instructions precisely.
2. Dexterity to handle and shake potentially hazardous solutions in small test-tubes and to handle a hot test-tube.
3. Arithmetic skills necessary for writing formulas and balancing equations.
4. Stoichiometry problems and quantitative laboratory activities should be added if this material is deferred until late in the year. (Representative sources for such quantitative material are listed at the close of this module.)

PERFORMANCE OBJECTIVES

Following their study of halogens, students should be able to:

1. identify halogens as a distinct family of elements.
2. describe the highly reactive nature of halogens.
3. describe how to prepare halogens electrochemically or chemically from halide melts of halide solutions.
4. identify the electron configuration of a halogen.
5. use electron configurations of halogen elements to explain why they dimerize and act as oxidants.
6. list halogens in order of increasing strength as oxidizing agents.
7. identify the characteristic properties of halogens.
9. recognize that halogens, except for fluorine, form oxyanions that are highly reactive and serve as bleaching agents and disinfectants.
10. demonstrate, with a Lewis diagram, how a halogen can complete its octet by forming an oxoanion in which the halogen has a positive oxidation state.
11. identify halogen-containing organic compounds.
12. explain, using the fact that halo-organic compounds are stable and thus desirable in applications, why halo-organic compounds pose an environmental problem.
13. use halogens as the basis for a confirmation of the periodic law.



Concept/Skills Development

Activity 1: Production and Chemistry of Chlorine

Introduction

Halogens represent a very reactive family of elements. One of the most common uses for halogens is as oxidizing agents.

Purpose

To prepare chlorine gas from common household bleach and use it to oxidize various materials.

Safety

1. Wear protective goggles throughout the laboratory activity.
2. Chlorine gas is highly corrosive and thus must *not* be allowed to enter the laboratory atmosphere. For this reason all work should be done in a properly operating fume hood. It is possible to detect the odor of chlorine at 3.5 ppm; chlorine is toxic at 1000 ppm.
3. Work toward the rear of the hood to avoid a backdraft of fumes from the front of the hood.
4. Be sure to empty carefully all three chlorine gas generator bottles into the NaOH wash solution when you complete the laboratory activity.
5. 12 M HCl is very corrosive and must be handled with care and dispensed in the hood.
6. When heating the steel wool in Step 6b be careful not to heat the test-tube and steel wool too strongly to avoid either melting the test-tube or igniting the steel wool.
7. Any substances spilled on your skin or clothing should be immediately washed off with large amounts of water and the incident should be reported to your teacher.
8. Dispose of all as your teacher directs.

Procedure

Part I. Preparation of Chlorine Gas

1. Obtain four wide-mouth bottles and one stopper fitted with a gas delivery tube. Place 70 mL of 2 M NaOH washing solution into one bottle (see Figure 1).
2. In all subsequent steps be sure to avoid splashing the sides of the bottles while adding the bleach and acid. Place 20 mL of commercial bleach into one bottle. Add 5 mL of concentrated HCl to the bleach and *immediately* insert the stopper fitted with gas delivery tube. Submerge the free end of the glass tube in the NaOH washing solution.
3. After a few seconds the bottle fitted with the stopper will be filled with chlorine gas, which you can then use in the tests.

LABORATORY ACTIVITY: STUDENT VERSION





Part II. The Oxidizing Power of Chlorine

Each of the following steps requires a fresh bottle of chlorine. Use the first bottle in Step 4, prepare another bottle in the manner described in Steps 1 through 3 for Step 5, and then yet another for Step 6. Cover the bottles with watch glasses or flat glass plates.

4. Obtain two strips of denim or other dyed cloth. Wet one strip of cloth with tap water; leave the other one dry. Remove the stopper and suspend each strip over the lip of the bottle filled with chlorine gas, making sure the strips do not touch each other. Cover the bottle. Record your observations.
5.
 - a. After you have prepared a new bottle of chlorine gas, obtain a strip of white paper. Write on it with pen, ordinary pencil, and various colored felt-tipped markers. Remove the stopper and suspend this paper in the bottle, once again covering the bottle with a watch glass or glass plate. Try other samples such as a strip of newsprint or a flower petal. Record your observations.
 - b. Repeat Step 5a with the same items moistened with tap water. Record your observations.
6.
 - a. Place a small amount of steel wool into a new bottle of chlorine gas; quickly cover the bottle. Record your observations.
 - b. Place a small (1-cm diameter) ball of steel wool into a clean, dry 15 x 150mm test-tube and, holding the test-tube with a test-tube holder, heat the tube and steel wool in a flame. Once the steel wool is hot, remove the cover from the bottle of chlorine gas used in Step 6a and quickly “pour” the steel wool into the bottle; replace the cover. Record your observations.
7. To clean up, remove the solids from the bottles (steel wool, cloth, paper, and other tested items) with forceps and dispose of as directed by your teacher. Carefully and slowly pour the entire contents of the three chlorine gas generator bottles into the bottle containing 70 mL of NaOH wash solution. Pour the entire contents down the drain in the fume hood, while flushing with plenty of water. Then carefully rinse all bottles with tap water three times.
8. Thoroughly wash your hands before leaving the laboratory.

Data Analysis

1. Which strip of cloth—wet or dry—reacted more with chlorine? On what observation did you base your answer?
2. Which marks written on the paper reacted with chlorine? On what observation did you base your answer?
3. Which piece of steel wool—hot or room temperature—reacted to a greater extent with chlorine? On what observation did you base your answer?

Implications and Applications

1. Write a balanced equation representing the reaction of bleach solution with acid. Assume the bleach solution is NaClO(aq).
2. Why is it important to keep the sides of the bottles dry?
3. Provide reasons for your observation regarding the reactivity of wet *vs.* dry materials.

4. Was there any pattern to the reactivity of the inks? Can you make any generalization about their reactivity toward chlorine?
How do you account for the behavior of the pencil mark on the paper?
5. a. Why did one piece of steel wool react more vigorously than the other? Did you expect this?
b. Why did you not just heat the steel wool in the flame directly?
6. Write a balanced equation for the reaction of chlorine with steel wool, assuming the steel wool is pure iron.
7. Would you expect fluorine to react similarly to chlorine in the above tests? Why?
8. Would you expect bromine to react similarly to chlorine in the above tests? Why?

Chlorine Gas Preparation

The excess chlorine gas is absorbed into NaOH solution rather than into air. [Franz and Malm. (1968, 1969). *Fundamental experiments for college chemistry* (2nd Ed.). San Francisco, CA: Freeman.]

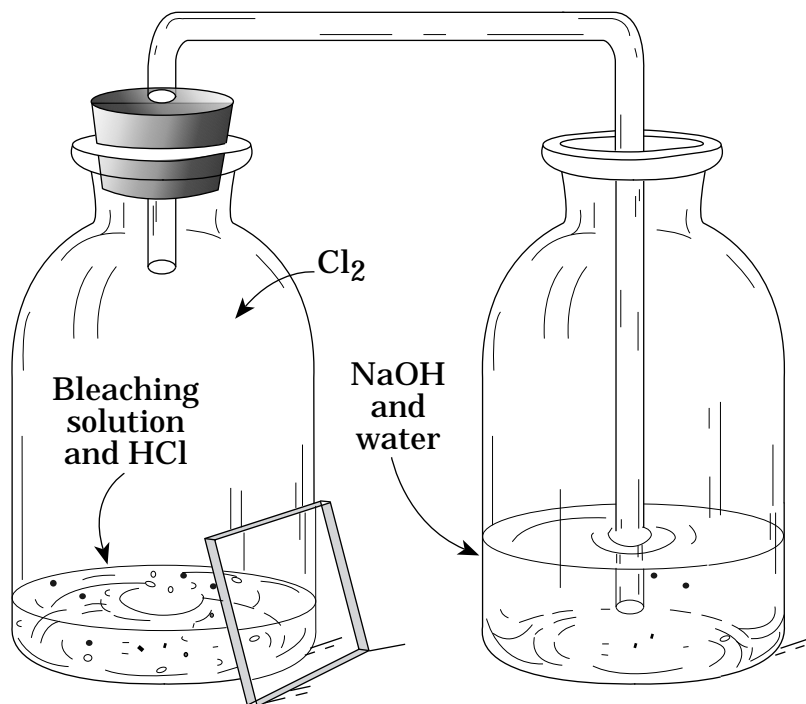


Figure 1. Apparatus for chlorine generation.



**LABORATORY
ACTIVITY:
TEACHER
NOTES**

Activity 1: Production and Chemistry of Chlorine

Major Chemical Concept

This is an introductory laboratory activity, designed to be descriptive in nature, involving the reactivity of chlorine gas.

Level

Activity appropriate for basic, general, and honors students.

Expected Student Background

The major prerequisite for this laboratory activity is the ability to follow written instructions, make observations, and handle hazardous materials safely. You may choose to include this activity early in the year, since very little chemical knowledge is required.

Related concepts somewhat depend upon when this activity is used and what principles are being developed. Related concepts needed for understanding this activity include atomic structure, ions, formula writing, and equations. The activity is useful in developing an understanding of oxidation-reduction and periodicity.

Time

While the time to complete the activity depends on the availability of hood space and the number of students trying to use each hood, work can be completed in one 45-min period. Teacher preparation time will be about one hour, provided the glass tubing is already prepared. If not, then about a half-hour extra is required.

Safety

1. If insufficient hood space is available, consider conducting this activity as a demonstration. The chlorine is generated and stored in the hood; you then carry individual gas bottles (covered) back to the demonstration bench as needed. The bottles are *only* uncovered long enough to insert materials and then *immediately* recovered. Items to be investigated can be taped to other cover glasses, which then replace the original cover glasses.
2. Be certain the laboratory has adequate ventilation and is vented to outside of the school before you do this activity. The NaOH traps are very effective in preventing chlorine from entering the atmosphere.
3. Allow each student adequate room in the fume hood. Crowding can lead to accidents. The need for a burner in Step 6b means that only two students should work in a normal 4-foot hood.
4. An acid pump is recommended for dispensing the 12 M HCl to avoid the hazard of spills. Alternatively, a buret makes a very safe dispenser for small amounts of acid if you lack an acid pump. You must cover, but not seal, the top of the buret; students should still dispense the acid into a graduated cylinder. The reason for this is that it will be quicker and safer than trying to use buret markings to determine the volume and, more importantly, the acid must be added to the bleach quickly since the reaction is so rapid. Recognize, however, that the buret will need to be refilled often if you are supplying a large class.
5. **CAUTION:** Chlorine bleaches and ammonia-containing cleansers should never be mixed, since they react to form very toxic chloramine (NH_2Cl). *No bottles of aqueous ammonia should be present on the benches during this activity. An inadvertent error could cause a serious problem.*

Materials (For 24 students working in pairs)

- 48 Wide-mouth bottles, 250-mL capacity
- 12 Rubber stoppers fitted with glass tubes
- Chlorine bleach, such as Clorox™
- 2 M Sodium hydroxide, NaOH, 1 L (80 g diluted to 1 L)
- 12 M Hydrochloric acid, HCl, 250 mL
- 12 Graduated cylinders, 10- and 100-mL sizes
- 36 Pyrex watch glasses or flat glass plates to cover the bottles
- 12 Strips of denim and/or other dyed cloth (used or prewashed so it wets easily)
- 12 Strips of newsprint
- 12 Flower petals
- Other items to be bleached—add your own items to the list, *but test them first!*
- A small amount of fine steel wool. (*NOTE: Inexpensive, commercial steel wool is often oil coated and gives poor results.*)
- 12 Test-tubes, 15- x 150-mm
- 12 Test-tube holders
- 12 Burners and lighters
- 12 Pairs forceps

Advance Preparation

Complete the activity yourself with the bleach you intend to use. It would be wise to use a fresh bottle of bleach. If the bleach is old you may not get much reaction, and thus not much chlorine. Should you find yourself without any bleach, consult the school custodian.

Pre-Laboratory Discussion

Insure that students understand the safety instructions. Demonstrate proper placement of the stopper in the chlorine generator and the glass tube in the NaOH solution. Also focus on the difference between *chlorine* and *chloride*.

Teacher-Student Interaction

Monitor the generation of gas in the hood. This way you can prevent the release of unwanted gas into the atmosphere and ensure that things are working properly.

Expect students to want to test the reactivity of chlorine with such unorthodox items such as hair, gum, or anything else that they can find. *This must be prevented!*

Anticipated Student Results**Data Analysis**

(These answers correspond to *Data Analysis* Questions 1, 2, and 3.)

1. **Step 4:** Wet strips of cloth will discolor more quickly and completely than the dry ones. From this observation it is concluded that the wet strips reacted more with the chlorine.
2. **Step 5:** The blue inks will turn brown. Felt-tipped marker behavior must be determined by trial. Do this yourself. The pencil mark will not discolor. These observations help determine which inks reacted more with the chlorine.
3. **Step 6:** Cool steel wool will not react; hot steel wool will react vigorously with evolution of much brown smoke. From these observations it can be concluded that the hot steel wool reacted more vigorously with chlorine.

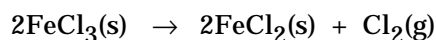


Answers to Implications and Applications

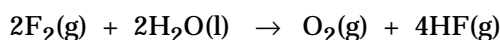
1. $2\text{HCl}(\text{aq}) + \text{NaClO}(\text{aq}) \rightarrow \text{Cl}_2(\text{g}) + \text{NaCl}(\text{aq}) + \text{H}_2\text{O}(\text{l})$
2. The sides must be dry so the strips of tested material are not able to react with the bleach or acid—the observed results are thus due only to reaction with chlorine gas.
3. The wet cloth reacts faster and more completely than does the dry cloth because the gas can dissolve in the water and be brought into chemical contact with the dye.
4. It is expected that some inks will be more reactive than others. Therefore, you will need to determine the answer to this question by testing the actual inks used. (We anticipate that the wet paper, and “wetter” inks should be more reactive than the dry ones.)

The pencil “lead” is actually graphite (carbon), and carbon is not reactive with chlorine at room temperature. (It is only reactive with chlorine at very high temperatures.)

5. a-b. The cool steel wool (iron) does not react rapidly due to the activation energy required. Hot steel wool possesses the needed activation energy. The steel wool was not heated directly in the flame because it would be oxidized in the flame—there could be some confusion regarding what caused the reaction.
6. $3\text{Cl}_2(\text{g}) + 2\text{Fe}(\text{s}) \rightarrow 2\text{FeCl}_3(\text{s})$. Iron in the III oxidation state is expected because chlorine is an oxidizing agent, although above 500 °C FeCl_3 begins to spontaneously reduce to FeCl_2 :



7. Yes. It would be expected, based upon element positions on the Periodic Table, that fluorine would be even more reactive than chlorine toward the test materials. Note that the following side reaction also occurs with fluorine:



8. It would be expected, based upon positions in the Periodic Table, that bromine would be less reactive than chlorine toward all test materials.

Post-Laboratory Activities

Allow students ample time to answer the questions before discussing the laboratory activity.

Possible Extensions

1. You may repeat Steps 4 through 6 with chlorine bleach and compare the results with those involving chlorine gas. Note that the oxidizing agent in bleach is the hypochlorite (ClO^-) ion.
2. You may also repeat Steps 4 through 6 with nonchlorine bleach and compare results with those of the chlorine gas and chlorine bleach.
3. a. If this activity comes after a study of kinetics, students can understand that the vigor of an oxidation-reduction reaction can depend on the concentrations of reactants. For example, to illustrate redox and the concept of relative oxidation strengths, heat the steel wool directly in the flame and compare the reaction to steel wool in chlorine. This is evidence that chlorine is more reactive than the oxygen in the air. (Be sure to compare the reactivities with the same grade (fineness) and compactness of “wad.”)

- b. To further reinforce this concept, point out that oxygen in air does not oxidize the dye in their clothing or any other materials they tested.
- c. Recognizing that the Cl_2 concentration in the bottle is higher than that of O_2 in air, you could drift into a discussion that includes more than you had probably intended. The whole concept of concentration effects and their importance in reaction kinetics is probably beyond most students. You may recall, however (even though your students will not) that the concentrated oxygen environment of the first *Apollo* spacecraft was blamed for the fire that killed three men on the launch pad and resulted in the destruction of much of the space capsule contents.

Assessing Laboratory Learning

Written Examination

1. Write equations to represent the reactions of chlorine gas with the materials tested. What is the main feature of all of the reactions?
2. Comment on the reactivity of chlorine gas and predict how fluorine gas, bromine vapor, or iodine vapor would react with the same materials.



**LABORATORY
ACTIVITY:
STUDENT
VERSION**

**Activity 2: *Relative Reactivity of
Halogens and Halides***

Introduction

The halide anions and halogen elements are appreciably different in their tendencies toward oxidation and reduction.



Purpose

To determine the relative ease of oxidation of chloride, bromide, and iodide ions and the relative oxidizing strengths of their respective elements.

Safety

1. Wear protective goggles throughout the laboratory activity.
2. Do not inhale vapors from the halogens or cyclohexane.
3. All reagents should be placed in the fume hood and dispensed from there.
4. Do not interchange droppers used to dispense the solutions.
5. No operating burners or other flames should be present in the laboratory during this laboratory activity.
6. Any chemicals spilled on your skin or clothing should be immediately washed off with large amounts of water; report the incident to your teacher.
7. Do not cover the test-tubes with your thumb to mix the reagents—use a cork instead. Corks should not be interchanged and should be left loose on the test-tubes after mixing.
8. Read the labels carefully; *e.g.*, *chloride* vs. *chlorine*.
9. Dispose of the materials as your teacher directs.

Procedure

1. Obtain nine small, clean test-tubes. They need not be dry since aqueous solutions will be placed in them. With a wax crayon, label them from 1 to 9. To one test-tube, add 1 mL water. Mark the level with a wax crayon. Add two successive milliliters water and mark the tube at the 2- and 3-mL levels. Using this test-tube as a guide, mark the other eight test-tubes in a similar fashion.
2. Take Tubes 1-6 to the hood.
In Tube 1 place 1 mL chlorine water, $\text{Cl}_2(\text{aq})$;
in Tube 2 place 1 mL bromine water, $\text{Br}_2(\text{aq})$;
in Tube 3 place 1 mL iodine water, $\text{I}_2(\text{aq})$;
in Tube 4 place 1 mL potassium chloride (KCl) solution;
in Tube 5 place 1 mL potassium bromide (KBr) solution; and
in Tube 6 place 1 mL potassium iodide (KI) solution.

(Remember, KCl in aqueous solution consists of K^+ ions and Cl^- ions. KBr and KI are also dissociated in aqueous solution.)
3. Add a few drops of cyclohexane to the first tube. Note whether the cyclohexane floats or sinks to the bottom. Use this observation to determine the position of the cyclohexane layer in all succeeding trials.

- Add 1 mL cyclohexane to Test-Tubes 1-6. Stopper, shake, and loosen stopper. Record the colors of the top and bottom layers in all test-tubes. (Colors in the cyclohexane layers are due to the extraction of chlorine, bromine, or iodine into the organic layer.)
 - Save and use Tubes 1-6 for comparison later.
 - Take Tubes 4-9 to the hood.
In Tubes 4 and 7, place 1 mL KCl solution;
in Tubes 5 and 8, place 1 mL KBr solution; and
in Tubes 6 and 9, place 1 mL KI solution.
 - Place 1 mL $\text{Cl}_2(\text{aq})$ in Tubes 5 and 6;
place 1 mL $\text{Br}_2(\text{aq})$ in Tubes 4 and 9; and
place 1 mL $\text{I}_2(\text{aq})$ in Tubes 7 and 8.
- Shake each test-tube after stoppering it as above. Then remove the corks and add 1 mL cyclohexane to each tube (4-9). Re-stopper, shake the test-tubes to observe the layering of the halogen that is present in the tube after the initial shaking. Prepare a data table (see Figure 2). Record the colors in both layers of each test-tube.
- Show your data table and test-tubes to your teacher before discarding the tube contents in the appropriate waste container. Rinse and clean the tubes thoroughly and return them to the appropriate place in your laboratory.
 - Thoroughly wash your hands before leaving the laboratory.

Data Analysis

- From the colors in Tubes 4-9 and the reagents you added, determine in which test-tubes a chemical reaction occurred. (For example, if the color of the cyclohexane layer in Tube 4 is similar to that in Tube 2, no reaction occurred between bromine and the chloride ion. However, if the color in the cyclohexane layer of Tube 4 is similar to that in Tube 1, bromine *has* reacted with the chloride ion to produce chlorine and the bromide ion.)
- Record your results (color) in a table such as the one shown. Also draw each tube and use colored pencils to record your results.

	Cl^-	Br^-	I^-	None	
Cl_2		(5)	(6)		Cyclohexane layer
		(5)	(6)	(1)	Water layer
				Control	Reaction?
Br_2	(4)		(9)	(2)	Cyclohexane layer
	(4)		(9)	(2)	Water layer
				Control	Reaction?
I_2	(7)	(8)		(3)	Cyclohexane layer
	(7)	(8)		(3)	Water layer
				Control	Reaction?

Figure 2. Data table format. (Numbers in parentheses refer to the test-tube number.)



Implications and Applications

1. If you were given an unknown solution containing one of the halide ions (Cl^- , Br^- , or I^-), what single, simple test could you use to determine which ion was in the solution? Describe the procedure and results expected for each of the three ions.
2. Rank the three halogen elements used in terms of their relative oxidizing ability, from the strongest oxidizer to the weakest.
3. How does the order of the halogens specified in Question 2 compare with their relative positions in the Periodic Table? Based on its position in the Periodic Table, would you expect fluorine to be a stronger or weaker oxidizing agent than the other halogen elements studied here?
4. Write a net ionic equation for each reaction that occurred in your trials.

**Activity 2: Relative Reactivity of
Halogens and Halides****LABORATORY
ACTIVITY:
TEACHER
NOTES****Major Chemical Concept**

Halide ions and halogens differ in their tendencies toward oxidation and reduction.

Level

Activity appropriate for basic, general, and honors students.

Expected Student Background

Related concepts needed for this exercise include oxidation-reduction, ions, formula writing, equations, and periodicity. Required laboratory skills include following directions fully and the ability to handle potentially hazardous materials.

Time

40 min of work time—longer if insufficient hood space is available.

Safety

1. Read the *Safety* section in the student procedure.
2. Place all reagents in dropping bottles to facilitate dispensing by students. We recommend plastic bottles with nonrubber dropper tops for $\text{Cl}_2(\text{aq})$, $\text{Br}_2(\text{aq})$, and $\text{I}_2(\text{aq})$. If rubber dropper tops are used, check the caps and replace any that have cracks. *Do not* store halogen solutions in bottles with rubber dropper tops.
3. Place all solutions in scrupulously clean bottles.

Materials (For 24 students working in pairs)

See previous safety suggestions regarding reagents and reagent bottles.

12 Test-tube blocks or racks

108 Test-tubes, 13- x 100-mm

108 Corks to fit test-tubes

Cyclohexane or mineral spirits (paint thinner), 150 mL

0.1 M Potassium chloride, KCl, 100 mL (0.75 g KCl per 100 mL solution)

0.1 M Potassium bromide, KBr, 100 mL (1.2 g KBr per 100 mL solution)

0.1 M Potassium iodide, KI, 100 mL (1.7 g KI per 100 mL solution)

Chlorine water, $\text{Cl}_2(\text{aq})$, 100 mL

Bromine water, $\text{Br}_2(\text{aq})$, 100 mL

Iodine water, $\text{I}_2(\text{aq})$, 100 mL

The 0.1 M solutions of KCl, KBr, and KI are made by dissolving 0.75 g potassium chloride, 1.2 g potassium bromide, and 1.7 g potassium iodide, respectively, in sufficient distilled water to make up 100 mL solution. This is enough for 20 student groups. The X_2 solutions are commercially available chlorine water, bromine water, and iodine water.

Waste disposal bottles to hold about 100 mL waste solutions per student group should be available (see waste disposal information in the *SourceBook Safety* section).



Advance Preparation

1. Chlorine water solution cannot be stored for extended periods. It has a very short shelf-life and should be tested just before students are to start the activity—*i.e.*, check with KBr solution to ensure that enough bromine is liberated to be extracted into the cyclohexane layer. (The formation of a yellow color in the aqueous layer is not conclusive.) In an emergency, chlorine water can be prepared by setting up the apparatus shown in *Laboratory Activity 1* of this module and bubbling the generated chlorine into water.
2. Inspect the KI solution for decomposition. Even if no coloration is visible, several milliliters of KI can be tested with a few drops of starch solution. A blue color indicates that a fresh solution is needed. If corks are reused from class to class, be sure they are washed thoroughly.
3. Be sure to complete the laboratory activity yourself before allowing students to attempt it.
4. Tell students to shake test-tubes for a fairly long time.

Pre-Laboratory Discussion

Insure that students understand all safety instructions. Consider a brief review of related concepts (see *Expected Student Background*). Stress the nomenclature distinction between halide ions (such as chloride, Cl^-) and halogens (such as chlorine, Cl_2).

Teacher-Student Interaction

The teaching value of this laboratory activity can be increased if you move from group to group and ask students about the Part 1 extractions to ensure that they understand the difference between an *extraction* and a *chemical reaction*. Confirm that students follow safety instructions provided. During Part 1, stress the importance of allowing the aqueous components to react prior to extraction. Students may be tempted to mix all three components together, which, unfortunately, would minimize the chance of complete reaction in a short time span and may generate ambiguous results. Students should shake the cork-stoppered test-tubes *thoroughly* to promote extraction.

Anticipated Student Results

1. **Procedure Step 3** The cyclohexane layer remains above the water layer.
2. **Procedure Step 4**
 - Tube 1** top (cyclohexane) layer: yellow; bottom (water) layer: colorless
 - Tube 2** top (cyclohexane) layer: orange; bottom (water) layer: light yellow
 - Tube 3** top (cyclohexane) layer: violet; bottom (water) layer: light yellow
 - Tube 4** top (cyclohexane) layer: colorless; bottom (water) layer: colorless
 - Tube 5** top (cyclohexane) layer: colorless; bottom (water) layer: colorless
 - Tube 6** top (cyclohexane) layer: colorless; bottom (water) layer: colorless
3. **Steps 6 and 7** See Data Table

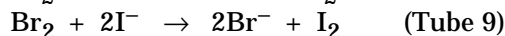
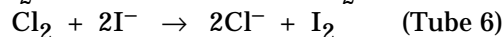
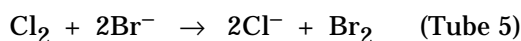
	Cl ⁻	Br ⁻	I ⁻	None	
Cl ₂		Orange (5)	Violet (6)	Yellow	Cyclohexane layer
		Lt. yellow (5)	Lt. yellow (6)	Colorless (1)	Water layer
		Yes	Yes	Control	Reaction?
Br ₂	Orange (4)		Violet (9)	Orange (2)	Cyclohexane layer
	Lt. yellow (4)		Lt. yellow (9)	Lt. yellow (2)	Water layer
	No		Yes	Control	Reaction?
I ₂	Violet (7)	Violet (8)		Violet (3)	Cyclohexane layer
	Lt. yellow (7)	Lt. yellow (8)		Lt. yellow (3)	Water layer
	No	No		Control	Reaction?

Figure 3. Sample data table.

Answers to Implications and Applications

1. Add chlorine water to the solution containing the halide ion and shake. Add cyclohexane and shake again. A yellow color in the cyclohexane layer indicates no reaction occurred—the anion must have been chloride. However, an orange layer indicates formation of bromine—the anion must have been bromide. A violet layer indicates iodine—the anion would be iodide in this case.
2. Chlorine is the strongest oxidizing agent, bromine is intermediate, and iodine is the weakest oxidizing agent.
3. The higher the halogen is located in the Periodic Table, the stronger its character as an oxidizing agent. On this basis, fluorine would be expected to act as a stronger oxidizing agent than chlorine—which is true.
4. **Step 4:** No chemical reactions take place.

Steps 6 and 7:



Post-Laboratory Activity

Help develop the *Answers to Implications and Applications* Question 1 and then demonstrate the reaction of chlorine water with an unknown halide ion solution.

Possible Extensions

1. Each student could be given an unknown halide ion solution and asked to determine which halide ion it contains, again using the procedure developed in Question 1.
2. The relative reactivity of halide ions as reducing agents could be explored by more advanced students. Iron(III) and copper(II) are allowed to react with iodide and bromide ion solutions. The iodide ion reduces both metal ions—to iron(II) and copper(I), respectively. The bromide ion is unable to reduce either metal ion.



Assessing Laboratory Learning

Laboratory Practical

Each student could be given an unknown halide ion solution and asked to determine which halide ion it contains, again using the procedure developed in Implications and Applications Question 1.

Demonstration Examination

Same as laboratory practical, but you would demonstrate the tests on one or more “unknowns” with students observing the results and identifying the ion in the unknown or unknowns.

Written Examination

- Write net ionic equations for the reaction between
 - Cl_2 and Br^- [$\text{Cl}_2 + 2\text{Br}^- \rightarrow \text{Br}_2 + 2\text{Cl}^-$]
 - Cl_2 and I^- [$\text{Cl}_2 + 2\text{I}^- \rightarrow \text{I}_2 + 2\text{Cl}^-$]
 - Br_2 and I^- [$\text{Br}_2 + 2\text{I}^- \rightarrow \text{I}_2 + 2\text{Br}^-$]
- Consider the data table (see Figure 4). In which trials did a reaction occur? Explain your reasoning for each answer.

Data for combinations of Br_2 and halide ions

	Cl^-	Br^-	I^-	
Br_2	Orange	Orange	Violet	Cyclohexane layer
	Lt. yellow	Lt. yellow	Lt. yellow	Water layer
				Reaction?

Figure 4. Colors observed in bromine-halide systems.

[TEACHER NOTE: Bromine has not reacted with Cl^- or Br^- , since Br_2 color appears in organic layer. Br_2 has reacted with I^- to give I_2 .]

Note that another row or column could be used for this question.

- Consider another halogen element X. An organic solvent added to an X_2 solution exhibits a colorless organic layer by itself, even when shaken vigorously. When X_2 solution is added to solutions of chloride, bromide, and iodide ions, the results shown below are observed.

Data for combinations of X_2 and halide ions

	Cl^-	Br^-	I^-	
X_2	Yellow	Orange	Violet	Cyclohexane layer
	Colorless	Lt. yellow	Lt. yellow	Water layer
				Reaction?

Figure 5. Unknown halogen sample data table.

Where does this halogen fit in the Periodic Table relative to Cl, Br, and I?
[TEACHER NOTE: This is undoubtedly fluorine, since Cl_2 , Br_2 , and I_2 have been produced. A similar table with a fictitious element or with astatine could be developed.]

Suggestions for Other Laboratory Activities

A quantitative laboratory activity might be advisable if this material is presented late in the school year—provided you perform demonstrations that cover the principles involved in the laboratory activities presented here. One quantitative activity is the “Ferric Ion/Iodide Ion Reaction” of the *Doing Chemistry* Videodisc Set, distributed by the Education Division, American Chemical Society, 1155 16th Street, N.W., Washington, DC 20036.

Demonstration 1: Halogen and Halide Reactivity

Option A

The reactivity of a halogen *vs.* relative nonreactivity of the halide ion:

Safety

Follow the standard safety procedures for any demonstration. For this particular demonstration, be sure to:

1. Wear protective goggles and apron.
2. Wash off any chemicals spilled on your skin or clothing with large amounts of tap water.
3. Dispose of chemicals by dissolving them in tap water and washing them down the drain with copious amounts of tap water.

Materials

Sodium chloride (table salt) solution (any concentration) in a beaker
Chlorine water in another beaker
Strips of denim or other cotton cloth

Directions

Dip a strip of cotton denim into an aqueous solution of sodium chloride. Dip another strip into a fresh chlorine water solution. The strips of cloth should be large enough to be seen by all students. Pass the strips around the class *after* washing the strips in water to remove excess sodium chloride and chlorine.

(This simple demonstration can set the stage for *Laboratory Activity 1*.)

Option B

As a counterintuitive demonstration, solutions of potassium bromide and potassium iodide can be mixed with solutions of iron(III) and copper(II) chlorides.

Materials

1 M Potassium bromide, KBr, 10 mL (1.2 g KBr per 10 mL solution)
1 M Potassium iodide, KI, 10 mL (1.7 g KI per 10 mL solution)
1 M Copper(II) (cupric) chloride, CuCl_2 , 10 mL (1.7 g $\text{CuCl}_2 \cdot 2\text{H}_2\text{O}$ per 10 mL solution)
1 M Iron(III) (ferric) chloride, FeCl_3 , 10 mL (2.7 g $\text{FeCl}_3 \cdot 6\text{H}_2\text{O}$ per 10 mL solution)
8 Small Petri dishes on overhead projector (image quality is best with plastic Petri dishes, intermediate with glass Petri dishes, and poorest with small beakers)

DEMONSTRATIONS



Directions

Pour a layer of the four respective solutions thick enough to see the color in four Petri dishes as controls (see Figure 6). Then pour equal volumes of the Fe^{3+} solution in two remaining dishes and equal volumes of Cu^{2+} solution in the final two dishes. Add equal volumes of potassium bromide to one dish containing Fe^{3+} and one containing Cu^{2+} . Note any color changes. Now add equal volumes of potassium iodide solution to the second dish of Fe^{3+} and Cu^{2+} solutions. Observe the color changes. (Iodide is able to reduce these ions to Fe^{2+} and Cu^+ , respectively, with concurrent changes in the brown color of iodine in water.) As an extra touch, the brown solutions can be transferred by pipets to test-tubes. Add cyclohexane, stopper, and shake to transfer the iodine to the cyclohexane layer. The violet color can be observed on the overhead projector if the cyclohexane layers are transferred to Petri dishes.

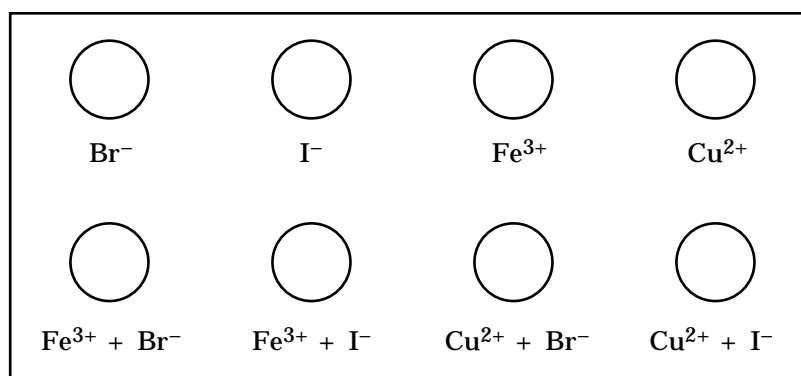


Figure 6. Arrangement of Petri dishes and labels on overhead projector stage.

Alternatively, the demonstration can be presented on a larger scale with more dilute solutions from a demonstration bench at the front of class. In this case, color changes are more readily observed if a sheet of white posterboard is placed behind the solutions.

This demonstration can be made an extension of *Laboratory Activity 2*. This develops a more thorough understanding of relative oxidizing and reducing abilities of redox couples as well as better understanding of halogen chemistry.

Demonstration 2: Chlorine Production by Electrolysis of a Chloride Solution

Introduction

$\text{CuCl}_2(\text{aq})$ is electrolyzed rather than $\text{NaCl}(\text{aq})$ since it removes possible confusion inherent in simultaneous production of $\text{H}_2(\text{g})$ and $\text{Cl}_2(\text{g})$.

Safety

Follow the standard safety procedures for any demonstration. For this particular demonstration, please be sure to:

1. Wear protective goggles and apron throughout the demonstration.
2. Wash off any chemicals spilled on your skin or clothing with large amounts of tap water.
3. Dispose of chemicals by dissolving them in tap water and washing them down the drain with copious amounts of tap water.

Materials

- 1 M Copper(II) chloride, CuCl_2 , 50 mL (8.5 g $\text{CuCl}_2 \cdot 2\text{H}_2\text{O}$ per 50 mL solution)
- Petri dish
- 2 Mechanical pencil “leads” (about 6 cm long; graphite) or larger diameter graphite rods
- 2 1.5-V Dry cells connected in series with alligator clip leads, or a 9-V battery wrapped with tape and connectors wired to alligator clips
- 2 Small pieces (0.5 x 3 cm) of dyed cotton and/or litmus paper (litmus paper preferred since many dyes are bleach proof)
- Overhead projector

Directions

Place the Petri dish containing 1 M CuCl_2 solution on the overhead projector. Disconnect the wire connecting the two cells in series. Connect the alligator clips to the pencil “lead” electrodes. Position the electrodes in the CuCl_2 solution so they are parallel and about 2 cm apart, with the top of the electrodes being supported by the rim of the Petri dish (see Figure 7). *Be sure that the electrodes do not contact each other during the demonstration.* (The graphite electrodes have very little resistance. If they touch, you will short the cells and create a possible hazardous condition.) About 2-3 cm of the electrodes should be submerged at an angle in the solution.

Alternatively, two graphite electrodes can be taped to a 9-V radio battery (pretaped to avoid shorting out of the electrodes through the case). The electrodes should be taped at an angle that allows 2-3 cm to be submerged in the solution.

The length of the electrodes should be visible on the projection screen. Reconnect the dry cells. You may or may not wish to identify the anode and cathode. After an initial induction time of about 20 seconds, ask students what they observe. *[Small bubbles should form at the anode and rise to the surface of the solution.]* Allow the electrolysis to continue for about 3-4 min. Call a student to the overhead projector and ask for a report on any apparent odor. Although only a fraction of a milliliter of Cl_2 gas has been produced, a distinct chlorine odor should be detectable near the overhead projector.

Disconnect the wire connecting the two cells. Skewer the piece of dyed cloth or litmus paper with the tip of the anode (see Figure 8). Reposition the anode in the CuCl_2 solution as before, with the skewered part of the cloth/litmus paper submerged and the electrode beneath the cloth/litmus paper. A second piece of cloth/litmus should be partially submerged in the CuCl_2 solution away from the electrodes.



Figure 8. Dyed cloth or litmus paper attached to anode.

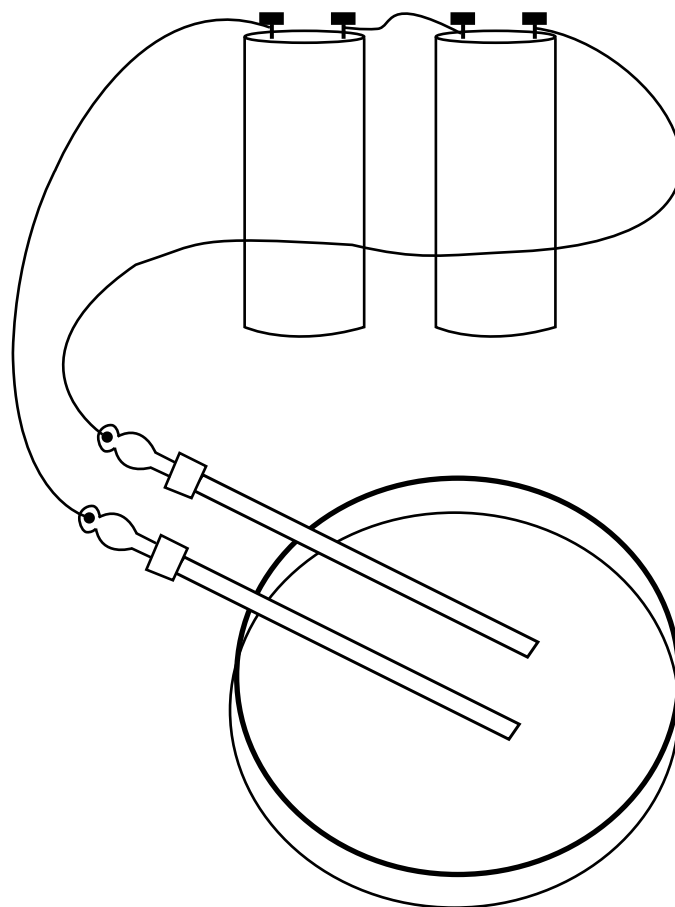


Figure 7. Electrolysis set-up for Demonstration 2.



Reconnect the cells and permit electrolysis to occur for 2-3 min. Disconnect the wire connecting the cells and remove both pieces of cloth/litmus paper from the solution. Rinse the cloth/litmus in water and pass them around the room. Ask students to compare the pieces of cloth/litmus and to explain their observation. *[The piece of dyed cloth/litmus not attached to the electrode may be slightly discolored due to the CuCl_2 solution. The piece of dyed cloth/litmus skewered on the anode will be obviously bleached. This is secondary indication that the gas produced at the anode is chlorine. It is worth noting that litmus, a natural dye, works better than the dyed cloth.]*

Remove the cathode from the solution, rinse it in water and pass it around the room for students to observe. Ask students to explain their observations. *[Copper plating should be clearly visible on the cathode. The reaction $\text{Cu}^{2+} + 2e^- \rightarrow \text{Cu}$ takes place at the cathode.]*

A discussion of commercial production of Cl_2 by electrolysis of NaCl solutions could precede or follow this demonstration. Depending on when this activity is performed, you might elect to tackle the question of why Cu is plated at the cathode in this demonstration while H_2 is released at the cathode in the electrolysis of NaCl . *[This is because water is easier to reduce than are the sodium ions.]* Try to keep emphasis on Cl_2 production.

Demonstration 3: The Activity of $\text{HF}(\text{aq})$ as an Acid

Introduction

Hydrofluoric acid is a very active weak acid. It is classified as a weak acid due to its low ionization in aqueous solutions yet, seemingly paradoxically, it can etch glass.

Purpose

To use $\text{HF}(\text{aq})$ to etch glass and plastic and to compare the results.

Safety

Hydrofluoric acid is highly corrosive and thus must be handled with care. For this reason a paste form, available in some stained glass or art supply shops, is used. Do not allow your skin to come into contact with the paste. Flush the residues down the drain with plenty of water when finished.

Be careful not to drop the glass sample when it is passed around the room. Wear goggles and apron while performing this demonstration.

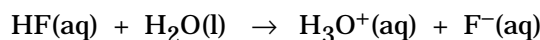
Materials

Small bottle or jar of commercial $\text{HF}(\text{aq})$ paste, with plastic applicator
Small piece of soft window glass, without sharp edges
Small piece of plastic
Tape for masking glass and plastic
Protective plastic sheet for desk top

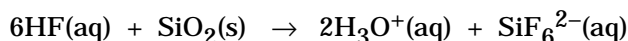
Procedure

1. Prior to conducting the demonstration for the class, do the demonstration yourself, using scrap materials.
2. Prior to the demonstration, distinguish the oxidizing power of halogens (F_2 in particular) from the replacement reaction occurring in this demonstration.
3. Place a piece of tape across the middle of the glass plate. You may elect to be artistic and mask out a design.
4. Using a plastic applicator, smear a small amount of commercial $\text{HF}(\text{aq})$ paste across the entire glass plate including the tape.

- Note the instructions on the container of HF(aq) paste. After a few minutes, rinse the glass with copious amounts of water. Remove the tape to display the etched glass.
- Repeat Steps 3-5 with the piece of plastic.
- Pass the well-rinsed pieces of glass and plastic around the room so students can observe the action of HF(aq) on the glass and the contrasting lack of reaction with the plastic.
- Ask students to describe the difference in the glass and plastic surfaces where the HF(aq) was in contact with glass or plastic and where the tape covered the surface. *[Negligible change should be observed with the plastic.]* You can also ask students to write equations that represent the ionization of HF(aq) in aqueous solution:



and the equation representing the action of HF(aq) on glass (SiO₂):



Ask students to comment on the power of HF(aq) to etch glass and to suggest reasons for this behavior. *[The silicon to fluorine bond is more stable than the silicon to oxygen bond. Therefore, fluorine displaces oxygen in the glass structure. The frosted surface is the result of the once smooth glass surface becoming heavily pitted.]* Consider asking more able students to indicate why the HF(aq) paste did not react with the plastic. *[The bond strength for hydrogen to fluorine is about the same as the bond strength for carbon to hydrogen. The added steric hindrance associated with the smaller carbon atom (relative to silicon) together with the lack of a driving force for the reaction prevents any appreciable reaction being observed.]*

NOTE: If unavailable locally, glass etching cream can be obtained from Armour Products, Wyckoff, NJ 07481; (201) 847-0404. Call to determine a retail outlet in your area. Cost: about \$6.00 for 3 oz.

Demonstration 4: Halogen Elements and Vapors

Option A

The sublimation of iodine makes a good demonstration.

Safety

Follow the standard safety procedures for any demonstration. For this particular demonstration, please be sure to:

- Wear protective goggles and apron throughout the demonstration.
- Wash off any chemicals spilled on your skin or clothing with large amounts of tap water.
- Save the iodine for future demonstrations. Small amounts remaining on container surfaces can be washed from the vessels with scrubbing and then washed down the drain with copious amounts of tap water.

Materials

Plastic coffee can lid

Large beaker, size depends on size of coffee can plastic lid or cover

Small beaker filled with ice/water/salt mixture for cooling

A few iodine crystals, I₂(s)

Hot plate



Directions

Cut a hole in the coffee can plastic lid, allowing the small beaker to be suspended over the large beaker. Iodine crystals are placed in the large beaker, which is placed on the hot plate (low heat). Dark iodine crystals sublime as beautiful violet vapors and condense on the outer surface of the cold small beaker.

Option B

Demonstrate by textbook illustrations, by a photographic Periodic Table, or other media presentation the appearance of other elements and their vapors. Media sources are provided in the *Media* section.

Suggestions for Other Demonstrations

1. Other demonstrations are possible. See for example, Shakhashiri, *Chemical Demonstrations*, Volume 1:
Demonstration 1.25: Reaction of Sodium and Chlorine
Demonstration 1.26: Reaction of Antimony and Chlorine
Demonstration 1.28: Reaction of Aluminum and Bromine
Demonstration 1.29: Reaction of White Phosphorus and Chlorine
Demonstration 1.30: Reaction of Red Phosphorus and Bromine
2. A number of oscillating reactions also contain halogen compounds, but details of these reactions are often “over the heads” of high school students. On the other hand, able students can be challenged by such reactions; c.f., Epstein, I. (1987). *Chemical and Engineering News*, 65(13), 24-36. Two overhead projector oscillating reaction demonstrations appropriate for this module are found in a short note by Kolb, D. (1988). *Journal of Chemical Education*, 65(11), 1004.

GROUP AND DISCUSSION ACTIVITIES

Key Questions

1. Where and in what form are halogens found in nature? [*Halogens are found as halide salts, often in solution, either in oceans or in subterranean brines, or as solid deposits on land. Insoluble calcium fluoride, and soluble alkali metal chlorides, bromides, and iodides are most common. Iodine has been found as the iodate in some calcium minerals, but known deposits have been largely used up. Iodine from seaweed was also a common source at one time.*]
2. Why aren't these elements found in free form in nature? [*Halogens are too reactive to be found in their free or elemental form in nature.*]
3. What processes are employed to obtain halide ions from natural sources? [*Calcium fluoride is dissolved in sulfuric acid to provide HF, which can be used as a source of metal fluoride salts by adding a metal hydroxide or carbonate to the HF. The soluble halide salts are typically dissolved and reprecipitated.*]
4. What processes are employed to obtain free halogens from natural sources? [*Fluorine and chlorine are typically obtained through electrochemical oxidation of their halides, either in aqueous media or in a melt. Bromine and iodine are typically made from oxidation of bromide or iodide, respectively, by chlorine.*]
5. What are some properties of halogen elements? [*Fluorine and chlorine are yellow-green gases, bromine is a deep red liquid, and iodine is a very deep violet (essentially black) lustrous solid, etc. For further elaboration, see an inorganic textbook that emphasizes descriptive chemistry, such as Greenwood and Earnshaw, Chemistry of the Elements.*]

- How do chemical properties of halogen elements vary with their positions in the Periodic Table? [For example, as the family is surveyed from fluorine to iodine, ionization energies decrease, electron affinities maximize at chlorine, but electronegativity decreases from fluorine on, radii increase, electrode potentials and oxidizing powers decrease. Also see Question 5.]
- What are some uses of halogens and halogen compounds in industry and in consumer products? [Uses have been summarized in Content in a Nutshell and in Links/Connections.]

Counterintuitive Examples and Discrepant Events

- HF(aq) is a very reactive, weak acid. This does, at first glance, seem to be a contradiction. It is not. The great attraction that fluorine has for most other atoms is the cause of HF(aq) being a weak acid. This high attraction of fluorine for most other atoms gives rise to a very strong H—F bond that is not broken when HF dissolves in water. The designation of HF as a weak acid does not mean that it is unreactive, only that it does not ionize completely in water. Indeed, periodicity is confirmed by the great attraction between H and F—an attraction that is greater than $\text{H—Cl} > \text{H—Br} > \text{H—I}$ (see *Demonstration 3*).
- Iodide is a reactant in Option B of the *Halogen Reactivity* demonstration (*Demonstration 1*), and is thus possibly not “stable.” This discrepant event is really nothing more than confirmation that Br^- is more stable to oxidation than is I^- and that I_2 is more stable to reduction than Br_2 —confirmation of periodic trends illustrated in the laboratory activities.

Metaphors and Analogies

- Halogens can be regarded as very “electron greedy” species. Their high electronegativities point out the fact that, in a covalent bond, they attract the shared pair of electrons aggressively. Indeed, if at all possible, a halide anion will form as the halogen seeks the bonding pair of electrons for itself. Family relationships involving younger siblings can provide a suitable analogy.
- The *Picture in the Mind* diagram (Figure 9) of a square dance is another good analogy for halogen atom reactivity.
- The use of an analogy of striving for perfection (complete energy level or stable octet) as the reason for the high “desire” of halogens for one more electron can be quite useful.

Pictures in the Mind

Thief: The chlorine atom attracts an electron from the bromide ion to complete its electronic octet (as the chloride ion) and, in so doing, leaves bromine one electron short. It is analogous to a thief at a square dance who completes his square at the expense of someone else.

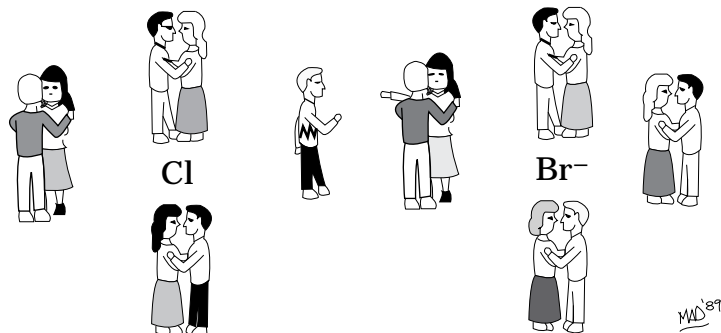


Figure 9. Square dancer representing electrons in Cl^- and Br^- .



Other Activities

- Home halogen hunt** This event can take many forms. Ask students to hunt at home (or at work) for places where halogens are used. This can be accomplished by reading labels or by following a list of possible uses compiled from a source such as an encyclopedia. You can process a wide variety of student responses as a class discussion. Point out that, in almost all cases, the reason for halogen use is its high reactivity or high stability depending upon which form is present.
- Pervasiveness of human-introduced halogens in the environment** There are altogether too many examples of PCBs, insecticides, herbicides, plastics, and chlorofluorocarbons present in the environment. It is useful to note that the very reason these products are used is the same as the reason they plague the environment—their high stability in certain forms. A good background source is *Environmental Chemistry* by Lucy Pryde or *Chemistry in Perspective* by Mohrig and Child.
- Chlorofluorocarbons and the ozone layer** This is another contemporary case of persistence that lends itself to a good discussion—not only of the chemistry involved, but also of the possibility that environmental impact considerations should be placed ahead of personal convenience and comfort.
- Use of fluoride as a preventive measure for tooth decay** Many communities have placed this question on the ballot with passion evident on both sides of the issue. Here is a vehicle to inform your community regarding this issue. An excellent background source is a fluoridation article in the August 1, 1988 issue of *Chemical and Engineering News*.

TIPS FOR THE TEACHER

Language of Chemistry

Bromine nomenclature

Bromide	Br^-	Hydrobromic acid	$\text{HBr}(\text{aq})$
Bromine	Br_2	Hypobromous acid	HOBr
Hypobromite	BrO^-	Bromous acid	HBrO_2
Bromite	BrO_2^-	Bromic acid	HBrO_3
Bromate	BrO_3^-	Perbromic acid	HBrO_4
Perbromate	BrO_4^-	Bromine dioxide	BrO_2
Dibromine oxide	Br_2O		

Chlorine nomenclature

Chloride	Cl^-	Hydrochloric acid	$\text{HCl}(\text{aq})^*$
Chlorine	Cl_2	Hypochlorous acid	HOCl
Hypochlorite	ClO^-	Chlorous acid	HClO_2
Chlorite	ClO_2^-	Chloric acid	HClO_3
Chlorate	ClO_3^-	Perchloric acid	HClO_4
Perchlorate	ClO_4^-	Chlorine dioxide	ClO_2
Dichlorine oxide	Cl_2O		

*Gaseous HCl should be called hydrogen chloride.

See overhead transparency master for structure of oxoanions.

Fluorine nomenclature

(Given its high electronegativity, it is limited to -1 and 0 oxidation states)

Fluoride	F^-	Hydrofluoric acid	$\text{HF}(\text{aq})^*$
Fluorine	F_2		
Oxygen difluoride	OF_2		

*Gaseous HF should be called hydrogen fluoride

Iodine nomenclature

Iodide	I^-	Hydroiodic acid	HI (aq)
Iodine	I_2	Hypoiodous acid	HIO
Hypoiodite	IO^-	Iodous acid	HIO_2
Iodite	IO_2^-	Iodic acid	HIO_3
Iodate	IO_3^-	Periodic acid	HIO_4
Periodate	IO_4^-	Iodine dioxide	IO_2
Diiodine oxide	I_2O		

Fluorocarbon- A $(CF_2)_n$ polynuclear species

Freon—Organic chlorofluorocarbon compound; *i.e.*, a hydrocarbon with chloro and fluoro substitution in place of some or all hydrogens of the parent hydrocarbon

General Tips

1. *Emphasize to students that bleach and ammonia should never be mixed.* Chloramine, the result of reaction between chlorine or hypochlorites with ammonia, is very toxic. This caution is also important regarding household cleaning materials, where again, products containing ammonia or ammonia derivatives should not be mixed with products containing chlorine or chlorine derivatives.
2. The mix of laboratory activities and demonstrations you select in teaching about halogens depends on fume hood facilities available to you and your students. *Safety considerations are vitally important with halogens.*
3. Check regarding any respiratory problems or color blindness of students before undertaking this module. Students with respiratory problems should be allowed to observe the laboratory activities, but should probably not be allowed to come close enough to conduct the activities themselves. Color-blind students should be told the observed colors in cases where a color change is undetectable by them.

Pattern Recognition

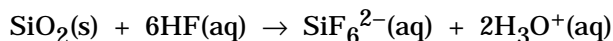
1. **Periodic Table and oxidizing ability** This module allows students to develop relationships between the oxidizing ability of elements and their Periodic Table positions. From *Laboratory Activity 2*, students learn that $Cl_2 > Br_2 > I_2$ in terms of oxidizing ability. The extension to F_2 as the strongest is straightforward. Extension to the left on the Periodic Table is hinted at in questions provided with the laboratory activity—you can expand upon this, if you wish. Sulfur (relative to chlorine) provides a simple example beyond oxygen.
2. **Periodic Table and halide acid strength** Although the hydrohalic acids HCl, HBr, and HI are essentially completely ionized in aqueous solution, HF is a weaker acid. The small size of fluorine and hydrogen atoms can be used to justify the greater attraction between the two. This can be extended to the left in the Periodic Table as well—for example, water is a much weaker acid than is hydrogen sulfide.
3. **Periodic Table and atomic and ionic sizes** As just noted, fluoride is the smallest halide ion and fluorine is the smallest halogen molecule. The sizes of halogens can be related to their physical properties, *e.g.*, electrons on larger halogen molecules are less tightly held by the nuclei and interact with neighboring halogen molecules (London dispersion forces) more strongly. Halogens become less volatile as the group is traversed from top to bottom, from gases (F_2 and Cl_2), to liquid (Br_2), and to solids (I_2 and At_2) at room temperature.



Common Student Misconceptions

1. “HF is a strong acid.”

This incorrect notion arises, in part, since hydrofluoric acid is remarkably reactive, particularly with glass (silica):



However, HF is a weak acid in terms of its low ionization in water.

2. “Chlorine hysteria.”

Many individuals and some environmental groups have what could be termed “chlorine hysteria”—they seem unable to ascertain the important difference between chlorize and chlorides.

3. “All silver halides are insoluble in water.”

Actually, silver fluoride, AgF, has very high water solubility (greater than 10 mol/L at room temperature).

4. “The light in a halogen lamp is caused by a halogen.”

A halogen lamp is actually a tungsten filament lamp with iodine added to trap tungsten atoms as they vaporize from the filament. The lamp body is intentionally small; this insures the lamp is hot enough to keep the tungsten iodide in the vapor state until it hits the very hot filament. There it decomposes back to tungsten and iodine, allowing the tungsten to return to the filament.

Problem Solving

1. Identification of a laboratory unknown (see *Laboratory Activity 2*)
2. Risk assessment (see *Decision Making*)
3. Solving the environmental pollution problem—this can be handled in a fashion analogous to the fluoridation example described in *Decision Making*.

Decision Making

This module’s *Group Activities* includes a section on water fluoridation as a preventive measure to help prevent tooth decay. A useful (although time consuming) event that will help students become more responsible citizens is to stage a public hearing (debate) on a hypothetical ballot question asking voters to decide whether this should be done. Divide the class into two groups, establish hearing procedures, appoint a moderator (yourself?) and challenge each side to get the facts and support their side.

A key to the public hearing is to explore whether the risk of fluoridation is outweighed by its benefits. Students will be forced to decide and then support a position regarding this issue.

This hearing could be held before a larger audience and be videotaped—or whatever else you think will help instill a sense of “reality.” You need to encourage, however, sound scientific arguments and respect for alternative beliefs. The opportunity to practice tolerance and understanding of other positions is one of many benefits of this type of activity.

**HISTORY: ON
THE HUMAN
SIDE**

1. **Fluorine**(L. *fluo*, flow) was not prepared as an element until 1886, even though the fluorine-containing mineral fluorspar or fluorite was described in 1529 by Georg Bauer, the German physician and mineralogist better known as Agricola. It appears likely that crude hydrofluoric acid was first prepared in the early 18th century by an unknown English glassworker and used to etch glass. Subsequently, in 1771, Swedish chemist Carl Wilhelm Scheele obtained impure hydrofluoric acid—over a hundred years before French chemist Henri Moissan isolated the element in 1886. The delay was largely due to the reactivity and toxicity of fluorine. After the nearly anhydrous hydrofluoric acid was prepared in 1809, French scientist André-Marie Ampère suggested (1811) that it was a compound of hydrogen with an unknown element, analogous to chlorine, for which he suggested the name fluorine. Fluorspar was then recognized to be calcium fluoride.

Fluorine's toxicity caused serious health problems for several chemists. Sir Humphry Davy tried to prepare the element by electrolytic decomposition of various fluorides, but succeeded only in ruining his health. French chemist Edmond Frémy, as well as George and Thomas Knox of the Irish Academy, Gay-Lussac, and Thénard all suffered loss of health due to their efforts to make fluorine. At least two chemists—Paulin Louget and Jerome Nickles—died as a direct result of attempts to isolate fluorine. Even Moissan, who finally prepared the gas by electrolysis of anhydrous hydrofluoric acid containing KHF_2 as an electrolyte, had earlier completed many unsuccessful experiments, resulting in damage to his health. He received the Nobel prize in 1906, when he was 54, but died the following year. Prior to World War II, fluorine remained a laboratory curiosity. The use of uranium(VI) fluoride in the separation of uranium isotopes and development of organic fluorine compounds and polymers has made fluorine an important and much more familiar element.

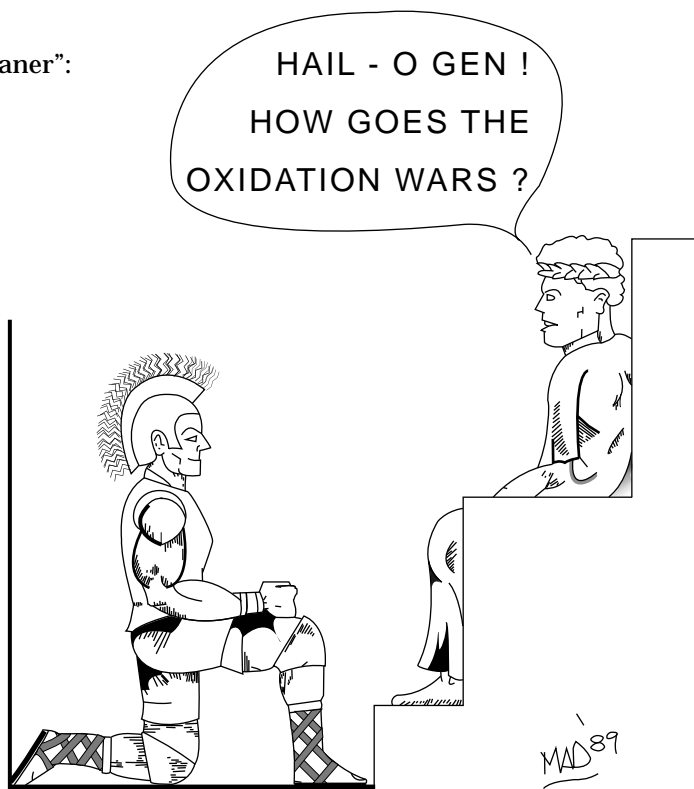
2. **Chlorine**(Gr. *chlorous*, greenish-yellow) was discovered in 1772 by Scheele, who thought it was an oxygen-containing substance. By 1810, Humphry Davy had completed a careful search for the oxygen, but, failing to find any, changed its name from oxymuriatic acid (muriatic acid is HCl and chlorine is an oxidation product of HCl) to chlorine, since he was convinced this was an element. He had some difficulty convincing the French of this, but his views eventually prevailed. Chlorine has been directly or indirectly involved in human history for centuries. At one time salt (NaCl) was more valuable than gold—wars were fought over the control of its sources. Chlorine gas was used as a weapon in World War I, but by contrast, in 1988 it became a federally required water disinfectant in all U.S. public drinking water supplies. Chlorine and other halogen-containing hydrocarbons show a similar apparent dichotomy in their use in a wide variety of consumer, agricultural, and industrial products, while also being banned because of environmental and health concerns. Even so, halogen-containing polymeric hydrocarbon derivatives continue to ease our everyday lifestyle.
3. **Bromine**(Gr. *bromos*, stench) This element's discovery is credited to French chemist Antoine Jérôme Balard, who, in 1826, noted that bromine could be liberated from a solution of residues remaining after sodium chloride had been removed from sea water by bubbling chlorine through the solution. He deduced that this was a new element similar to chlorine because the distillation of these residues (containing MgBr_2) with manganese dioxide and sulfuric acid also produces bromine and is analogous to a known procedure for producing chlorine. German chemist Justus von Liebig had actually isolated bromine prior to its discovery by Balard, but he interpreted its properties (between those of chlorine and iodine) as indicative of iodine chloride.



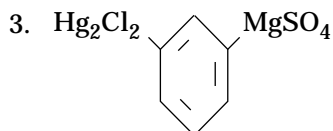
4. **Iodine**(Gr. *iodes*, violet) The discovery of iodine is credited to French chemist Bernard Courtois. In 1811, from the ashes of burnt seaweed, he observed a violet vapor that attacked his copper vessels. He called the condensed black crystalline product “substance X.” In 1813, Davy, who was passing through Paris, recognized substance X as an element analogous to chlorine and suggested the name iodine. Historically, iodine has been prepared by a number of methods and sources ranging from extraction from sea kelp and sea animals to various methods of I^- oxidation and IO_3^- reduction.
5. **Astatine**First prepared in 1940 by bombardment of bismuth with alpha particles.

HUMOR: ON THE FUN SIDE

1. Yes, another “groaner”:



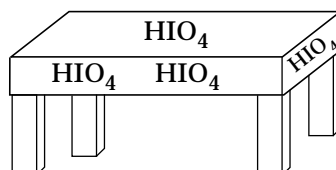
2. HIOAg = Hi O Silver—the Lone Ranger rides again!



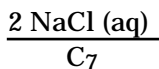
(Both salts have been used as cathartics or physics; 1,3 substitution is called *meta* substitution.)

Metaphysics

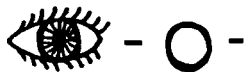
4. A restaurant is where *iodine*.
5. When I go home I walk on the *fluorine* my house.
6. Chlorous Line: $HClO_2-HClO_2-HClO_2-HClO_2-HClO_2$
7. Periodic Table:



8. Sailing, sailing, over the 7 seas
(Saline – saline – over the 7 C's)



9. **WHAT'S THIS?**



Answer: Iodine (I dine!)

CHEM 13 NEWS, February 1983, p. 2



10. **ON SNIFFING CHLORINE**

Donald asked his teacher if,
The jar of chlorine he could sniff:
Teacher queried, as he rose,
“How do we waft a gas to nose?”
Donny grinned and waved a hand;
In the jar his nose he slammed,
Donny crumpled in a fall;
The teacher ran for ethanol.

First aid was rendered on the spot
But Don said he felt “not so hot.”
And since he surely was not well
They sent him to the hospital.
From his bed he soon arose
And was putting on his clothes
When nursie caught him in the act;
She hid his clothes without much tact.

Now in bed, no pen or ink,
He had the time to think and think.
He understood the reason why
The teacher used to cry, and try
To get his students to take care
And mix a gas with lots of air,
And breathe in tiny little sniffs;
Not gulp down gas in great big whiffs.

(CHEM 13 NEWS, February 1979, p. 2)

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

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



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

1. Name of the anion ClO^- .
2. Most electronegative halogen.
3. Halide used to prevent tooth decay.
4. Halogen that is a yellow-green gas.
5. Largest halide anion.
6. General name of XO^- ion.
7. Number of electrons in outer energy level (any halogen).
8. Salt former.
9. Halogen that is a deep red liquid.
10. Name of the acid HIO_2 .

Answers: 1. HYPOCHLORITE 2. FLUORINE 3. FLUORIDE
4. CHLORINE 5. IODIDE 6. OXOANION 7. SEVEN 8. HALOGEN
9. BROMINE 10. IODOUS

12. Halogens Crossword Puzzle (see *Appendix*)
13. See relevant cartoons at end of module.

MEDIA

1. The *World of Chemistry* (high school version) videotape "Number 8: Chemical Bonds" includes a demonstration of a nitrogen triiodide explosion using a feather to detonate the solid and the spectacular synthesis of table salt when sodium metal is added to chlorine gas. WINGS for Learning/SUNBURST, 101 Castleton Street, Pleasantville, NY 10570; (800) 321-7511; (914) 747-3310; (914) 747-4109 (FAX).
2. A number of activities on the *Doing Chemistry* videodiscs (distributed by the Education Division, American Chemical Society, 1155-16th Street, N.W., Washington, DC 20036) relate to this halogen module. Macintosh computer materials provided with the videodiscs aid in use of the videodiscs, although the 630-page *Teacher's Guide* eliminates the need for a Macintosh. Here are relevant parts (location on the videodisc is given in parenthesis).

DEMO C02 (C02720) *Preparation and Sublimation of Iodine*

EXPT E28 (E33508) *MicroScale Iodine Clock Reaction*

EXPT F43 (F21505) *A Kinetics Study of the Ferric Ion/Iodide Ion Reaction*

The latter requires a colorimeter connected to a recorder or computer. A simple setup is provided as an Apple II add-on:

DMEX F02 (F00195) *Building and Testing a Blocktronic I Colorimeter*

3. Software published by *JCE: Software*, a publication of the *Journal of Chemical Education*, Department of Chemistry, University of Wisconsin-Madison, 1101 University Avenue, Madison, WI 53706-1396: (608) 262-5153 (voice) or (608) 262-0381 (FAX).
 - a. *KC? Discoverer with Knowledgeable Counselor*, by Daniel Cabrol, John W. Moore and Robert C. Rittenhouse. Special Issue 2, for IBM PS/2, PC compatible computers.
 - b. *KC? Discoverer: Exploring the Properties of the Chemical Elements*, by Aw Feng and John W. Moore. Vol. I B, No. 1, for IBM PS/2, PC compatible computers.

c. *KC? Discoverer?*, by Michael Liebl, Vol. IV A, No. 2, for all Apple II computers.

d. *The Periodic Table Stack*, by Michael Farris. Vol. I C, No. 1, for the Apple Macintosh.

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

For the Apple II computer: AP 207, AP 605.

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

a. "Changes of State in Bromine," a chapter on *The World of Chemistry: Selected Demonstrations and Animations*: Disc II (double sided, 60 min.), Special Issue 4.

b. "Bromination of Alkanes," "Addition Reactions of Alkenes," and "Acetylene – Preparation and Reactions," three chapters on the videodisc *Demonstrations in Organic Chemistry* (double sided, 60 min.), Special Issue 6.

c. *The Periodic Table Videodisc* (single side, 30 min.). Special Issue 1. The videodisc includes frames of the following:

Element	Element Shown	Reactions	Uses
Fluorine	Not shown	Not shown	6411-22
Chlorine	14228	14234-16819	36510-15
Bromine	35171	35187-36284 (base only)	36732-49
Iodine	45067	45079-46088 (base only)	36924-29

6. *The Science Series* of Media Guild Video (England) provides excellent demonstrations of the reactions of Na through S with F_2 in the videotape segment "Elements Organized." These are demonstrations that cannot be done in a normal classroom.

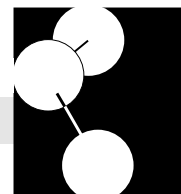
7. A section of the CHEM Study film *Chemical Families* deals with halogens and is recommended, as is the CHEM Study film *Bromine: Element from the Sea*. New versions of the CHEM Study films have recently been released as videotapes. Available from Ward's Natural Science Establishment, P.O. Box 92912, Rochester, NY 14692-9012. Toll free: 800-962-2660.

8. Coronet Films 1966 production *The Halogens* has been recommended as appropriate. Coronet/NTI Film and Video, 108 Wilmot Road, Deerfield, IL 60015; (800) 621-2131; (708) 940-3640 (FAX).

The primary equipment requirement for this module is availability of fume hoods and adequate ventilation within the room where activities are to be conducted. The venting of both the hoods and the room should be to the outside and *not* to another room or rooms within the building.

EQUIPMENT AND INSTRUMENTATION

Links/Connections



WITHIN CHEMISTRY

1. See Related Concepts and Skills for the most direct links.
2. Chemistry of halogens is very important in organic chemistry—many haloorganics can be synthesized easily and have been found to have very useful properties.
3. Halogen chemistry has importance in inorganic chemistry—inorganic halides provide starting materials for other inorganic species and organometallics. By contrast, some halogen-containing substances, such as sulfur hexafluoride (SF_6), are very inert dielectrics (and find use commercially because of their inertness).

BETWEEN CHEMISTRY AND OTHER DISCIPLINES

1. **Agriculture** Organic halogen compounds are very important in agriculture. Some important uses include polychlorinated organic compounds as insecticides (such as DDT); fluoro and chloro aromatic heterocyclic compounds and urea derivatives as herbicides; and chlorinated and organic compounds as solvents. Chlorinated inorganic compounds include chlorine bleach as a disinfectant, and salt blocks for animals in hot weather. For more details, see “Organic Halogen Compounds” and “Halogens” entries in the *Encyclopedia Britannica* or some other modern encyclopedia.
2. **Environmental science** The escape of large numbers of chlorofluorocarbons (Freons) into the upper atmosphere where they can react photochemically with ozone is thought to be causing a depletion of the ozone layer, especially near the South Pole. This problem involves an ironic twist—Freons are chemically inert and have been used to replace toxic materials in many applications such as refrigeration, where ammonia (which is very toxic when released in large quantities) was the common refrigerant prior to synthesis of Freons. Environmental science is also concerned with potential side effects, both in humans and nature, of some agriculturally important haloorganics and with the effects that chlorination of impure water supplies may have on formation of toxic haloorganics in water.
3. **Hygiene** Halogen chemistry contributes to personal hygiene (*e.g.*, dentifrices containing tin(II) fluoride, sodium fluoride, or a fluorophosphate; antiperspirants and deodorants containing aluminum chlorhydrate; and other preparations containing sodium chloride). In the public health arena, water purification with chlorine is considered so important that all public water supplies in the United States must be treated with chlorine. Chlorine is also used to treat sewage sludge. Although an excellent antibacterial, pHisoHex is only available by prescription; doctors use it for surgical scrubbing in certain cases only.
4. **Photography** Silver halides (particularly AgBr, though AgCl and AgI have been used as well) are the basis of the photographic industry. For more details, see the *Photochemistry* module.
5. **Polymer science** Polyvinyl chloride, $\text{PVC} = (\text{CH}_2\text{-CHCl})_n$, is useful in a variety of common applications, including electrical insulation, rainwear fabrics and upholstery fabrics. Poly(tetrafluoroethylene) [Teflon = $(\text{CF}_2\text{-CF}_2)_n$] and poly(chlorotrifluoroethylene) [Kel-F = $(\text{CClF-CF}_2)_n$] have excellent electrical resistance, thermal stability, heat conductivity, and low intermolecular forces (low friction) and are used for thermal coatings, bearings, lubricants (in low molecular weight forms), heat transfer insulators, *etc.* Viton-fluorinated copolymers are related derivatives that are very thermally stable elastomers.

Community

Field Trips

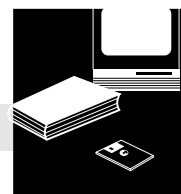
1. Water plant to see chlorination of water process
2. Sewage disposal plant to see chlorination of sewage sludge and reclaimed water
3. Manufacturing facilities as appropriate

Societal

1. See *Discussion Activities*.
2. Air conditioning has become widespread as a result of Freon use. If Freon use were to be discontinued immediately as a result of ozone layer depletion, finding a substitute that does not have even more serious problems would be a real concern.
3. Deodorants and air quality; see *Discussion Activities*.

TO THE CONTEMPORARY WORLD

References



Module developed by Ronald D. Archer, William G. Cumming, and Abraham M. Rennert, the New England team.

Epstein, I. (1987, March 30). Patterns in time and space. *Chemical and Engineering News*, 65(13), 24-36.

A number of these oscillating reactions contain halogen compounds, but details may be beyond typical high school students. On the other hand, exceptionally able students can find these challenging.

Fortman, J. J. (1993, September). A simpler tomato juice demonstration of halogen addition to double bonds. *Chem 13 News*, p. 30.

Franz, H. W., and Malm, E. (1968). *Fundamental experiments for college chemistry* (2nd Ed.). San Francisco, CA: Freeman.

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

Hileman, B. (1988, August 1). Fluoridation of water. *Chemical and Engineering News*, 66(31), 26-42.

Excellent information on the use of fluoride as a preventive measure for tooth decay.

Kolb, D. (Ed.). (1988). *Journal of Chemical Education*, 65(11), 1004-1005.

This short note contains two overhead projector oscillating-reaction demonstrations appropriate for this module.

Mohrig, J. R., and Child, W. C., Jr. (1987). *Chemistry in perspective*. Newton, MA: Allyn & Bacon.

Good background source for this module.

The New Encyclopaedia Britannica. (1990). Chicago, IL: Encyclopedia Britannica.

See Organic halogen compounds, Halogens, Photography (Technology of), in this or other modern encyclopedia for additional information concerning halogens.

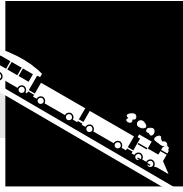
Pryde, L. (1973). *Environmental chemistry*. Menlo Park, CA: Benjamin/Cummings.

Good background source for this module.

Shakhashiri, B. Z. (1983). *Chemical demonstrations: A handbook for teachers of chemistry, Volume 1*. Madison, WI: University of Wisconsin Press.

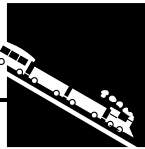
The following are relevant to this module: Demonstration 1.25: Reaction of Sodium and Chlorine; Demonstration 1.26: Reaction of Antimony and Chlorine; Demonstration 1.28: Reaction of Aluminum and Bromine; Demonstration 1.29: Reaction of White Phosphorus and Chlorine; and Demonstration 1.30: Reaction of Red Phosphorus and Bromine.

Topics in Chemistry: Ozone-Chlorofluorocarbons and the Hole in the Ozone Layer., available from ICE-Institute for Chemical Education, Department of Chemistry, University of Wisconsin-Madison, 1101 University Avenue, Madison, WI 53706-1396: (608) 262-3033 (voice) or (608) 262-0381 (FAX).

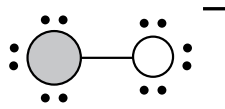


Appendix

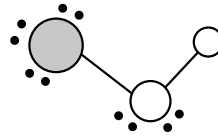
- **Transparency Masters**
 1. Oxoanions and Acids of Chlorine
 2. The Halogens
 3. Word Search
 4. Halogens Crossword Puzzle
- **Humor**



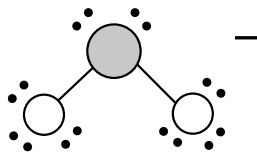
Oxoanions and Acids of Chlorine



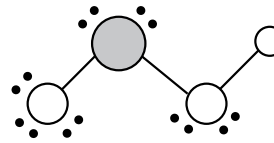
Hypochlorite: ClO^-



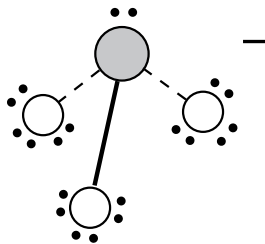
Hypochlorous acid: HOCl



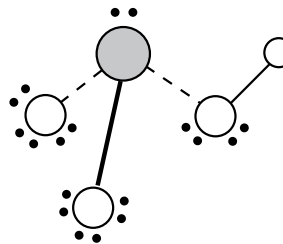
Chlorite: ClO_2^-



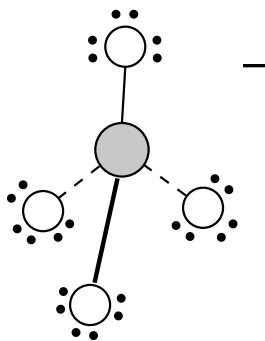
Chlorous acid: HClO_2



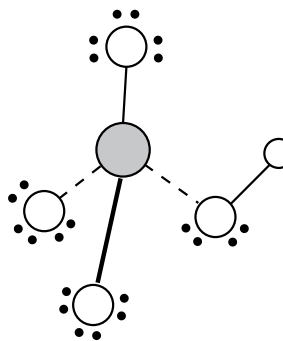
Chlorate: ClO_3^-



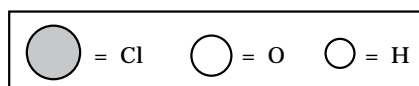
Chloric acid: HClO_3



Perchlorate: ClO_4^-



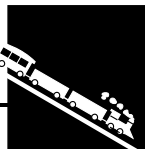
Perchloric acid: HClO_4



The Halogens*

Element	At. Mass		Normal Form at STP	b.p., °C
Fluorine F	19.0	F ₂	pale-yellow gas	-187.0
Chlorine Cl	35.5	Cl ₂	greenish-yellow gas	-34.5
Bromine Br	79.9	Br ₂	red-brown liquid	58.0
Iodine I	126.9	I ₂	black solid (mp: 113 °C)	184.0

* Astatine, a less familiar element, is not included.



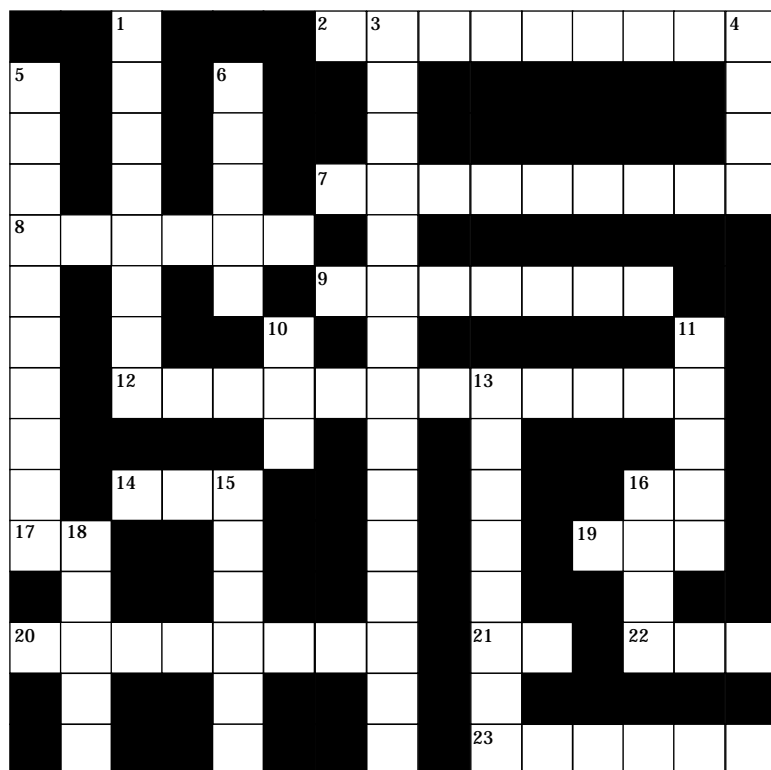
Word Search

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

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

1. Name of the anion ClO^- .
2. Most electronegative halogen.
3. Halide used to prevent tooth decay.
4. Halogen that is a yellow-green gas.
5. Largest halide anion.
6. General name of XO^- ion.
7. Number of electrons in outer energy level (any halogen).
8. Salt former.
9. Halogen that is a deep red liquid.
10. Name of the acid HIO_2 .

Halogens Crossword Puzzle



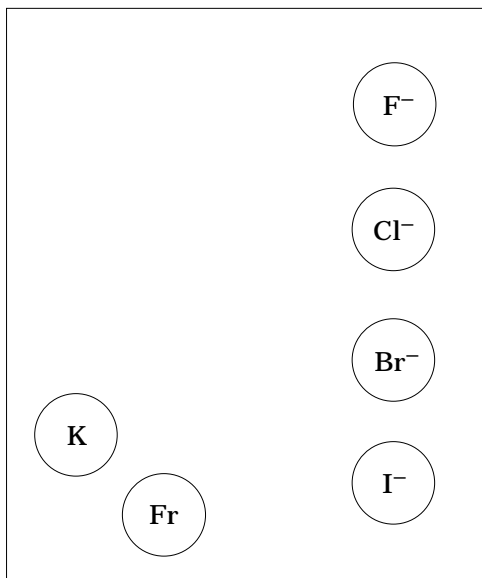
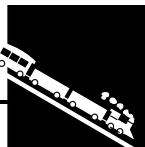
Across

2. Salts containing ClO_3^- .
7. HIO_3 (two words)
8. Element contained in CFC's.
9. BrO_3^-
12. NaIO_3 (two words)
14. Oxidation number (in Stock notation) for chlorine in chlorites.
16. Element No. 2 (Symbol)
17. Element No. 98 (Symbol)
19. Hydrocyanic acid (Formula)
20. _____ acid, HIO_4
21. Element No. 30 (Symbol)
22. Oxidation number for bromine in 3-Down.
23. Type of covalent bond where four electrons are shared.

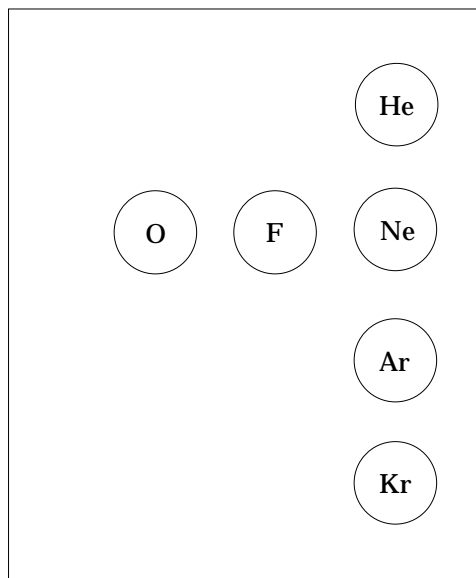
Down

1. _____ acid, HClO_2
3. HBrO (two words)
4. Silicon dioxide
5. _____ acid, HClO_4
6. Root for Element No. 9.
10. Hypiodous acid (Formula)
11. Oxidation number of chlorine in 5-Down.
13. Chlorine must be _____ to form 5-Down from chloric acid.
15. _____ acid, HIO_2
16. Hypochlorous acid (Formula)
18. An organic chlorofluorocarbon compound.

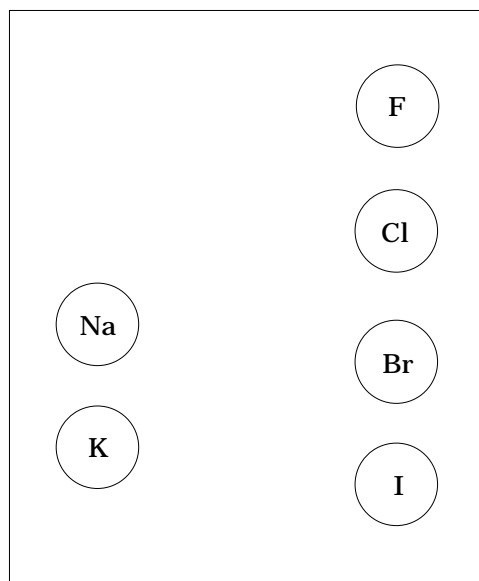
23. DOUBLE	1. CHLOROUS
22. ONE	2. CHLORATES
21. Zn	3. HYPOBROMOUS ACID
20. PERIODIC	4. SAND
19. HCN	5. PERCHLORIC
17. Cl	6. FLUOR
16. He	7. IODIC ACID
14. III	8. CARBON
12. SODIUM IODATE	9. BROMATE
11. SEVEN	10. IODUS
10. HIO	11. OXIDIZED
8. FLUOR	12. SEVEN
5. PERCHLORIC	13. OXIDIZED
4. SAND	14. IODUS
3. HYPOBROMOUS ACID	15. IODOUS
1. CHLOROUS	16. HClO
2. CHLORATES	17. FREN
7. IODIC ACID	18. FREN
8. CARBON	19. IODOUS
9. BROMATE	20. PERIODIC
10. IODUS	21. Zn
11. OXIDIZED	22. ONE
12. SEVEN	23. DOUBLE



“It’s disgusting Kay, Flo’s family gets such a charge from picking up stray electrons.”

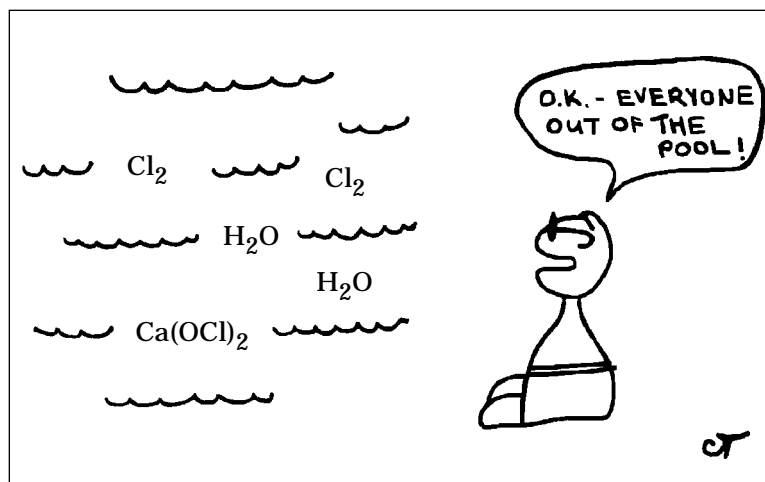


“Flo, I don’t know how you stand living in such a conservative neighborhood.”

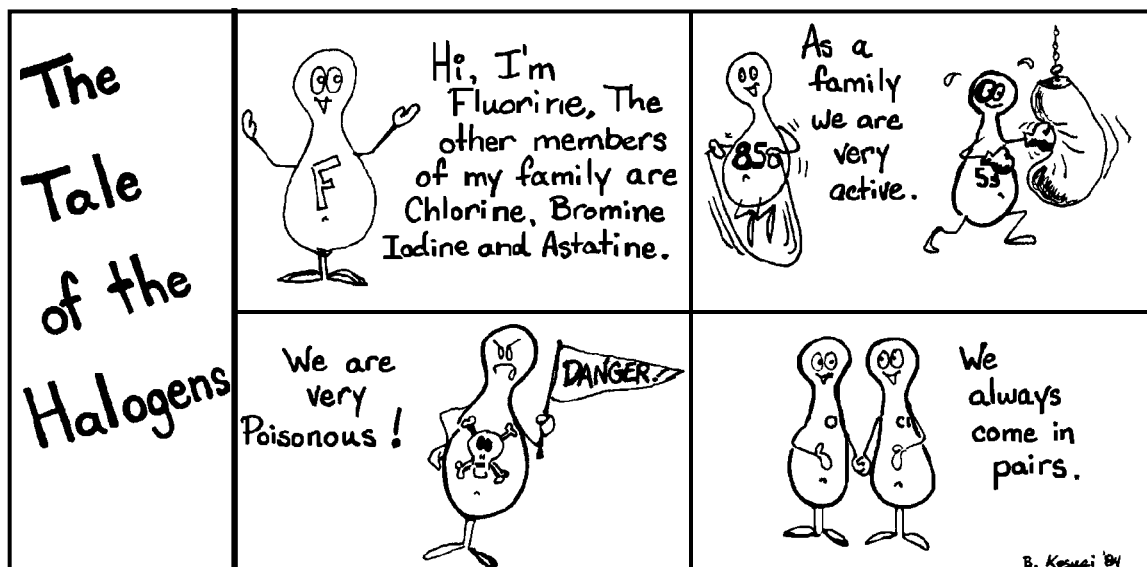
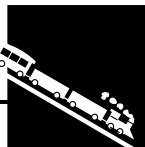


“Take, Take, Take, that’s all those halogens ever do.”

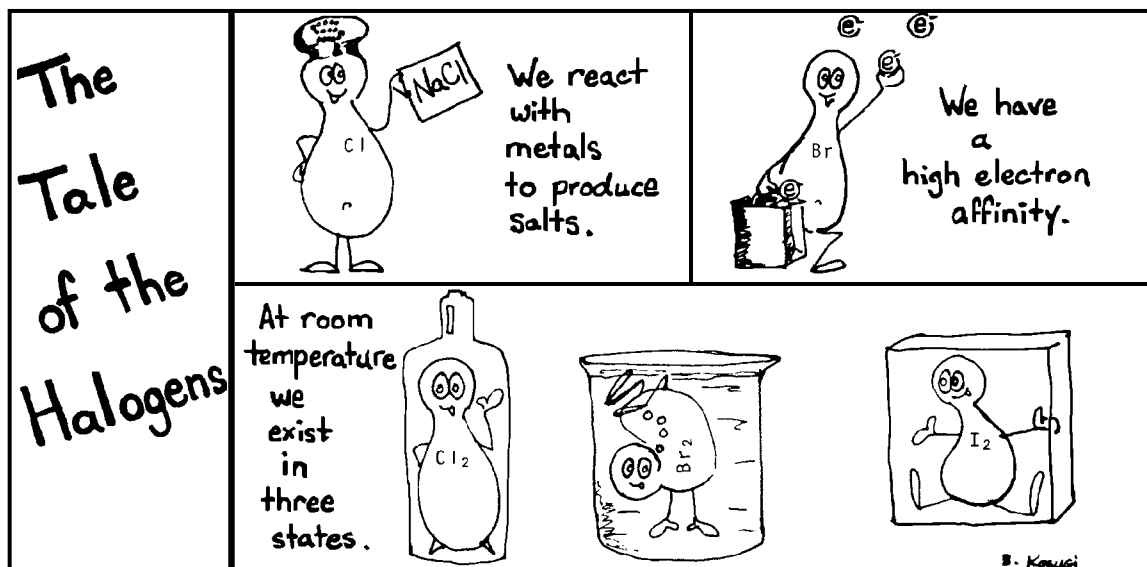
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