> To be nobody but yourself in a
> world which is doing its best
> night and day to make you everybody
> else means to fight the hardest
> battle any human being can fight
> and never stop fighting.
> --e.e. cummings

Investigating Periodic Properties

The chemical and physical properties of elements (and their similar compounds) generally change gradually with atomic number. We say they are *periodic* because this change in properties repeats as a function of atomic number (every eight, not counting transition metals and inner transition metals).

From your studies in class and your reading you will know (or soon know) that this regular change in properties is tied to the regular change in electron structure as one moves from left to right in a period of the table or as one moves from top to bottom in a group. But it is one thing to mention or memorize such properties and another to see them face-to-test tube, so to speak. So in this experiment you will have an opportunity to see some of them and try to explain why they change as they do.

There are so many fascinating properties to choose from and there is only a limited amount of time and certain constraints of safety and economics. So we have chosen the following survey for you:

1. Properties within the alkali metal group*
2. Properties within the alkaline earth metal group
3. Properties within the halogen group
4. Properties of period 3 elements
5. Properties of period 3 oxides

The properties to be examined for *metals* are the following:

1. reaction with room temperature water
   ---check acidity or alkalinity of resulting solution
2. if no reaction in (1), then with boiling water
   ---check acidity or alkalinity of resulting solution
3. electrical conductivity

*your instructor will demonstrate the behavior of Li and Na

Halogen generation and indicators adapted from: <u>Small Scale Chemistry Laboratory Manual</u>, Edward L. Waterman & Stephen Thompson, *Addision Wesley*, 1995

In each case, only a small amount of metal is required and only a small amount of water. If no reaction occurs at first, the same sample of metal may be used for the next test. Gases that may be produced as metals react can be assumed to be hydrogen. Your instructor will demonstrate the detection of such gases with larger samples.

The properties to be examined for the *halogens* are the following:

1. physical appearance
2. reactions with alkali metals*
3. solubility in water
4. oxidizing/reducing strength

*your instructor will demonstrate

The properties to be examined for the remaining *period 3 elements* include:

1. physical appearance
2. reaction with/solubility in water
   ---check acidity or alkalinity of resulting solution
3. electrical conductivity

The properties to be examined for the *period 3 oxides* are:

1. reaction with/solubility in water
   ---check acidity or alkalinity of resulting solution
2. physical state at room temperature

You will notice that some of these test groups overlap. For example, Na is a metal, a member of the alkali metal family *and* a period 3 element. If you prepare your observation tables correctly, you may be able to eliminate duplicate tests, or just fill in the information rather than repeating the tests.

Preparing to experiment

You will be provided with the following materials:

1. samples of Li†, Na†, Mg, Ca, Al, Si, P†, S
   samples of Na_2O‡ , MgO, Al_2O_3, SiO_2, P_4O_{10}, SO_2*
2. bromthymol blue indicator
3. 2 M H_2SO_4
4. 0.5 M Na_2SO_3
5. 5% NaClO (household bleach) (to produce Cl_2)
6. 5% $KBrO_3$ + KBr (to produce Br_2)
7. 5% KIO_3 + KI (to produce I_2)
8. 3 M NH_3
9. redox indicating solutions [see **Technique**]
10. conductivity device
11. room temperature boiled distilled water
12. boiling distilled water
13. 24-well microplate
14. petri dish
15. hand lens

† to be displayed by instructor
‡ supplied already dissolved in water [see **Chemicals**]
* see **Technique**

Study the **Technique** section carefully and review the procedures recommended there before laying out your experiments. In your notebook you should plan out each section clearly. Tables will be helpful in organizing your observations.

Technique

1. Acidity and alkalinity

This is more of a reminder than anything else. Bromthymol blue is a 3-color indicator which is yellow in acid solution, green in neutral and blue in base. Solutions can be tested by simply adding a drop or two of the indicator. When gases are being tested (e.g., the gaseous oxides of period 3), it is easiest to place a drop of the indicator in the container where the gas will be generated. If any significant *dissolving* occurs and the acidity changes, the drop will change color. Thus a color change denotes *both* solubility in water *and* a change in acidity.

2. Redox indicators

The redox indicators contain I^- and starch (to indicate when oxidation has occurred) or I_2 and starch (to indicate when reduction has occurred). When the I^- is oxidized to I_2 it forms a dark blue color with the starch present. The darker the color, the stronger the oxidizing agent. In the presence of a reducing agent the blue indicator fades or becomes colorless as the I_2 is reduced to I^-. As with the acid/base indicator, a color change indicates *both* solubility in water *and* the presence of an oxidizing or reducing agent agent.

3. Generating toxic gases safely in the lab--small scale

In the past you have worked with chlorine and bromine in solution but for this experiment you will need them in gaseous form. A plastic petri dish (often used in microbiological work to grow bacteria) works well for this. Taking chlorine as an example the process works something like this:

a. place a drop of NaClO (the source of the Cl_2) in the center of the bottom half of the dish
b. to test solubility in water and redox activity place a few drops of redox indicator solution at various places in the dish, but not touching the reactant
c. hold the cover of the dish at an angle almost closing the dish and add a drop or two of 2 M H_2SO_4 to the central drop of NaClO; close the lid quickly
d. after observations have been made, open the lid slightly and add a drop or two of 3 M NH_3 to the central drop in order to neutralize the mixture and stop the production of gas; close the lid for a minute or two
f. clean out the dish with water and dry thoroughly before reuse

Similar techniques apply to the other gases. The reactants all include a source of H^+ (2 M H_2SO_4) and the following:

1. for Cl_2-----NaClO
2. for Br_2-----$KBrO_3$ + KBr
3. for I_2------KIO_3 + KI
4. for SO_2-----Na_2SO_3 [**SO_2 is an oxide of period 3**]

The Chemicals

Lithium is a light metal in the alkali metal family which occurs to the extent of about 0.005% in the earth's crust. It is prepared by electrolysis of molten salts. Typical ores contain 3-10% lithium.

The metal is silvery white, but tarnishes on exposure to air, acquiring a yellowish tint. Like some other alkali metals, lithium dissolves in liquid ammonia, giving a blue solution. It has been suggested that this color results from the "solvation" of the valence electron. It is unaffected by oxygen at room temperature but burns with a brilliant white flame when heated above 200^{o}C, forming Li_2O. Lithium and its compounds impart a carmine-red color to a bunsen flame.

It is used in the manufacture of alloys, especially hardened bearing metals, in catalysts for the manufacture of some plastics and in fuels for aircraft. Lithium salts are used in porcelain enamels. Lithium compounds are also used in the treatment of manic psychosis, but their toxicity (especially if sodium intake is limited) is significant.

Sodium was first prepared by Davy in 1807 by electrolysis of fused sodium hydroxide. It constitutes 2.83% of the crust of the earth but does not occur free. It is a light, silvery metal which is lustrous when freshly cut but tarnishes on exposure to air. Sodium is soft at ordinary temperatures.

It reacts vigorously with oxygen, burning with a yellow flame and combines directly with most non-metals.

Sodium compounds such as the cyanide, azide, peroxide, etc. have been used in the past to manufacture tetraethyllead--the former anti-knock and "octane" boosting additive in leaded gasoline. Sodium vapor is used in street lamps and it can be alloyed with potassium metal for use as a heat transfer coolant.

Calcium is an alkaline earth metal, fifth most abundant in the crust of the earth (3.64%). Sea water contains about 400 g/ton. It can be produced by the electrolysis of molten calcium chloride. Like sodium, it is lustrous and white when first cut. Unlike sodium, it may be handled occasionally for short periods with bare (dry) hands in the laboratory. It burns, when finely divided, with a crimson flame. It is harder than sodium but softer than magnesium.

Calcium can be used to harden lead for bearings and alloyed with cerium to make flints for cigarette and gas lighters.

Aluminum is a tin-white metal with can take and hold a very high polish. It oxidizes superficially in moist air. Finely divided aluminum will burn and may cause explosions.

The pure metal or its alloys are important structural materials where weight is an important factor, such as in aircraft. Aluminum is an excellent conductor and is used in some wiring. The coarse powder may be used for the thermite process and fine powder is used in flash photography. Aluminum has been used in skin protective pastes but it can result in contact dermatitis and even bronchial asthma. Recently some studies have implicated ingested aluminum as playing some part in the development of ailments such as Alzheimers.

Silicon does not occur free in nature but is abundant in silica (sand, quartz, sandstone) and as silicate minerals. It is the second most abundant element on earth (27.6%). Only oxygen is present in greater proportions. It is black to gray and lustrous. Silicon is used in the manufacture of transistors, diodes, etc. It can also be alloyed with metals such as copper, iron, and tin. Silicon appears to be biologically inert, although prolonged exposure to its dust may cause pulmonary irritation.

Sulfur is known by the ancient name of brimstone. It occurs in the free state as well as in sulfides and sulfates. It exists in several allotropic forms: two crystals and at least two amorphous and two liquid forms. It is used in the manufacture of sulfuric acid, insecticides, plastics, vulcanization of rubber, and the synthesis of dyes. Sulfur has low human toxicity but it may cause skin irritation and injury to the lungs from prolonged breathing of sulfur dust has been reported.

Sodium oxide is a white amorphous substance which combines violently with water. Above 400^{o}C it decomposes into sodium peroxide (Na_2O_2) and the metal.

Aluminum oxide or alumina is used as an adsorbent, desiccant, and abrasive. It can also be used in making refractory materials for high temperature work. High concentrations of dust are harmful to the lungs. Some special grades of aluminum oxide can be used in column chromatography for the separation of mixtures.

Silicon dioxide is used in the manufacture of glass, sodium silicate ("water glass"), refractory materials, abrasives and molds for casting.

Tetraphosphorus decoxide or diphosphorus pentoxide (it actually exists in the dimer form, but is often labeled as the monomer) is an extremely deliquescent white powder that is used as a drying and dehydrating agent. It is a strong irritant and very corrosive. In any but small amounts it reacts violently with water and should be handled with extreme care.

Sodium sulfite is used chiefly in photography in place of "hypo" (sodium thiosulfate) both in developers and fixer. It also has applications in bleaching.

Sodium hypochlorite is an unstable solid, but its solutions are very stable, liquid Clorox being a good example. It can be used as an antiseptic and anti-fungal agent. Ingestion may cause corrosion of mucous membranes. Prolonged skin contact may result in irritation. Household bleach contains about 5% NaClO and should never be mixed with other cleaning agents since chlorine gas will be produced by acidic additions and chloramines may be produced by addition of ammonia. Both are toxic gases.

Potassium bromate is a bread and flour improving agent ("bromated flour" is often sold as "bread flour"). Ingestion may cause vomiting, diarrhea, and renal injury.

Potassium iodate is used as an oxidizing agent in chemical analysis and has been used as a topical antiseptic. In animal feed it is sometimes used as a source of iodine.

Analysis

1. Write balanced net-ionic reactions for Li and Na with water.

a. What type of reaction is this? (precipitate, redox, etc.)
b. What conclusion can you draw about the trend in reactivity for alkali metals based on your observations of these reactions?
c. Give at least one explanation for this trend based on some periodic property that is relevant to the type of reaction you selected in (a) [*hint:* what is happening to the alkali metal in the reaction?]

2. Same as #1, but for Mg and Ca.

3. Now consider the *horizontal* trend in period 3 for the three metals examined (Na, Mg, and Al). Compare the reactivity with water and explain the apparent trend.

4. Based upon the demonstrated reactions of Na with Cl_2 and Br_2, describe the reactivity trend within the halogen family (at least as it relates to alkali metals). Explain this trend in light of some relevant periodic property [*hint:* what is happening to the chlorine or bromine during the reactions? check oxidation numbers!]

5. Write a balanced redox reaction for the production of Cl_2 when ClO^- is combined with H^+. The skeleton half-reactions are:

$$ClO^- \rightarrow Cl_2$$
$$ClO^- \rightarrow ClO_3^-$$

a. Based on your observations, are the halogens all equally soluble in water?
b. Account for your observations in (a) based on at least one relevant periodic property. [*hint:* in order to dissolve, the halogen molecules must "fit" into the empty spaces in the liquid water]
c. Based on your observations, do the halogens all have the same strength as oxidizing agents?
d. Account for your observations in (c) based on a relevant periodic property [*hint:* for a halogen to be an oxidizing agent what must it be able to do?]

6. Account for your observations for the trend in conductivity of elements in period 3 with reference to at least one periodic property.

7. Even chemical compounds may exhibit periodic properties if most variables remain unchanged., The *oxides* of period three elements illustrate some periodic behavior that may not have been discussed in class. What trends do you observe in these compounds in terms of solubility in water and the acidity of their resulting solutions?

8. Chlorine forms several oxides, none of which were tested in this experiment since they are all dangerous to handle. Based on your observations of the other period 3 oxides, what phase would you expect the oxides of chlorine to exist in at room temperature? Would you expect them to be soluble in water, and if so, would the solutions be acidic or basic?