4.2: Groups of Related Elements

The macroscopic, descriptive approach to chemical knowledge has led to a great deal of factual information. Right now more than 100 million chemical compounds and their properties are on file at the Chemical Abstracts Service of the American Chemical Society[1]. Anyone who wants information about these substances can look it up, although in practice it helps to have a computer do the looking! Even with a computer's memory it is hard to keep track of so many facts–no single person can remember more than a fraction of the total.

Fortunately these millions of facts are interrelated in numerous ways, and the relationships are helpful in remembering the facts. To illustrate this point, we shall present part of the descriptive chemistry of about 20 elements. Although each element has unique physical and chemical properties, it will be obvious that certain groups of elements are closely related. Members of each group are more like each other than they are like any member of another group. Because of this close relationship a special name has been assigned to these collections of elements. It is also possible to write general equations which apply to *all* members of a family of elements. Practical laboratory experience with one member gives a fairly accurate indication of how each of the others will behave.

Because of their similarities, lithium, sodium, potassium, rubidium, and cesium are grouped together and called the **alkali metals**. What do we mean when we say these elements are similar? The following video of lithium, sodium, and potassium reacting in water demonstrates the similarities quite well.

In the video, each metal is added to a dish containing water. All three metals react with the water, flying over the surface as H_2 is produced (albeit at different rates). LiOH, NaOH, and KOH, are each produced respectively. These hydroxides are evidenced through the use of phenolphthalein indicator, which turns pink in the presence of OH^- ions. While the reactivity of each metal differs (potassium is clearly more reactive with water than sodium, which is more reactive than lithium) all three are undergoing the same reaction. The three reactions are:

$$\mathrm{2Li}(s) + \mathrm{2H_2O}(l) \rightarrow \mathrm{2LiOH}(aq) + \mathrm{H_2}(g)$$

$$\mathrm{2Na}(s) + \mathrm{2H_2O}(l) \rightarrow \mathrm{2NaOH}(aq) + \mathrm{H_2}(g)$$

$$\mathrm{2K}(s) + \mathrm{2H_2O}(l) \rightarrow \mathrm{2KOH}(aq) + \mathrm{H_2}(g)$$

Indeed, all alkali metals react with water in this exact way, according to a general equation:

$$\mathrm{2M}(s) + \mathrm{2H_2O}(l) \rightarrow \mathrm{2MOH}(aq) + \mathrm{H_2}(g) \qquad \mathrm{M} = \mathrm{Li, Na, K, Rb, or\ Cs}$$

Physical similarities are also apparent in the video. All three are metallic, silver-gray in color, and all three metals are less dense than water. All float on the surface while they react. Other properties not obvious in the video exist. Alkali metals are soft and easily cut. All are solid at room temperature, but melt below 200°C, low for a metal.

Beyond similar reactions with water, all alkali metals undergo analogous reactions with oxygen from the atmosphere, forming oxides, M_2O. Alkali metals react with hydrogen to form hydrides, MH, and sulfur to form sulfides, M_2S. In all of these compounds, the alkali metals are positive ions, Li^+, Na^+, K^+, Rb^+ or Cs^+.

Each member of the chemical family of alkali metals has physical and chemical properties very similar to all the others. In most cases *all alkali metals behave the same with regard to the formulas of their compounds.* The peroxides and superoxides are exceptions to this rule, but formulas for oxides and each of the other types of compounds we have described are identical except for the chemical symbol of each alkali metal.

For a demonstration of alkali metals on a larger (and more exciting scale), check out what Mythbusters did with Alkali metals.

Another set of elements with similar properties are fluorine, chlorine, bromine, and iodine, known collectively as the **halogens**. All four elements exist as diatomic molecules, in the form of: X_2, where X=F, Cl , Br, and I. Further, all the halogens react with the alkali metals to form salts according to the reaction:

$$2M + X_2 \rightarrow 2MX \qquad M = \text{Li, Na, K, Rb, or Cs and } X = \text{F, Cl, Br, I}$$

All of the resulting compounds have similar properties as well, such as tasting "salty".

Another example of similarity in chemical properties is with mercury, whose reaction with bromine was discussed in the section covering macroscopic and microscopic views of a chemical reaction. Mercury reacts with other halogens in the same way:

$$Hg(l) + X_2(g, l, \text{or} s) \rightarrow HgX_2(s) \qquad X = \text{F, Cl, Br, or I}$$

The halogens also react directly with hydrogen, yielding the hydrogen halides:

$$H_2 + X_2 \rightarrow 2HX \qquad X = \text{F, Cl, Br, I}$$

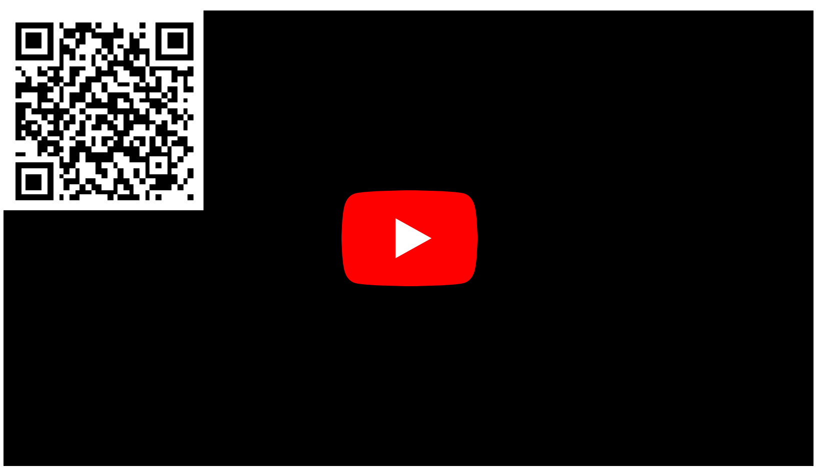
Even though they differ in phase (F and Cl are gases, Br is a liquid, and I is a solid), all are water soluble, and, except for HF, are strong acids in aqueous solution.

In all these examples, the halogens are anions, F^-, Cl^-, Br^-, and I^-. From these examples, it should be clear that the halogens, like the alkali metals, represent a grouping of elements which share a number of chemical and physical properties.

There are several other examples of related groups of elements. Beryllium, magnesium, calcium, strontium, barium, and radium all show similarities, and are called **alkaline earth metals**. All alkaline earths are silvery-gray metals which are ductile and relatively soft. However, they are much denser than the alkali metals, and their melting points are significantly higher. They are also harder than the alkali metals. Further, they all form form hydrides, MH_2; oxides, MO; halides, MX_2; with M = Mg, Ca, Sr, Ba, or Ra and X = F, Cl, Br, I. In all these compounds the alkaline-earth elements occur as dipositive ions, Mg^{2+}, Ca^{2+}, Sr^{2+}, or Ba^{2+}.

Another example of related elements are the **coinage metals**, copper, silver, and gold, which often occur naturally as elements, not in compounds. They have been used throughout history to make coins because they do not combine rapidly with atmospheric oxygen. The reddish brown and golden colors of copper and gold are distinctive among the metals, and the electrical conductivities of the coinage metals are greater than those of any other elements. The **chalcogens** (sulfur, selenium, and tellurium) are another related group of nonmetallic elements. Their hydrogen compounds (hydrogen sulfide, hydrogen selenide, and hydrogen telluride) are all gases which have revolting odors. The familiar smell of rotten eggs is due to hydrogen sulfide and the other two are even worse. These compounds are also highly poisonous and more dense than air. Numerous cases are known where persons working in ditches or other low-lying areas have been rendered unconscious or even killed by hydrogen sulfide resulting from natural sources or from industrial activities such as petroleum refining.

One group of elements, the **noble gases** (helium, neon, argon, krypton, xenon, and radon), forms almost no chemical compounds. Although small concentrations of the noble gases are present in the earth's atmosphere, they were not discovered until 1894, largely because they underwent no reactions. Fluorine is sufficiently reactive to combine with pure samples of xenon, radon, and (under special conditions) krypton. The only other element that has been shown conclusively to occur in compounds with the noble gases is oxygen, and no more than a couple of dozen noble-gas compounds of all types are known. This group of elements is far less reactive chemically than any other.



1. ↑ "Substance and Registry Number Counter." Chemical Abstracts Service-American Chemical Society. 1 July 2009.www.cas.org/cgi-bin/cas/regreport.pl