

CPC 022

**DAY 6**

*Periodic Table*

Dr. Olivieri



This man is dynamite in the world of chemistry...literally! Alfred Nobel invented dynamite and made a pretty penny off of it in the 1800's. As a result of the \$9 million he acquired, he developed awards for people who worked to benefit humanity. We know this award today as the Nobel Prize.

- **It is an orderly arrangement of the elements**

What does periodic mean?

- If something repeats itself in a regular and predictable fashion we say its behavior is periodic.
  - The earth rotates periodically once every 24 hours.
  - A swing moves back and forth periodically because it regularly passes the same point.
- **We can tell about the properties of an element from its position in the table**

### **Periodicity in the Elements**

The elements behave periodically in the following sense:

- As you increase atomic number you periodically and predictably run into elements which always have ions with a -1 charge and are similar in other ways.
  - These elements are called the **halogens**
- You also periodically run across elements which are metallic, soft reactive, and tend to form ions with a +1 charge
  - These elements are called the **alkali metals**
- You run across a whole host of other periodic behaviors: groups of elements that always form 4 bonds, elements that hardly react at all, metallic elements that always form ions with a +2 charge.

The important point is that these properties occur **periodically** as you increase atomic number. All the periodic table does is to impart some order to all these (and more) observations:

**The periodic table is simply a human invention in which elements that act the same are organized so that they all fall into the same column in the table. The remarkable thing about the table is that, once we have one column lined up, they all line up.**

To sum up:

We can construct a table, the periodic table, and arrange all the elements in it such that elements with similar properties are grouped together in the same column.

Examples:

- Alkali Metals
- Halogens
- Alkaline Earths

Another remarkable thing is that the columns themselves cluster together into bigger groupings, such that columns adjacent to each other sometimes share certain chemical properties. Examples of this:

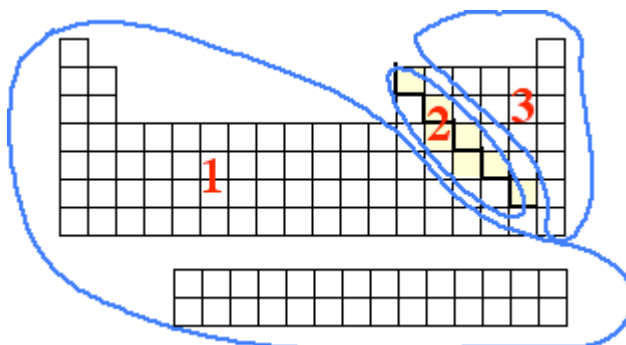
- **metals**
- **transition metals**
- **nonmetals**

- **Gross tendencies**

The roughest groupings of elements lead us to define three groups:

- Metals
- Nonmetals
- Metalloids

**Metals are on the left side of the table and nonmetals on the right.** There is a jagged line dividing the two kingdoms along which lies the metalloids. This is shown schematically below:



In the above drawing:

Region 1 = metals

Region 2 = metalloids

Region 3 = nonmetals

In fact, to be a bit more precise, only those yellow-colored squares are considered to be metalloids.

- **Metals**

There are many more metals than nonmetals.

The alkali metals are in column 1 of the table.

The alkaline earth metals are in column 2.

The next 10 columns comprise the transition elements.

These are sometimes referred to as the inner transition elements to distinguish them from the outer transition elements, the 2 rows of metals detached set off at the bottom of the periodic table.

- **Nonmetals**

Nonmetals often (but not always) form negative ions. They also form covalently bonded compounds with one another. They can occur naturally in any phase, and are often highly colored

The inert gases, which are extremely un-reactive nonmetals, are located in the final column of the table.

The halogens, F, Cl, Br, I, and At, are in the next to last column.

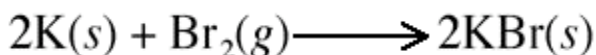
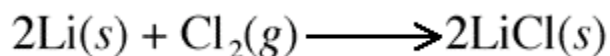
The carbon, nitrogen and oxygen families have nonmetals at the tops of their respective columns and transition to metalloids, and metals, as you go down each column, the transition occurring in the vicinity of that jaggy line we spoke of earlier.



- **More specific families**
  - **Alkali metals**

### **Li, Na, K, Rb, Cs**

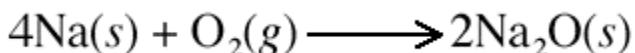
These metals all form ions with a +1 charge and enter into ionic compounds with halogens (you can actually "form" them in halogens):



(Note: these are examples of combination reactions)

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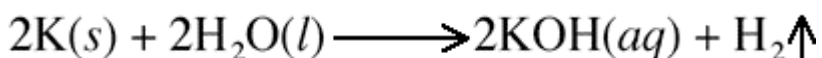
Alkalis react with the oxygen in the air forming a white powder.



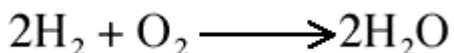
For this reason they are usually stored under kerosene or mineral oil.

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They react violently with water.



Although most of the explosiveness of this reaction comes from the subsequent reaction of the evolved hydrogen with oxygen in the air:

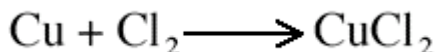


Alkalis are soft and give bright colors when held in a flame.

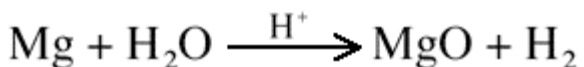
- **Alkaline earth metals**

**Be, Mg, Ca, Sr, Ba**

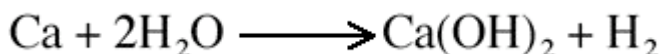
These metals all form ions with a +2 charge and enter into ionic compounds with halogens:



They also release H<sub>2</sub> gas from water, although the reaction is generally less violent than that of the alkali metals:



Mg (OH)<sub>2</sub> is not formed because the MgO is insoluble but:



These metals are brittle and also lead to brightly colored flames.

- **Oxygen family**

**Oxygen Group**

As we proceed down the oxygen group we find a trend from nonmetal to metal.

Oxygen

Sulfur

Selenium

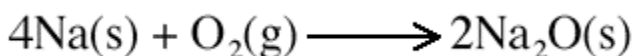
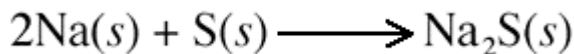
Tellurium is a metalloid

Polonium is a metal

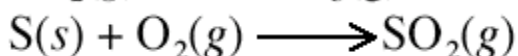
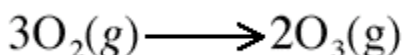


These are all nonmetals

Oxygen and sulfur are the 2 most important members of this group and they share many similarities in their patterns of reactivity e.g.

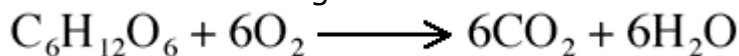


**or**



Both elements also form covalent compounds with hydrogen,  $\text{H}_2\text{O}$ , and  $\text{H}_2\text{S}$ , organic alcohols in the case of oxygen, such as  $\text{CH}_3\text{OH}$  and thiols in the case of sulfur such as  $\text{CH}_3\text{SH}$ , and peroxides and persulfides  $\text{H}_2\text{O}_2$  and  $\text{H}_2\text{S}_2$ .

By far the most important (in human terms) reaction of oxygen is its oxidation of hydrocarbons and other organic compounds exemplified in the metabolism of glucose:



Another important reaction is combustion of natural gas (of which methane is the primary component).



Sulfur, because it is not as "nonmetallic" as oxygen, tends to have a more complex chemistry.

- **Halogens**

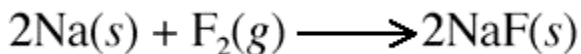
The group of elements that most clearly illustrates trends and behaviors in nonmetals is the halogens.

Every metal forms a salt with each halogen, in every case, the halide ion has a charge of -1. Examples:

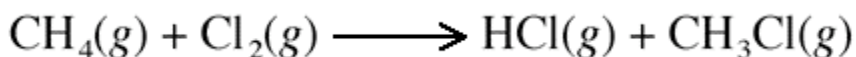
NaBr	FeCl <sub>3</sub>
SnCl <sub>4</sub>	AlCl <sub>3</sub>
AgCl	PbI <sub>2</sub>

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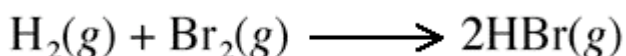
Halogens react combustively with alkali and alkaline earths:



They react readily with organic compounds forming a large variety of organohalides.



They react with hydrogen to form gases:



- HF, HCl, HBr, HI, when dissolved, in water give acidic solutions.
  - HF is a weak acid and the others are strong acid.
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Halogens also form "oxyacids", for example:

HClO      hypochlorous

HClO<sub>2</sub>      chlorous

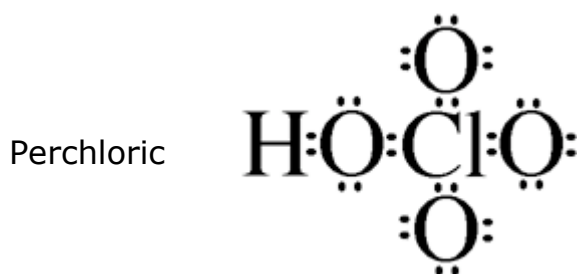
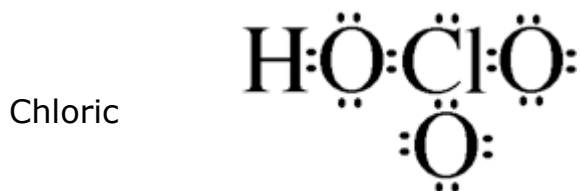
HClO<sub>3</sub>      chloric

HClO<sub>4</sub>      perchloric

You try - Draw the Lewis Structure for the above compounds.

### Halogen Oxyacids Answers





▪ **Lewis dot**

**Physical Properties of the Halogens**

They are highly colored

- 1.)  $\text{F}_2$  = pale yellow gas.
- 2.)  $\text{Cl}_2$  = yellow-green gas.
- 3.)  $\text{Br}_2$  = reddish-brown liquid.
- 4.)  $\text{I}_2$  = purple-black solid.

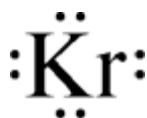
Note how the boiling point and melting point increases as you go down the column.

- **"Inert gases"**

**He, Ne, Ar, Kr, Xe**

They are very unreactive but Kr and Xe form a few compounds.

They are nonatomic gases and have a characteristic "full octet" Lewis Structure, e.g.,



- **Transition metals**

One of the most striking aspects of transition metals is that they can have multiple oxidation states:

- $\text{Fe}^{2+}$ ,  $\text{Fe}^{3+}$
- $\text{Sn}^{2+}$ ,  $\text{Sn}^{4+}$
- $\text{Cu}^+$ ,  $\text{Cu}^{2+}$

They tend to form ionic compounds and some ions have characteristic colors in aqueous solution.

- $\text{Fe}^{2+}$  - light green
- $\text{Fe}^{3+}$  - gold
- $\text{Cu}^{2+}$  - blue
- $\text{Ni}^{2+}$  - green
- $\text{Co}^{2+}$  - pink

- **Lanthanides, Actinides**

These are the two rows at the bottom of the periodic table, and each containing 14 elements.

Chemically, these elements strongly resemble each other and for this reason are very difficult to separate.

- **Other Generalizations**

### **Phases**

All metals, **except mercury (Hg)**, are solids at room temperature. Metals have low vapor pressures. (They do not evaporate rapidly. When is the last time you saw a steel girder evaporate?)

Many nonmetals are gases - there is only 1 liquid ( $\text{Br}_2$ ) and some solids, such as sulfur, carbon and phosphorous.

Frequently (but not always) solid and liquid nonmetals have high vapor pressures. Example: if solid iodine is stored in a glass container, you will see a purple cloud of iodine vapor above the solid iodine.

- **Colored elements**

With few exceptions (e.g. Au and Cu), metals are neutral in color and all can be polished to high reflectivity.

Finely divided (powdered) metals often appear black but this is because the light "gets lost" due to multiple reflections.

Nonmetals can be crystalline ( $\text{I}_2$ , diamond, B) or--as is more usual--dull in luster. They are often highly colored however.

e.g.

- black carbon (graphite)
- halogens
- sulfur - yellow
- phosphorous - red or white

- **Radioactive elements**

Although most elements have radioactive isotopes, the elements whose predominant isotope is radioactive are almost all at the high end of table (atomic number 84 and above).

Two notable exceptions:

- Element 43 Technetium (Tc).
- Element 61 Promethium (Pm).

## Periodic trends

### Trends in Metallic Character

As you go **down** a column, elements become more metallic.

As you go left to right **along a row** elements become less metallic.

Thus:

- Cs is more metallic than K
- Pb is more metallic than C
- But C is more metallic than O--this doesn't mean C is a metal, however--the fact that Michael Jordan is shorter than Shaquille O'Neal does not mean that Michael Jordan is short.

- **Size**

### Trends in Size

As you move across a row (left to right) size **decreases**.

As you go down a column size **increases**.

Example:

- "Lanthanide Contraction"--each lanthanide atom is a tiny bit smaller than the one to its left.

- **Electronegativity**

Electronegativity is a measure of how easily an atom can accept an electron to form a **negative** ion.

The element with the highest electronegativity is fluorine. The lowest is cesium.

Nonmetals have high electronegativity. Metals have low electronegativity.

All other things being equal we expect that:

- Electronegativity increases left to right across a row
- Electronegativity decreases as you go down a column.
-

- **Ionization potential**

The **ionization energy is the amount of energy needed to remove an electron from an atom**. It is also known as the ionization potential.

Ionization energy increases as you go across (left to right) a row and decreases as you go down a column. (Not surprising since this follows precisely the trends for metallic character.)

Thus sodium has a lower ionization energy than phosphorous

But cesium has a lower ionization energy than sodium.

- Remember - low ionization energy means easy formation of a positive ion.

- **Number of bonds formed can be dependent on position in table**

You can help yourself reason out the structure or composition of many compounds if you can remember how many bonds are formed by a few elements:

C - 4

N - 3

O - 2

F - 1

But beware - as elements get bigger or compounds more complex, you have to do the Lewis structure to figure out the bonding.

- **Characteristic ionic charge can be dependent on position in table**

## Ionic Charge

The charges on positive ions for active metals as well as some negative ions can be deduced immediately from their position in the table.

Group 1	+1
Group 2	+2
Group 3	+3 Al only - the others have multiple oxidation states.
Group 15	-3 usually only N does this.
Group 16	-2 O,S and sometimes Se.
Group 17	-1 all halogens.

- **Oxidation number**

## Oxidation Numbers (1)

These are like charge...but not exactly the same thing.

Here are the rules:

- For an element - the oxidation number is 0.
- For a monoatomic ion - the oxidation number = charge.
- Nonmetals usually have negative oxidation numbers...but not always.
- Oxygen--is -1 in peroxides and -2 in other compounds.
- Hydrogen--is -1 when bonded to metals and +1 when bonded to non-metals.
- Fluorine is always -1.
- Other halogens -1 binary compounds and positive when bonded to oxygen.
- The sum of all oxidation numbers in a neutral compound is 0.
- The sum of all oxidation numbers in a polyatomic ion is the charge on that ion.

- **Examples**



Barium has an oxidation number of plus two (+2). Chlorine has an oxidation number of negative one.



In this case hydrogen has an oxidation number of plus one. Oxygen has an oxidation number of negative two (which is almost always true). Since the whole party has to add up to zero, chlorine has an oxidation number of plus five.



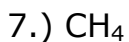
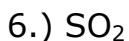
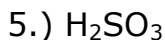
Oxygen has an oxidation number of negative two and hydrogen has a plus one oxidation number for each atom.



Again oxygen is negative two (-2) which gives a negative six total (-6). Since this is a negative one ion the oxidation numbers must add up to negative one and so nitrogen must be a plus five.

- **Problems**

What is the oxidation number of each of the elements in the following compounds and ions?



## Answers



O -2

S +6



H +1

N -3

C +2



H +1

Cl +3

O -2



H +1

O -2

S +4



O -2

S +4



C -4

H +1



O -2

P +5