NANO-MODULE: Introduction to Chemistry

Name: ___________________________ Date: ___________________

Objectives:

- To understand what an atom is
- To learn the trends that exist in the Periodic Table of Elements

Key Concepts: atom, subatomic particle, nucleus, electron, proton, neutron, atomic number, atomic mass number, isotope, valence octet, metal, cation, anion, ionic bond, molecule, covalent bond, lone pair, bond length, electronegativity, electron affinity, ionization energy, atomic radius

Background:

In beginner's chemistry, **atoms** (Greek for "uncuttable") are defined as the building blocks of matter. They are the simplest and smallest indivisible particle that can result from dividing something like a block of magnesium.

There have been several models of the atom throughout history, starting with Greek philosopher Democritus' 500 B.C. proposal that all matter is composed of small, indivisible particles called atoms. In 1803, Dalton proposed that atoms were small, hard indivisible spheres. In 1897, JJ Thompson discovered electrons and proposed the Plum Pudding model of the atom, where an atom small electrons were embedded in a sphere of positive charge. In 1908, Rutherford experimentally discovered that an atom was made up of mostly empty space and that electrons traveled around a small, dense positively charged nucleus. In 1913, Bohr suggested that electrons travel in certain orbits around the nucleus of positive charge like in our Solar System where the planets are like electrons *orbiting* the sun which acts as the nucleus.

The accepted model today – the electron cloud model was proposed in the 1920s when it was accepted that we did not know the exact position of an electron at a given time, only where it most probably will be. In figure 1, we see Dalton's "Billard Ball" model, the JJ Thompson's Plum Pudding model, Bohr's orbital model, and the electron cloud model.

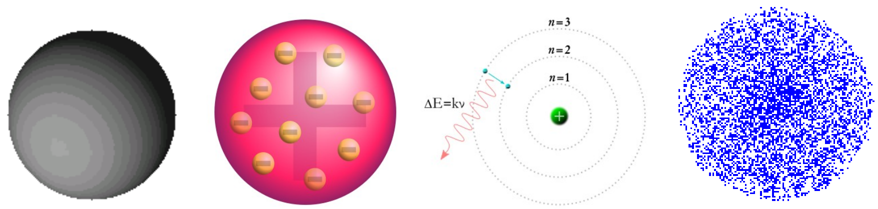

Fig. 1. Models of the atom past and present.[1]

Atoms are neutrally charged and have three **subatomic particles**. Atoms have very small negatively charged particles (**electrons**) revolving around a small, dense nucleus. The nucleus is made up of positively charged particles (**protons**) and neutral particles (**neutron**). The electrons and protons cancel each other's charges out, resulting in a neutral atom.

In all atoms, the number of protons is equal to the number of electrons. This number is known as the **atomic number**. The **atomic mass number** is the number of neutrons and protons added together. The number of electrons in an atom are neglected when representing the atomic mass because the mass of electron is approximately 1/1836 the mass of a proton or neutron[2].

6 C 12.01

Fig. 2. Carbon element in periodic table where 6 is the atomic number, 12.01 is the atomic mass, and C is the chemical symbol.

There are also naturally occurring elements in nature that have different mass numbers, due to a different number of neutrons. For example, carbon-12 has a mass number of 12.01 as shown in Fig. 2, but there is also carbon-13 and carbon-14. Since an element is defined by is atomic number, the number of

[1] Bohr's model: Image / Super Rad!, released under GNU Free Documentation License. Original image courtesy Wikipedia
Plum pudding model: Image / Fastfission, released under GNU Free Documentation License. Original image courtesy Wikipedia
Electron cloud model: http://www.fordhamprep.org/gcurran/sho/sho/lessons/lesson32.htm

[2] http://physics.nist.gov/cgi-bin/cuu/Value?me The fractional version's denominator is the inverse of the decimal value (along with its relative standard uncertainty of 5.0×10^{-8})

protons and electrons are the same in the other carbons. So instead of having 6 neutrons, carbon-13 and carbon-14 have 7 and 8 neutrons respectively. Carbon-12 and the other forms of carbon are collectively called **isotopes**. Isotopes are atoms of the same element that differ only in the number of neutrons that they have. Other famous isotopes are deuterium and tritium, which are isotopes of hydrogen. Hydrogen (protium) has a mass number of 1.0079 so it has only one proton and no neutrons. Deuterium has one proton and one neutron while tritium has one proton and two neutrons.

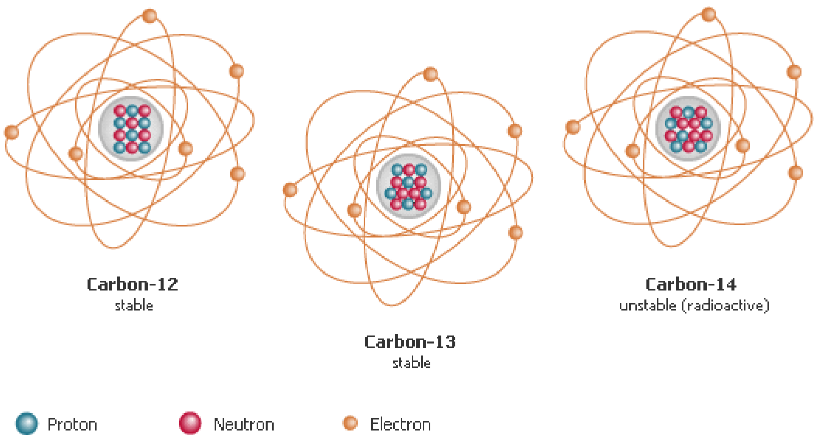

Fig. 3. Isotopes of carbon.[3]

The mass number of carbon on the Periodic Table, 12.01, is the weighted average of the masses of all the isotopes. To calculate the 12.01, we look for the abundance or how plentiful that isotope of carbon is in naturally and then the mass of it. Carbon-12 is the most plentiful with an abundance of 98.8944%; carbon-13 is 1.1056%; and carbon-14 only exists in trace amounts.[4] The weighted average of the masses is calculated by multiplying the mass number of the isotope times the abundance and then adding all the calculated values for each of the isotopes up. The calculation is shown below:

$$12(.988944) + 13(.011056) = 12.01106$$

In this calculation we see that the result is not 12.01 but this is because the periodic table used other references for the abundance and they might have more or less decimal places in their calculation.

[3] http://encarta.msn.com/media_461535237/isotopes_of_carbon.html

[4] De Laeter, J.R., Böhlke, J.K., De Bièvre, P., Hidaka, H., Peiser, H.S., Rosman, K.J.R., and Taylor, P.D.P. Atomic Weights of the Elements: Review 2000 (IUPAC Technical Report). *Pure Appl. Chem.* **75**, 683-799 (2003)

Elements are ordered by increasing atomic number in Mendeleev's Periodic Table of Elements. As of January 27, 2008, the Periodic Table contains 117 elements.

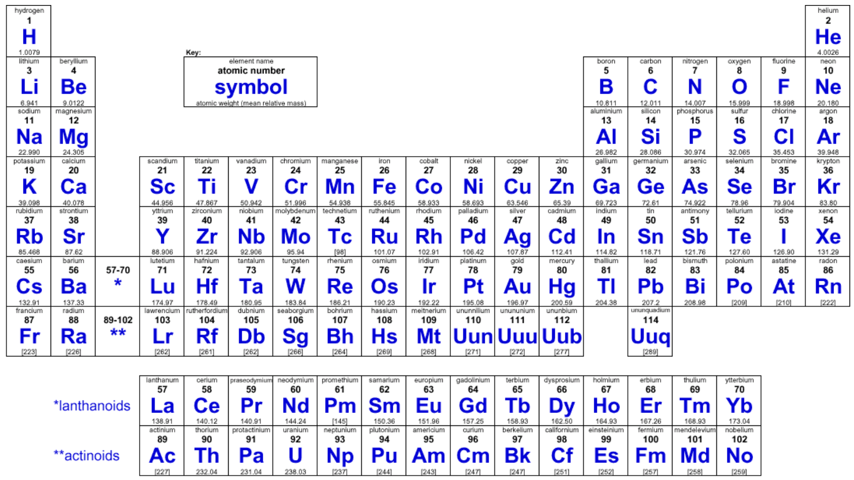

Fig. 4. The Periodic Table of Elements[5].

The table separates the elements by 18 groups (columns) and by 7 periods (rows). The elements in each group have similar chemical properties because the elements have the same number of electrons in their **valence shells** (the outermost level of electrons). The electrons in the inner shell that are not part of the valence shell are said to be in the **kernel**.

Electrons in the valence shell are the electrons that participate in chemical reactions because they are the most available. The electrons in one element may react with other elements to form different types of bonds or attractions. As people trade with others to get something they want such as exchanging money for a certain product, elements exchange or share electrons to attain a stable **octet**, which is a full set of eight electrons in its valence shell.

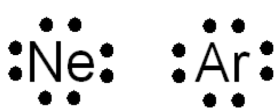

Fig. 5. Stable octets in Neon and Argon elements where the black dots represent valence electrons.

Name	Symbol	Name	Symbol

[5] http://fermat.csci.unt.edu/~mikler/Courses/biocomputing/resources/periodic_table.gif

Actinium	Ac	Neodymium	Nd
Aluminium (Aluminum)	Al	Neon	Ne
Americium	Am	Neptunium	Np
Antimony (Stibium)	Sb	Nickel	Ni
Argon	Ar	Niobium	Nb
Arsenic	As	Nitrogen	N
Astatine	At	Nobelium	No
Barium	Ba	Osmium	Os
Berkelium	Bk	Oxygen	O
Beryllium	Be	Palladium	Pd
Bismuth	Bi	Phosphorus	P
Bohrium	Bh	Platinum	Pt
Boron	B	Plutonium	Pu
Bromine	Br	Polonium	Po
Cadmium	Cd	Potassium (Kalium)	K
Caesium (Cesium)	Cs	Praseodymium	Pr
Calcium	Ca	Promethium	Pm
Californium	Cf	Protactinium	Pa
Carbon	C	Radium	Ra
Cerium	Ce	Radon	Rn
Chlorine	Cl	Rhenium	Re
Chromium	Cr	Rhodium	Rh
Cobalt	Co	Roentgenium	Rg
Copper (Cuprum)	Cu	Rubidium	Rb
Curium	Cm	Ruthenium	Ru
Darmstadtium	Ds	Rutherfordium	Rf
Dubnium	Db	Samarium	Sm
Dysprosium	Dy	Scandium	Sc
Einsteinium	Es	Seaborgium	Sg
Erbium	Er	Selenium	Se
Europium	Eu	Silicon	Si
Fermium	Fm	Silver (Argentum)	Ag
Fluorine	F	Sodium (Natrium)	Na
Francium	Fr	Strontium	Sr
Gadolinium	Gd	Sulfur (Sulphur)	S
Gallium	Ga	Tantalum	Ta
Germanium	Ge	Technetium	Tc
Gold (Aurum)	Au	Tellurium	Te
Hafnium	Hf	Terbium	Tb
Hassium	Hs	Thallium	Tl
Helium	He	Thorium	Th
Holmium	Ho	Thulium	Tm
Hydrogen	H	Tin (Stannum)	Sn
Indium	In	Titanium	Ti
Iodine	I	Tungsten (Wolfram)	W
Iridium	Ir	Ununbium	Uub
Iron (Ferrum)	Fe	Ununhexium	Uuh
Krypton	Kr	Ununoctium	Uuo
Lanthanum	La	Ununpentium	Uup
Lawrencium	Lr	Ununquadium	Uuq
Lead (Plumbum)	Pb	Ununtrium	Uut
Lithium	Li	Uranium	U
Lutetium	Lu	Vanadium	V
Magnesium	Mg	Xenon	Xe
Manganese	Mn	Ytterbium	Yb
Meitnerium	Mt	Yttrium	Y
Mendelevium	Md	Zinc	Zn
Mercury (Hydrargyrum)	Hg	Zirconium	Zr
Molybdenum	Mo		

Table 1. Elements

A basic understanding of the properties shared by each group in the period table is needed to predict the products formed in a reaction. The period table is broken down into three major groups – metals, nonmetals, and the metalloids.

The **metals** include the **alkali metals** (1st group: Li, Na, K, Rb, Cs, Fr), the **alkaline earth metals** (2nd group: Be, Mg, Ca, Sr, Ba, Ra), and the 38 **transition metals** (3rd group-Sc, Ti, V, … , Fe, Co, Ni, Cu, Zn …). Metals are conductors, meaning that they are good at transferring heat and electricity. Metals are also ductile (can be made into wire) and malleable (easily shaped). Transition metals also have metallic characteristics however their valence electrons are in more than one shell, which explains why they have several oxidation states. The following 3 figures shows where each group is on the periodic table of elements.

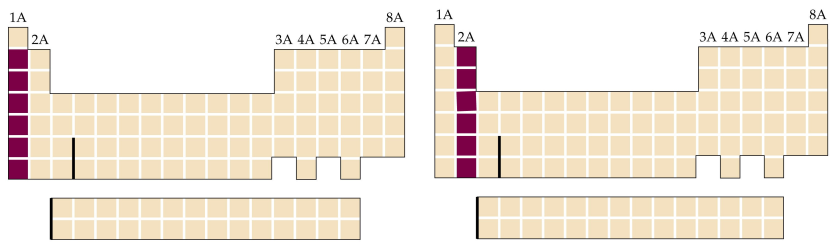

Fig. 6. Group 1 and 2 elements[6].

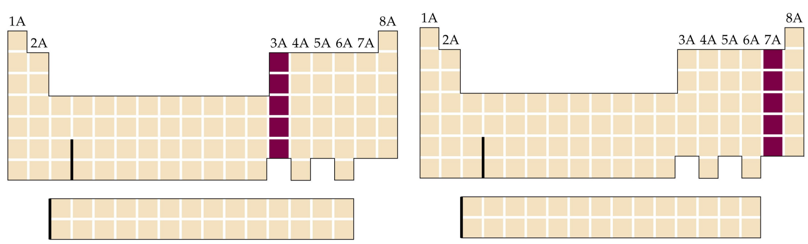

Fig. 7. Group 13 and 17 elements[2].

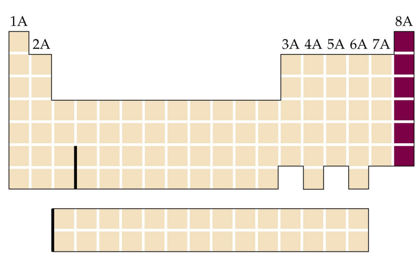

Fig. 8. Noble gases[2].

[6] http://wps.prenhall.com/wps/media/objects/602/616516/index.html

The **metalloids** have metallic and nonmetallic characteristics and border the bold stair-steps line on the periodic table (B, Si, Ge, As, Sb, Te, Po). Metalloids have properties of metals and nonmetals. The nonmetals consist of H, C, N, O, P, S, Se, the halogens (17th group: F, Cl, Br, I) and the noble gases (18th group: He, Ar, Kr, Xe Rn). The **noble gases** have a full stable octet, so they are unreactive. Nonmetals are very brittle and are neither ductile nor malleable. They are not shiny as metals are and do not reflect light.

Metals tend to *lose electrons* to nonmetals forming a positively charged atom (**cation**) and nonmetals tend to *gain electrons* from metals forming a negatively charged atom (**anion**). The purpose of this *transfer of electrons* is to attain a stable octet. Also, opposites attract, so the cation and anion experience electrostatic attraction (feel drawn to each other) and form an **ionic bond**. This can be seen through the reaction between Na and Cl. Na is an alkali metal with one valence electron that can be lost to Cl, who has seven valence electrons. After this, the resulting atoms are Na^+ and Cl^-. The positively charged Na is formed because it loses an electron, so there is one more proton than electron in the atom. The negatively charged Cl is formed because it gains an electron, resulting in one more electron than proton.

Electronegativity is the ability of an atom to attract electrons towards itself in a covalent bond. In the periodic table, electronegativity increases up a group and across a period. It is quantified by the Pauling scale, which ranges from 0.7 to 4.0. Fluorine has the highest electronegativity of 4.0 and cesium has the lowest electronegativity of 0.7.

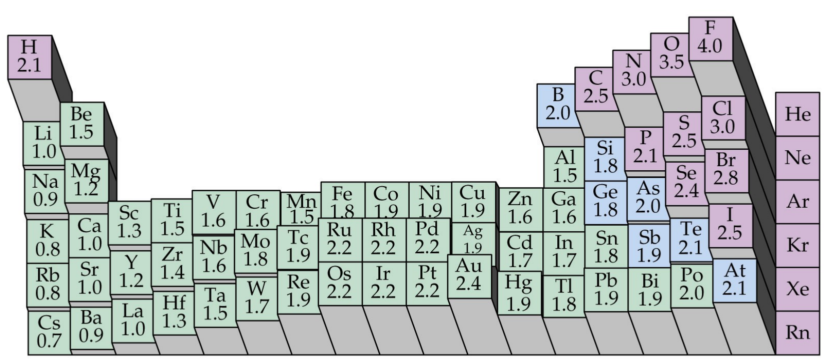

Fig. 9. Electronegativity on the Periodic Table[7].

[7] http://wps.prenhall.com/wps/media/objects/602/616516/index.html

Electron affinity is the energy required to remove an electron from a singly charged negative ion. **Ionization energy** is the energy required to remove an electron from the isolated atom or ion. Both follow the same trend as electronegativity.

Atomic radius is half the distance between the two nuclei of two adjacent atoms. Because atoms are so small and because they are mostly made up of empty space, it is difficult to determine their size. Atomic radius increases down a group and from right to left across the period.

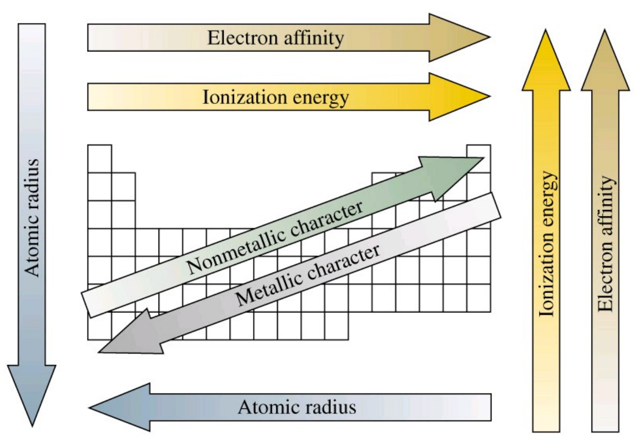

Fig. 10. Summary of trends in the periodic table[8].

Useful Links:

The Visual Elements Periodic Table
http://www.rsc.org/chemsoc/visualelements//pages/periodic_table.html

Dynamic Periodic Table
http://www.dayah.com/periodic/

Printable Periodic Tables

[8] http://cwx.prenhall.com/petrucci/medialib/media_portfolio/10.html

http://www.sciencegeek.net/tables/tables.shtml
Recommended: http://www.sciencegeek.net/tables/NYregents.pdf

Elements Song
http://www.privatehand.com/flash/elements.html

The Most Beautiful Periodic Table Poster in the World
http://www.theodoregray.com/PeriodicTable/Posters/index.html

"The Elements" song by Tim Lehrer
Media with animations:
http://www.privatehand.com/flash/elements.html
Lyrics:
http://www.edu-cyberpg.com/IEC/elementsong.html

Mnemonics
http://www.memory-key.com/Mnemonics/using.htm

Match-up: Match the definition with the term.
A. atom
B. octet
C. cation
D. anion
E. proton
F. valence shell
G. covalent bond
H. valence electrons
I. Lewis structure
J. electron

1. electrons found in the outermost shell _____

2. complete set of eight electrons _____

3. bond formed by sharing of electrons between two atoms _____

4. small negatively charged subatomic particle _____

5. representation of covalent bond using symbols and dots _____

6. positively charged atom _____

7. the outermost layer of an atom _____

8. positively charged subatomic particle _____

9. negatively charged atom _____

10. building blocks of matter ____