Science-1A Lab: Week-09, Wednesday, October 6, 2021

Last week you watched the Disney show "Our Friend the Atom" which provided an excellent introduction to atomic and nuclear physics. We will now proceed deeper into atomic physics - how atoms are built and have differing properties.

As was the case with the handouts for the physics half of the course, all handouts are individually available on the course website at *https://yosemitefoothills.com/Science-1A*. The weekly lecture and lab notes link to them.

Printed versions have been also available from the Campus Bookstore. You may have also bought the Chemistry Handouts when/if you bought the Physics Handouts.

Copies of the pdf files used to print those versions are posted in the Modules section of Canvas for Science-1A. There, the chemistry file is named "ChemistryHandouts-TopPriority.pdf". (An older version with some optional material is in the file labeled simply "ChemistryHandouts.pdf".)

The quiz preparation and Equation Sheet handouts you already have by downloading from the "Quiz and Test Preparation" section of the website at
https://yosemitefoothills.com/Science-1A-Fall-2021/#practice
were also included in the "PhysicsHandouts.pdf". They are therefore not part of this "Chemistry" handout group.

Normally, we would start our chemistry lab work by using molecular model atoms and bonds to build molecules. An overview is in the handout at
https://yosemitefoothills.com/Science-1A/Handouts/Week-09/MakingMolecularModels.pdf
which lists the characteristics (color, number of bond holes, angle of those holes, and diameter) of my plastic atom collection. Also listed are the types of bonds (short, normal, flexible for double and triple bonds, and small flexible bonds). When you are a teacher, I urge you to try to obtain a collection of these rather expensive parts for your classroom since kids really enjoy building things. Once built, some of the more interesting molecules can be hung from your ceiling.

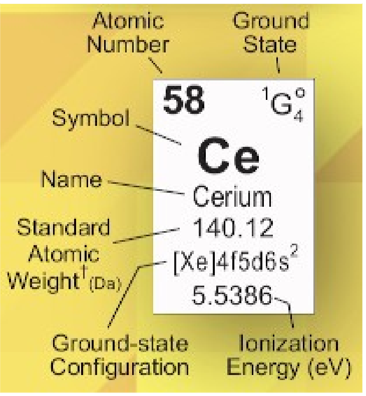
Of course, we are not able to play with the molecules this semester because of the need to protect ourselves from the COVID-19 virus. The best approximation is to use a **free** program named Avogadro (see *https://avogadro.cc/*). I have been using it for years on my main computer and on my Raspberry Pi's. I will not require that you install and use it, but I hope you will be curious enough to try it out. Avogadro could also be used by kids in your classroom.

In lieu of your creating them physically or with the Avogadro program, I have placed animated gif images at
https://yosemitefoothills.com/Science-1A/MolecularAnimations/
that can let you understand the three-dimensional structure of the molecules we will discuss. Those listed in bold face in this note are in that directory. I have capitalized their initial letters to match the names in the directory on that web page. Just clicking on each molecule name in that directory should make a rotating molecule appear.

Be sure to read the notes about Making Molecular Models linked above, and look at the animation of each molecule as it is mentioned on pages 4 and 5 of this note.

Periodic Table of Elements

The Periodic Table is at *https://yosemitefoothills.com/Science-1A/Handouts/Week-09/PeriodicTableOfElements.jpg* .



All 118 atoms known to exist long enough to be named are shown in this table. The legend shown in the lower-left corner of the chart is reproduced at the right. In this class, we care about the Atomic Number, Symbol, Name and Standard Atomic Weight. We do not care about the Ground State, Ground State Configuration, or Ionization Energy.

The Atomic Number is number of positive charges (protons) in the nucleus. It is also the number of electrons surrounding a neutral atom (one that is not an ion).

The Standard Atomic Weight (a better name would be Standard Atomic Mass) is the mass in Dalton units (Da) which can be interpreted in either of two ways:

1. It is the mass in units of $1.66053906660\times10^{-27}$ kg/Da which was chosen as exactly 1/12 the mass of a carbon atom that has a nucleus with 6 neutrons.

2. It is the mass in grams of 6.02214076×10^{23} atoms of that kind found in nature. It includes all isotopes of the atom and is sometimes not even close to an even number. For example chlorine has two common isotopes, one with 18 neutrons (76% abundance) and another with 20 neutrons (24% abundance). A sample of chlorine is a mix of these isotopes and has an average mass of 35.45 Da.

So the mass of a typical chlorine atom is $(35.45\,\mathrm{Da})\times(1.66053906660\times10^{-27}\,\mathrm{kg/Da})=5.887\times10^{-26}\,\mathrm{kg}$, and the mass of 6.02214076×10^{23} atoms of chlorine is 35.45 g.

When students are asked for the atomic mass of an atom, they sometimes carelessly provide the Ionization Energy shown at the bottom of the box for the atom. Be careful to use the number immediately below the element name.

The elements are arranged so that those in the same columns (Group) have similar properties:

- The Group 1 atoms, H, Li, Na, K, ... are highly chemically reactive, and become singly-charged positive ions (H^+, Li^+, Na^+, K^+,...) when bonding to other atoms.
- The Group 2 atoms Be, Mg, Ca, Sr, ... are somewhat less reactive, and become doubly-charged positive ions (Be^{++}, Mg^{++}, Ca^{++}, ...) when bonding.
- The Group 17 atoms, F, Cl, Br, I, ... are also highly chemically reactive, but become negative ions (F^-, Cl^-, Br^-, ...) when bonding.
- The Group 18 atoms, He, Ne, Ar, Kr, ... are inert and do not react with other atoms or themselves. They tightly hold on to all their electrons and rarely become ions.

Different regions of the Periodic Table have names:
The elements in Group 1 are called the **alkali metals**.
The elements in Group 2 are called the **alkali earth metals**.
The elements in Group 3 include elements 57-71 (**Lanthanides**) and 89-103 (**Actinides**).
The Lanthanides plus Sc (21) and Y (39) are called the **rare earth metals**.
The elements in Groups 4-11 are called the **transition metals**.
The elements in Groups 12, 13 (except B), Sn and Pb in Group 14, and Bi in Group 15 are called **post-transition metals**.
The elements in Group 16 are called the **chalcogens**.
The elements silicon and germanium are **semiconductors**.
The elements in Group 17 are called the **halogens**.
The elements in Group 18 are called the **noble gases** (also **inert gasses**).

The rare earth metals Nd (60) and Sm (62) are used to make very powerful magnets important for electric cars and windmill generators.

In general, the elements in the upper-right of the Periodic Table are electrical **insulators**, and those in the left and middle are **electrical conductors** (**metals)**. In between are **semiconductors**.

The chemistry of molecular attraction is determined by the number of electrons in the outermost shells of the atoms. The other electrons of the atoms, which are in filled inner shells, are too tightly held to their nucleus to participate in chemical bonding.

See if you can see the pattern in the following table of atoms and the number of electrons in their outermost shells:

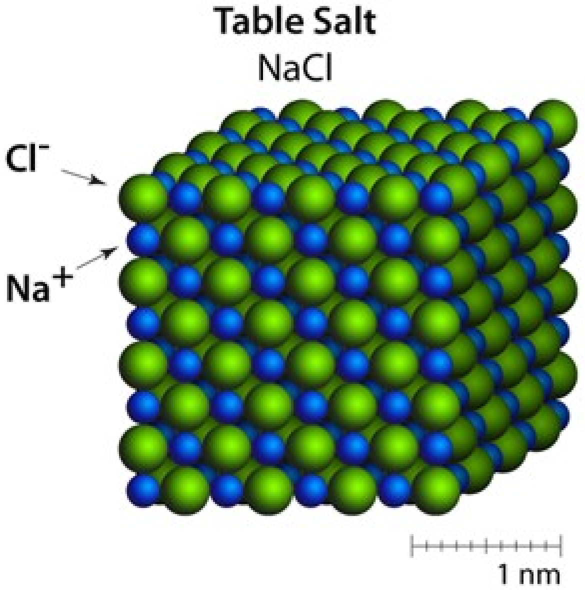
	Group 1	**Group 2**	**Group 13**	**Group 14**	**Group 15**	**Group 16**	**Group 17**	**Group 18**
Period 1	H 1							He 2
Period 2	Li 1	Be 2	B 3	C 4	N 5	O 6	F 7	Ne 8
Period 3	Na 1	Mg 2	Al 3	Si 4	P 5	S 6	Cl 7	Ar 8

The 1st shell can hold a maximum of only 2 electrons produces the elements of Period 1 as it is filled.
The 2nd and 3rd shells can hold a maximum of 8 electrons each produces the elements of Periods 2 and 3 as they are filled.
The 4th and 5th shells (producing Periods 4 & 5) are 18 atoms long and hold a maximum of 18 electrons.
The 6th and 7th shells (producing Periods 6 & 7) hold up to 32 electrons.
You don't need to remember the maximum numbers; just count the atoms in the corresponding row of the Periodic Table.

Ionic Bonding
Atoms are happiest when they feel that they have a full set of electrons in their outermost shell. For the two Period 1 atoms that magic number is 2, for those in Periods 2 and 3, it is 8. The Group 1 and 2 atoms are eager to give their outermost electrons away and have their electron structures look like that of the preceding Group 18 atoms. When Li or Na give up their single outermost electron, their electronic structure looks like that of He or Ne, respectively. When Be or Mg give up their 2 outermost electrons, their electronic structure then also looks like that of He or Ne, respectively.

Group 17 atoms want to steal one electron so that their electronic structures can look like that of the following Group 18 atoms. When F and Cl steal an electron, their electronic structures looks like that of Ne or Ar, respectively.

When Na meets Cl, they agree that the outermost electron of Na should join the 7 outermost electrons in Cl. The electronic structure of Na would then look like Ne and the electronic structure of Cl would look like Ar. Losing its electron makes Na into an **Na ion, Na^+**, and gaining an electron makes Cl into a **Cl ion, Cl^-**. With opposite charges they attract, and when many do this together they form a NaCl crystal, a crystal of table salt. An image of a NaCl crystal with 512 atoms is shown at the right. This type of arrangement is called **ionic bonding** where the atoms end up held together by electric charges because they willingly traded electrons.



Similarly O in Group 16 is 2 electrons short of a full set of 8, so it steals 2 electrons. S which is also a Group 16 atom usually steals 2 electrons, but sometimes gives up all 6 of its outermost electrons as mentioned in the example of hydrochlorothiazide at the end of this note.

This story works well for Group 1 or Group 2 atoms joining with Group 17 atoms or with O, making molecules like the following: HF, HCl, LiF, LiCl, NaF, NaCl, BeF_2, $BeCl_2$, MgF_2, $MgCl_2$, H_2O, Li_2O, Na_2O, BeO, and MgO. Here, the subscript 2 means that there are 2 of that atom. For example, H_2O means there is one O with two H's.

Covalent Bonding (mutual sharing)
Atoms can also **share** their outermost electrons where each atom has the illusion that its outermost shell is full. The simplest example is H_2 where the H atoms share their two outermost electrons equally and are able to convince themselves that their electronic structures both look like He. Other atoms like this are F_2, Cl_2, Br_2, I_2, O_2 and N_2. which feel that their outermost electrons are like those of Ne, Ar, Kr, Xe, Ne, and Ne, respectively.

These are often written as H:H, F:F, Cl:Cl, etc. which are called a Lewis structures. Many teachers love them, but not me. So those are the only Lewis structures you will see here in Science-1A.

Biochemistry involves tens of thousands of covalently-bonded atoms involving carbon. We will be spending 3 weeks learning about fats, sugars, amino acids, nucleic acids, proteins, and DNA.

Metallic Bonding (sharing of all electrons in a crystal)
When metal atoms are grouped together to make a solid metal with no non-metal atoms, the outermost electrons are shared throughout the metal and help hold the metal together in a flexible manner. Metals can be extruded into cups, drawn into wires, and bent into special shapes because of this flexibility. This is called **metallic bonding**.

Hydrogen Bonding
A relatively weak form of bonding between different molecules is mediated by hydrogen atoms violating the normal rules and extending an extra attractive bond to nearby oxygen or nitrogen atoms. These hydrogen bonds hold the double strands of DNA together, hold cellulose polymer stands together into sheets to make wood, and lock water molecules together into ice at temperatures below 0 °C.

Molecular Structure Diagrams

Chemical structures are nearly always three dimensional so drawing them on paper is a challenge. A handout about how this is done is at
https://yosemitefoothills.com/Science-1A/Handouts/Week-09/SimplifiedMoleculeDiagrams.pdf
Remember to refer to it when using the 11 pages of molecular diagrams at
https://yosemitefoothills.com/Science-1A/Handouts/Week-09/AllMolecularStructureImages.pdf .

In these diagrams each line represents a bond involving a pair of electrons, one from each atom being bonded. A pair of lines represents a double bond involving two pairs of electrons. Rare triple bonds such as in N_2 and C_2H_2 involve 3 pairs of shared electrons.

Molecular Models of Some Simple Molecules

The handout entitled "Beginning Exercises with Molecular Models" is at
https://yosemitefoothills.com/Science-1A/Handouts/Week-09/BeginningExercisesWithMolecularModels.pdf .
It was written to guide students in the creation of some simple molecules using the large collection of atoms and bonds enumerated at
https://yosemitefoothills.com/Science-1A/LabNotesAndLinks/MolecularModelIntroduction/MolyModInventory.pdf .

Since we are unfortunately unable to actually do these wonderful hands-on learning exercises, I have made animated gif images of them. As each molecule is discussed here and during the next few weeks, remember to go to
https://yosemitefoothills.com/Science-1A/MolecularAnimations/
and click on the molecule name to see its animation.

Real atoms are too small to show colors, but for modeling purposes, there are certain standard colors used for the most common atoms:

Hydrogen	white
Oxygen	red
Carbon	black
Nitrogen	blue
Phosphorus	purple
Sulfur	yellow
Chlorine	green
Bromine	orange
Iodine	purple (also)
Metal	grey

Each molecule that has an animation will be written in bold face as in the following discussions.

Here, I will just mention additional points that I would normally stress in lab as we build each molecule:

Water H_2O: The reason of the acute angle of 105° between the hydrogen atoms follows from the very strange quantum mechanical rules that nature follows. Different atoms have favorite angles, but atoms in a given Group (column) of the Periodic Table are likely to have similar angles. For example, oxygen and sulfur are both in Group 16 so water H_2O and hydrogen sulfide H_2S look similar.

Chlorine Cl, **Oxygen** O, and **Nitrogen** N are rarely found by themselves, but rather appear in nature as pairs (Cl_2, O_2, N_2), coupled by single, double, and triple bonds, respectively.

Methane, **Ethane**, **Propane**, and **Butane** are CH_4, C_2H_6, C_3H_8, and C_4H_{10} . They follow the pattern C_nH_{2n+2} with n=1, 2, 3, 4, … This trend continues to very large values of n. This family of molecules made of only carbon and hydrogen all have single bonds between their carbons.

Ethylene C_2H_4 and **Acetylene** C_2H_2 are like **Ethane** C_2H_6 except that ethylene has a double bond between its carbons and acetylene has a triple bond. Double and triple bonds are more energetic than single bonds so a welding torch that uses acetylene is extremely hot. Be sure to notice that each additional bond between the carbons leaves 2 fewer bonds available for hydrogens. This is obvious when building their molecular models.

Heptane C_7H_{16} is an n=7 version of the C_nH_{2n+2} group mentioned above.

Iso-octane $(CH_3)_3CCH_2CH(CH_3)_2$ and **Isopropyl Alcohol** $(CH_3)_2CHOH$ are variants of octane C_8H_{18} and **Propanol-1** $CH_3(CH_2)_2OH$ that have side groups extending from linear carbon chains.

Benzene C_6H_6 and **Cyclohexane** C_6H_{12} are both ring-shaped 6-carbon molecules, but they have very different chemical properties because of the three double bonds in benzene. Benzene is the basic starting unit for the assembly of many biological molecules.

Tolulene $C_6H_5CH_3$ is a benzene ring with a CH_3 group attached.

Trinitrotoluene $C_6H_2(NO_2)_3CH_3$ (also known as TNT) is tolulene with three NO_2 groups attached. Its nitrogens have more energy than N_2 so TNT is an explosive. Once ignited, its NO_2 groups become tightly bound N_2 groups and release energy.

Phenol C_6H_5OH is a benzene ring with an OH group attached.

Other molecules mentioned on the first page of our 11-page molecular diagrams handout at *https://yosemitefoothills.com/Science-1A/Handouts/Week-09/AllMolecularStructureImages.pdf* are **Acetone** $(CH_3)_2CO$ and **Formaldehyde** CH_2O which are similar except that **Acetone** has a pair of CH_3 groups connected to its central carbon while **Formaldehyde** just has hydrogens. Notice that the O's in these are connected with a double bond.

Methanol (Methyl Alcohol) CH_3OH, **Ethanol (Ethyl Alcohol)** C_2H_5OH, **Ethylene Glycol** $(CH_2OH)_2$, **Propanol-1** $CH_3(CH_2)_2OH$, **Isopropyl Alcohol (Propanol- 2)** $(CH_3)_2CHOH$, **Cyclohexanol** $C_6H_{11}OH$, and **Phenol** C_6H_5OH all have – OH groups attached that make them alcohols.

Note: Drinking **Methanol** permanently blinds a person. **Ethanol** is the usual alcohol in drinks that makes people think less clearly and stresses their livers. Sometimes someone breaks into a chemistry lab and takes methanol thinking it is the same as ethanol, drinks it, and has their optic nerve destroyed!

In nearly all cases, the number of bonds can be understood by remembering the number of outermost electrons listed in the table on page 2 of this note. The bonding must result in a complete shell either by giving up the outermost electrons or by stealing enough to complete the shell. Here are some common bond counts:

Carbon: 4
Nitrogen and Phosphorus: 3 or 5 (Note: 5+3=8. 8 is the number of atoms in Periods 2 and 3 of the Periodic Table.)
Oxygen and Sulfur: 2 or on rare occasions sulfur has 6 (Note: 6+2=8 again)
Hydrogen and Chlorine: 1

Some unusual bonding examples are:

Sulfur S has 2 bonds most of the time except in certain molecules like my blood pressure medicine **Hydrochlorothiazide** in which it has 6 bonds on each of its two sulfur atoms

The explosive **Nitroglycerin** has 5 on each of its three nitrogens.

To earn credit for this lab, report that you have done the following:

1. Read this note.
2. Looked at the Periodic Table at *https://yosemitefoothills.com/Science-1A/Handouts/Week-09/PeriodicTableOfElements.jpg* as you read about it.
3. Looked at the "Simplified Molecule Diagrams" and use that knowledge when looking at the 11-page "All Molecular Structure Images" handout. (See links at the top of page 4 above.)
4. Run the animations for the molecules mentioned here from water to nitroglycerin. Links are at *https://yosemitefoothills.com/Science-1A/MolecularAnimations/* with explanations above on pages 4 and 5. Don't rush through them. Take you time to notice double bonds, flat places and other distinct features.