ATOMS, CHEMICAL BONDS AND pH

Objectives:

At the end of the laboratory the student should be able to:

1. define these words and use them in appropriate context:

    a. atom
    b. acid
    c. base
    d. compound
    e. covalent bond
    f. element
    g. electron
    h. hydrogen bond
    i. ion
    j. ionic bond
    k. isotope
    l. molecule
    m. nucleus
    n. neutron
    o. non-polar bond
    p. orbital
    q. polar bond
    r. proton
    s. pH

2. The student should be able to diagram an atom from the information given in the periodic table.

3. The student should be able to construct and draw simple molecules, with the appropriate number of bonds and three dimensional structure.

4. The student should be able to compare and contrast hydrogen, ionic and covalent bonds.

5. The student should be able to determine the acidity or alkalinity of a solution using the following materials: pHydrion paper, bromthymol blue, phenolphthalein, pH meter.

6. The student should be able to interpret pH in terms of H^+. (hydrogen ion concentration)

Preface

The periodic table of elements (see appendix one) lists **elements** which have been found occurring naturally or have been created. These are substances that differ from each other in their chemical and physical properties. They have been arranged in the table with respect to their properties.

An **atom** is the smallest unit of an element that has the chemical and physical properties of that element. The structure of an atom determines the way in which it will combine with other atoms. The typical atom contains particles known as **protons, electrons and neutrons**. The protons and neutrons are found in the nucleus or center of the atom. Each of these particles has a mass of one **dalton** or atomic mass unit, amu. Protons are positively charged while neutrons have a neutral charge.

Electrons have a mass of about 1/2000 dalton. The number of electrons in a neutral atom is equal to the number of protons, while the number of neutrons may vary giving rise to isotopes of the same element. Electrons spin in orbitals about the nucleus and move very quickly. Sometimes they have so much energy that they leave the atom. When they leave the atom the number of negative charges is reduced, thereby conferring a net positive charge on the atom. We now refer to it as an ion. If an atom loses electrons it becomes a positively charged ion, a **cation**. If an atom gains electrons it is referred to as an **anion**.

6 ← atomic number
C ← symbol
12.01 ← mass number

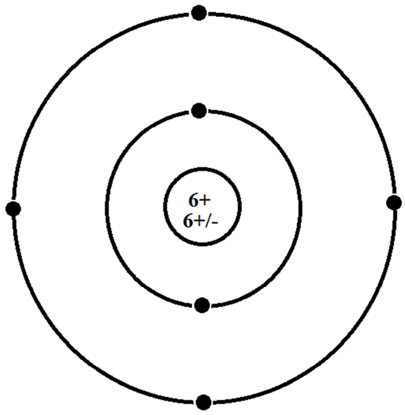
Note: The atomic number will always be equal to the number of protons. The number of electrons will equal the number of protons in a neutral atom, that is, the atom has a neutral charge.) But since electrons can be gained or lost, don't assume that the atomic number is the number of electrons. The number of neutrons may vary, giving different masses for the same element. These atoms with different masses are called **isotopes**.

Diagram the following atoms using the Bohr model. In the Bohr model, the neutrons and protons are found in the nucleus while the electrons are placed in energy levels about the nucleus.

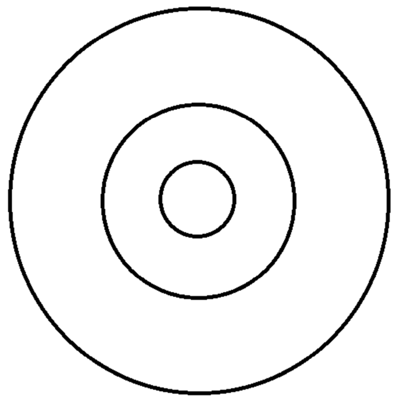
Place the electrons around the nucleus. Using the Bohr model, electrons are placed in energy levels around the nucleus. The level closest to the nucleus is the first energy level which can hold a maximum of two electrons. The next energy level is the L shell which can hold 8 electrons and the third energy level which can hold 18 electrons. Other shells follow but we will largely concern ourselves with these first few shells.

Diagram the following atoms, placing protons, neutrons and electrons in the model. Carbon has already been completed.

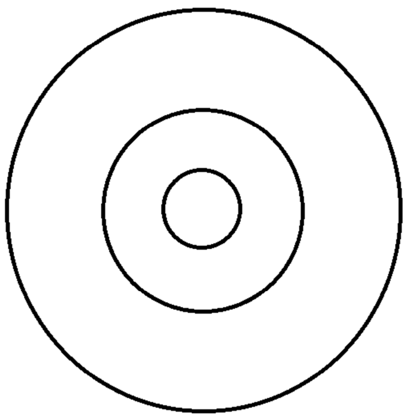
C



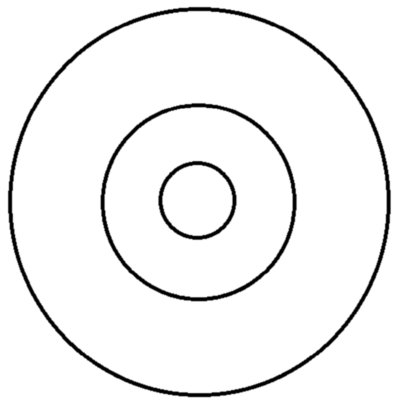
H



O

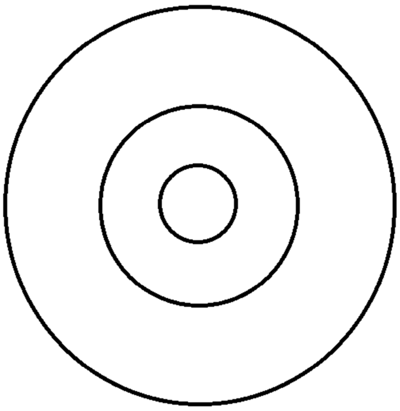


N

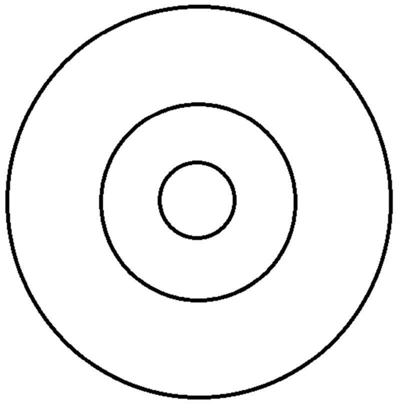


Three isotopes of carbon exist C-12, C-13, and C-14. Diagram each of these using the Bohr model.

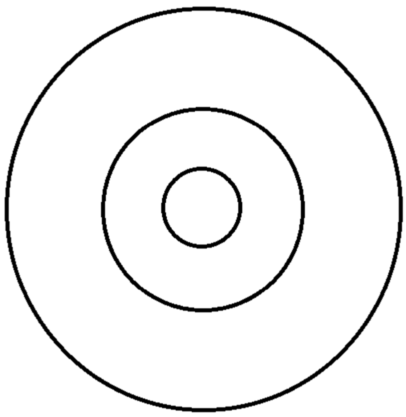
C_{12}



C_{13}



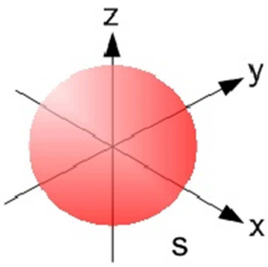
C_{14}



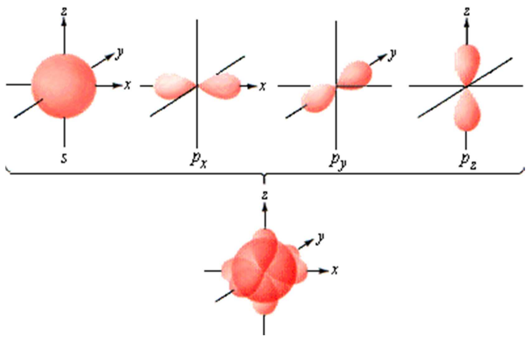
Orbitals

The energy shells themselves can be divided into orbitals. Each orbital can hold a maximum of 2 electrons. The lowest energy orbital is the 1s (diagram a) and is the only orbital in the first energy shell (or principle energy level) of an atom. Here we find two electrons in a spherical pattern spinning about the nucleus. The second energy shell has two kinds of orbitals: 2s and 2p. While the 2s orbital is still spherical it is larger than the 1s. The 2p orbitals are dumbbell shaped and intersect on three axes (X, Y and Z) of 3D-space. There are three of the 2p orbitals (see diagram b).

a)



b)



Electrons fill their orbitals according to the following diagram.

1s
2s 2p
3s 3p 3d
4s 4p 4d 4f
5s 5p 5d 5f
6s 6p 6d 6f

Your instructor will assist you in diagramming the order of electron filling for C, H, O, N.

O

2p _____ _____ _____

2s _____

1s _____

N

2p _____ _____ _____

2s _____

1s _____

Carbon is unusual in that it promotes one 2s electron to the third 2p orbital, creating stability. Carbon can now form four bonds instead of two. This results in four electrons of equal energy. This is sp^3 hybridization.

C	2p _____ _____ _____			2p _____ _____ _____
	2s _____	sp^3 hybridized C	⟶	2s _____
	1s _____			1s _____

Ionic Bonds: bonds of attraction between oppositely charged atoms or groups of atoms

The element sodium has an atomic number of 11 and a mass of 23 daltons. If we were to diagram it we would find that there was one electron in the 3rd energy level. A rule known as the octet rule states that elements gain or lose electrons in order to have a full outer, or valence, shell, which gives them the electron configuration of the nearest inert gas. If sodium loses the one electron in the outer shell to another atom it now has 8 electrons in the valence shell, identical to neon. However, it will then have 11 positive charges and 10 negative charges giving it a net charge of +1. The sodium atom is charged and is now called an ion.

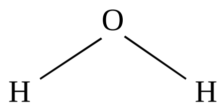
Complete the chart giving the correct number of protons, electrons and neutrons in the particle.

Particle	Protons	Electrons	Neutrons
Ca atom			
Ca^{++}			
Na atom			
Na^{+}			
K atom			
K^{+}			
Cl atom			
Cl^{-}			

Covalent bonds: bonds that are formed when two atoms share electrons with each other. The bonding capacity is determined by the arrangement of electrons and the need to complete their valence shell or energy level. A covalent bond is represented by a solid line connecting two atoms. If two atoms have the same electronegativity (tendency of an atom to pull electrons to it) the shared electrons will be equally distributed about the covalent bond. The difference in electronegativity (see Appendix 2) of the two atoms is zero and a non-polar bond results. An example of this is found in a molecule of H_2.

H-H A molecule of hydrogen.

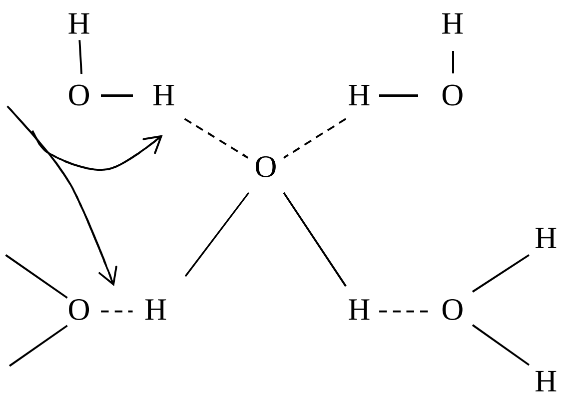
A polar bond is the result when two atoms are sharing electrons and they have different electronegativities, such as hydrogen and oxygen. The shared electrons between the hydrogen and the oxygen are pulled more strongly toward the oxygen, which results in an unequal distribution of the electron cloud making the oxygen part of the molecule more negative and the hydrogen atom more positive. The symbol for partial charge is δ.



H_2O is the water molecule.

Hydrogen bonds: a weak chemical bond that is formed when the small positive charge of a hydrogen atom in a polar covalent bond of one molecule is attracted to a negative atom involved in a polar covalent bond in another molecule. While hydrogen bonds are relatively weak bonds, they can stabilize a larger molecule if they are numerous. The hydrogen bond is directly responsible for many of the characteristics of water.

Hydrogen bonds



Note: hydrogen bonds are depicted variably in different sources. Some texts use broken or dotted lines to show hydrogen bonding.

Atoms and Bonding Capacity

Determination of the bonding capacity of the atom can be done by examining the structure of the atom, focusing on the valence electrons. Using the information in the chart below, you should be able to build models of common molecules.

Name of Atom	Symbol of Element	Number of Bonds	Bonding Capacity
Carbon	C	4	— C — (with one bond up and one bond down) or — C = (with one bond up)
Nitrogen	N	3	— N — or — N=
Hydrogen	H	1	H —
Oxygen	O	2	— O — or O=

When constructing the molecules, follow these rules:

1. Attach the carbons to each other in a chain or ring.
2. Then add the nitrogen's if needed.
3. Add oxygen atoms to the structure.
4. Fill in available bonds with hydrogen. If all the atoms are used and nonbonding electrons still exist, use flexible double bonds.

Construct the following molecules, give the structural formula and draw them:

1. Hydrogen (molecular) - H_2

2. Water - H_2O

3. Methane - CH_4

4. Ethane - C_2H_6

5. Ethyl Alcohol - C_2H_5OH

6. Glucose - $C_6H_{12}O_6$

Acids and bases: An acid is a substance that releases H^+ in aqueous solution while a base is defined as a substance that removes H^+ from solution. Acidity and alkalinity are measured on a scale referred to as the pH scale. The pH scale ranges from 0 to 14, with 0 being the most acidic and 14 the most basic, while 7 is neutral.

Note: Acids and bases must be handled carefully. Spills are to be cleaned immediately and contact with skin is to be avoided.

$[H+] [OH] = 10^{-14}$ If the concentration of either ion is known the concentration of the other can be calculated.

$pH = - \log [H^+]$ (pH is equal to the reciprocal of the log of the concentration of hydrogen ions.)

If the concentration of H^+ is .001 moles/liter or 1/1000 m/l = 10^{-3} m/l the reciprocal of the log 10^{-3} is equal to 3. If the concentration of ions is given as 10 to some exponent, then simply negate the exponent (multiply by a negative) and that number will be the pH.

0 1 2 3 4 5 6 7 8 9 10 11 12 13 14

Increasingly acidic ⟵ neutral ⟶ increasingly basic

pH Meter: The pH meter measures the hydrogen ion concentration of materials being tested. Note that standardized solutions are necessary to calibrate the machine. It is important that one carefully follow directions for the use of the pH meter.

Use of the pH meter

1. Switch dial to pH, lower electrodes into buffer.
2. Adjust temperature knob to temperature of buffer.
3. Calibrate so that the meter reads pH of buffer.
4. Raise electrodes, rinse with distilled water.
5. Lower electrodes into unknown solutions. Meter will read pH.
6. Raise and rinse electrodes, repeat for each unknown.
7. Switch to standby.
8. Store electrodes in buffer of 7 or lower.

Approximate the pH of the solution and the concentration of H^+ in each solution that your instructor selects.

Solution	pHydrion Paper	Bromthymol Blue	Phenolphthalein	pH meter	$[H^+]$ m/l
1.					
2.					
3.					
4.					
5.					
6.					

Questions (use extra paper if you need it to write your answer):

1. Compare and contrast covalent, ionic and hydrogen bonds.

2. What information can you gather from the periodic table?

3. What information is required in order that you are able to diagram an atom?

4. If the pH of a solution is 4, is it acidic or basic? What is the $[H^+]$ in m/l?

5. If the $[H^+]$ is .000001 m/l, what is the pH?

6. Explain the difference in the use of the indicators bromthymol blue, phenolphthalein and pHydrion paper.

Appendix

Periodic Table of the Elements

hydrogen 1 **H** 1.0079																		helium 2 **He** 4.0026
lithium 3 **Li** 6.941	beryllium 4 **Be** 9.0122												boron 5 **B** 10.811	carbon 6 **C** 12.011	nitrogen 7 **N** 14.007	oxygen 8 **O** 15.999	fluorine 9 **F** 18.998	neon 10 **Ne** 20.180
sodium 11 **Na** 22.990	magnesium 12 **Mg** 24.305												aluminium 13 **Al** 26.982	silicon 14 **Si** 28.086	phosphorus 15 **P** 30.974	sulfur 16 **S** 32.065	chlorine 17 **Cl** 35.453	argon 18 **Ar** 39.948
potassium 19 **K** 39.098	calcium 20 **Ca** 40.078		scandium 21 **Sc** 44.956	titanium 22 **Ti** 47.867	vanadium 23 **V** 50.942	chromium 24 **Cr** 51.996	manganese 25 **Mn** 54.938	iron 26 **Fe** 55.845	cobalt 27 **Co** 58.933	nickel 28 **Ni** 58.693	copper 29 **Cu** 63.546	zinc 30 **Zn** 65.39	gallium 31 **Ga** 69.723	germanium 32 **Ge** 72.61	arsenic 33 **As** 74.922	selenium 34 **Se** 78.96	bromine 35 **Br** 79.904	krypton 36 **Kr** 83.80
rubidium 37 **Rb** 85.468	strontium 38 **Sr** 87.62		yttrium 39 **Y** 88.906	zirconium 40 **Zr** 91.224	niobium 41 **Nb** 92.906	molybdenum 42 **Mo** 95.94	technetium 43 **Tc** [98]	ruthenium 44 **Ru** 101.07	rhodium 45 **Rh** 102.91	palladium 46 **Pd** 106.42	silver 47 **Ag** 107.87	cadmium 48 **Cd** 112.41	indium 49 **In** 114.82	tin 50 **Sn** 118.71	antimony 51 **Sb** 121.76	tellurium 52 **Te** 127.60	iodine 53 **I** 126.90	xenon 54 **Xe** 131.29
caesium 55 **Cs** 132.91	barium 56 **Ba** 137.33	57-70 *	lutetium 71 **Lu** 174.97	hafnium 72 **Hf** 178.49	tantalum 73 **Ta** 180.95	tungsten 74 **W** 183.84	rhenium 75 **Re** 186.21	osmium 76 **Os** 190.23	iridium 77 **Ir** 192.22	platinum 78 **Pt** 195.08	gold 79 **Au** 196.97	mercury 80 **Hg** 200.59	thallium 81 **Tl** 204.38	lead 82 **Pb** 207.2	bismuth 83 **Bi** 208.98	polonium 84 **Po** [209]	astatine 85 **At** [210]	radon 86 **Rn** [222]
francium 87 **Fr** [223]	radium 88 **Ra** [226]	89-102 **	lawrencium 103 **Lr** [262]	rutherfordium 104 **Rf** [261]	dubnium 105 **Db** [262]	seaborgium 106 **Sg** [266]	bohrium 107 **Bh** [264]	hassium 108 **Hs** [269]	meitnerium 109 **Mt** [268]	ununnilium 110 **Uun** [271]	unununium 111 **Uuu** [272]	ununbium 112 **Uub** [277]		ununquadium 114 **Uuq** [289]				

*Lanthanide series	lanthanum 57 **La** 138.91	cerium 58 **Ce** 140.12	praseodymium 59 **Pr** 140.91	neodymium 60 **Nd** 144.24	promethium 61 **Pm** [145]	samarium 62 **Sm** 150.36	europium 63 **Eu** 151.96	gadolinium 64 **Gd** 157.25	terbium 65 **Tb** 158.93	dysprosium 66 **Dy** 162.50	holmium 67 **Ho** 164.93	erbium 68 **Er** 167.26	thulium 69 **Tm** 168.93	ytterbium 70 **Yb** 173.04
**Actinide series	actinium 89 **Ac** [227]	thorium 90 **Th** 232.04	protactinium 91 **Pa** 231.04	uranium 92 **U** 238.03	neptunium 93 **Np** [237]	plutonium 94 **Pu** [244]	americium 95 **Am** [243]	curium 96 **Cm** [247]	berkelium 97 **Bk** [247]	californium 98 **Cf** [251]	einsteinium 99 **Es** [252]	fermium 100 **Fm** [257]	mendelevium 101 **Md** [258]	nobelium 102 **No** [259]

Table of Pauling Electronegativity Values

	IA	IIA	IIIB	IVB	VB	VIB	VIIB	VIII			IB	IIB	IIIA	IVA	VA	VIA	VIIA	VIIIA
1	1 **H** 2.1																	2 **He**
2	3 **Li** 1.0	4 **Be** 1.5											5 **B** 2.0	6 **C** 2.5	7 **N** 3.0	8 **O** 3.5	9 **F** 4.0	10 **Ne**
3	11 **Na** 0.9	12 **Mg** 1.2											13 **Al** 1.5	14 **Si** 1.8	15 **P** 2.1	16 **S** 2.5	17 **Cl** 3.0	18 **Ar**
4	19 **K** 0.8	20 **Ca** 1.0	21 **Sc** 1.3	22 **Ti** 1.5	23 **V** 1.6	24 **Cr** 1.6	25 **Mn** 1.5	26 **Fe** 1.8	27 **Co** 1.8	28 **Ni** 1.8	29 **Cu** 1.9	30 **Zn** 1.6	31 **Ga** 1.6	32 **Ge** 1.8	33 **As** 2.0	34 **Se** 2.4	35 **Br** 2.8	36 **Kr**
5	37 **Rb** 0.8	38 **Sr** 1.0	39 **Y** 1.2	40 **Zr** 1.4	41 **Nb** 1.6	42 **Mo** 1.8	43 **Tc** 1.9	44 **Ru** 2.2	45 **Rh** 2.2	46 **Pd** 2.2	47 **Ag** 1.9	48 **Cd** 1.8	49 **In** 1.8	50 **Sn** 1.8	51 **Sb** 1.9	52 **Te** 2.1	53 **I** 2.5	54 **Xe**
6	55 **Cs** 0.7	56 **Ba** 0.9	57 **La**	72 **Hf**	73 **Ta**	74 **W**	75 **Re**	76 **Os**	77 **Ir**	78 **Pt**	79 **Au**	80 **Hg**	81 **Tl** 1.8	82 **Pb** 1.9	83 **Bi** 1.9	84 **Po** 2.0	85 **At** 2.2	86 **Rn**
7	87 **Fr** 0.7	88 **Ra** 0.9	89 **Ac**	104 **Rf**	105 **Db**	106 **Sg**	107 **Bh**	108 **Hs**	109 **Mt**	110	111	112		114		116		

Lanthanides	58 **Ce**	59 **Pr**	60 **Nd**	61 **Pm**	62 **Sm**	63 **Eu**	64 **Gd**	65 **Tb**	66 **Dy**	67 **Ho**	68 **Er**	69 **Tm**	70 **Yb**	71 **Lu**
Actinides	90 **Th**	91 **Pa**	92 **U**	93 **Np**	94 **Pu**	95 **Am**	96 **Cm**	97 **Bk**	98 **Cf**	99 **Es**	100 **Fm**	101 **Md**	102 **No**	103 **Lr**