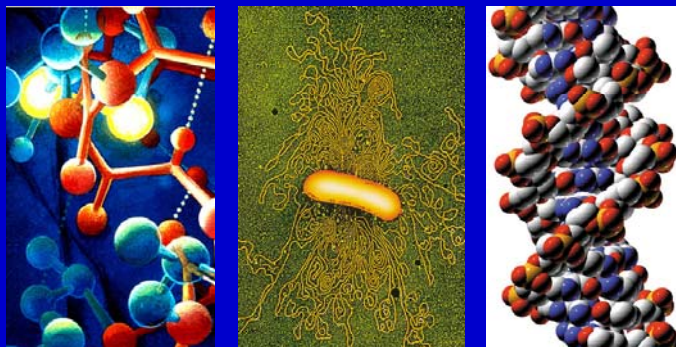


# Chemistry of Life



Life is a chemical process. All aspects of living creatures have a chemical basis. An understanding of life requires an understanding of the chemical basis of life.

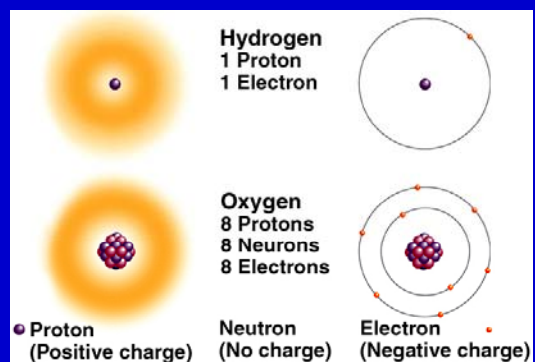
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Chemistry - the study of the properties of matter

The fundamental unit of matter is the atom. Everything that has mass and occupies space is composed of atoms or subatomic particles.

Atoms are composed of 3 subatomic particles  
**protons (+)**  
**neutrons**  
**electrons (-)**

Protons and neutrons are found in the nucleus



Electrons are found in shells surrounding the nucleus


2



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											aluminum 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 72.64	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																																															
cesium 55 Cs 132.91	barium 56 Ba 137.33	* 57-70	lanthanum 57 La 138.91	cerium 58 Ce 140.12	praseodymium 59 Pr 140.91	neodymium 60 Nd 144.24	promethium 61 Pm [145]	europium 62 Eu 151.96	gadolinium 63 Gd 157.25	terbium 64 Tb 158.93	dysprosium 65 Dy 162.50	holmium 66 Ho 164.93	erbium 67 Er 167.26	thulium 68 Tm 168.93	ytterbium 69 Yb 173.05	lutetium 70 Lu 174.967	hafnium 71 Hf 178.49	tantalum 72 Ta 180.95	tungsten 73 W 183.84	rhenium 74 Re 186.21	osmium 75 Os 190.23	iridium 76 Ir 192.22	platinum 77 Pt 195.08	gold 78 Au 196.97	mercury 79 Hg 200.59	thallium 80 Tl 204.38	lead 81 Pb 207.2	bismuth 82 Bi 208.98	polonium 83 Po [209]	astatine 84 At [210]	radon 85 Rn [222]	francium 87 Fr [223]	radium 88 Ra [226]	* * 89-102	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]	bohrium 103 Bh [264]	hassium 104 Hs [265]	meitnerium 105 Mt [268]	darmstadtium 106 Ds [271]	roentgenium 107 Rg [272]	copernicium 108 Cn [285]	nihonium 109 Nh [284]	flerovium 110 Fl [289]	tennessine 111 Ts [289]	oganesson 112 Og [289]	unbinilium 113 Uub [288]	ununilium 114 Uuq [288]	unununium 115 Uuu [288]	ununbium 116 Uub [288]	ununtrium 117 Uut [288]	ununquadium 118 Uuq [288]
* Lanthanide series																																																																
** Actinide series																																																																

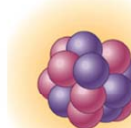
Within each element there is variation in the number of neutrons in the nucleus. Two atoms with the same number of protons and different numbers of neutrons are called **isotopes** of the element.

Element	Atomic Number	Atomic Mass	# p	# n
Hydrogen	1	1-3	1	0-2
Carbon	6	12-14	6	6-8
Oxygen	8	16-18	8	8-10



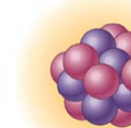
**Carbon-12**  
6 Protons  
6 Neutrons  
6 Electrons

<sup>12</sup>C



**Carbon-13**  
6 Protons  
7 Neutrons  
6 Electrons

<sup>13</sup>C



**Carbon-14**  
6 Protons  
8 Neutrons  
6 Electrons

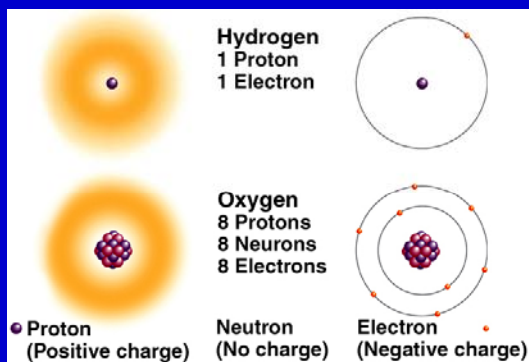
<sup>14</sup>C

Heavier isotopes tend to degrade to lighter isotopes or elements and as they do they emit radiation. They are radioactive. <sup>6</sup>

Electrons are found in orbitals around the nucleus. There is a fixed maximum number of electrons in each orbital. The first orbital has a maximum number of 2. The second has a maximum of 8. The third has a maximum of 8. The fourth has a maximum of 18.

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Progressing through the elements, as the number of protons increases so does the number of electrons in non-ionized atoms. As electrons increase they are **added to inner orbitals before outer orbitals.**



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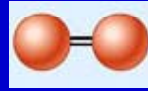
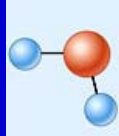
1 H																	8 O	2 He			
3 Li	4 Be											5 B	6 C	7 N	9 F	10 Ne					
11 Na	12 Mg															13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr				
37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe				
55 Cs	56 Ba	57 La	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn				
87 Fr	88 Ra	89 Ac	104	105	106	107	108	109	110												

The periodic table is a representation of the electron configuration of the elements. The first row has 2 elements. The second and third have 8. The fourth has 18, etc.

Hydrogen has 1 electron in its only orbital. Helium has 2. Lithium has 2 in its first orbital and 1 in its second. Beryllium has ...

8

Atoms can form associations called **molecules**. A water molecule consists of an association of 2 hydrogen atoms and 1 oxygen atom. Oxygen gas (molecular oxygen) is an association of 2 oxygen atoms.



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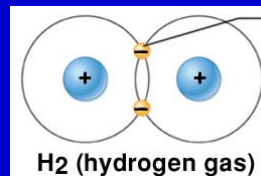
There is a regular order to the way atoms form associations with other atoms - and this order is determined by the number of electrons an atom has in its outermost orbital.

It is the “fullness” of the outermost orbital that determines the way an element can form molecules.

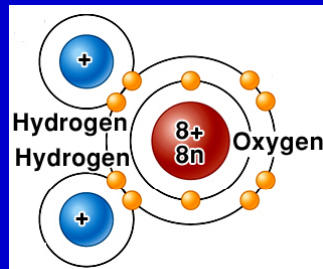
Atoms with outermost orbitals that are not full will associate with others elements that have outermost orbitals that are not full. They will either share, donate, or accept electrons to fill their outer orbital.

9

Hydrogen atoms will associate to share electrons. Each originally had one electron. After associating as a molecule of H<sub>2</sub> gas, each has 2 electrons part of the time.



Hydrogen “wants” to share one electron. Oxygen, with 6 electrons in its outermost orbital, wants to share 2 electrons. Two hydrogens and one oxygen atom will associate to form water (H<sub>2</sub>O).



10

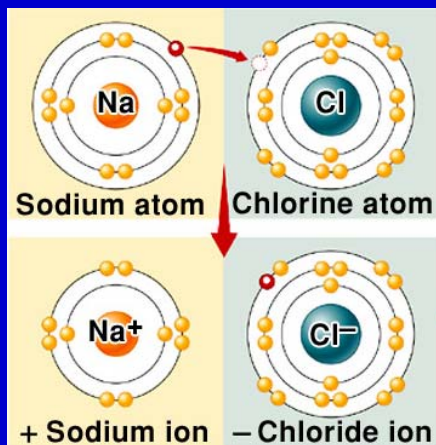
Sodium has one electron in its outer orbital. Donating that electron will leave it with an outer orbital that is full. It becomes Sodium ion ( $\text{Na}^+$ ).

Chlorine has an outer orbital that has 7 electrons.

Accepting 1 electron will give it a full outer orbital. It becomes Chloride ion ( $\text{Cl}^-$ )

Sodium and Chlorine associate to form Sodium Chloride ( $\text{NaCl}$  - table salt).

$\text{Na}^+$  is attracted to  $\text{Cl}^-$  and together they form  $\text{NaCl}$  crystals.



11

Elements on the far left of the periodic table are willing electron donators. Elements in the second to last column on the right are willing electron acceptors. Those two groups of elements associate to form **ionic compounds** ( $\text{NaCl}$ ,  $\text{KCl}$ ,  $\text{LiBr}$ , etc.)

1 H																	8 O	2 He
3 Li	4 Be											5 B	6 C	7 N	9 F	10 Ne		
11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar	
19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr	
37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe	
55 Cs	56 Ba	57 La	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn	
87 Fr	88 Ra	89 Ac	104	105	106	107	108	109	110									

Elements on the far right of the periodic table have outer orbitals that are full. Their atoms do not associate with other atoms. They are unreactive or inert.

12

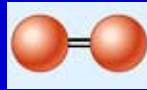
## Chemical bonds

**Covalent bonds** are formed when atoms share electrons. Covalent bonds are strong bonds - difficult to break.

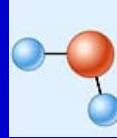
**Ionic bonds** are formed with atoms donate and accept electrons and the positive and negative charges attract each other. Ionic bonds are strong bonds, except in water. Ionic compounds like NaCl dissociate readily in water as  $\text{Na}^+$  and  $\text{Cl}^-$  ions.

Covalent and ionic bonds are extremes of a continuum.

Oxygen molecules represent a balanced sharing - a pure covalent bond.

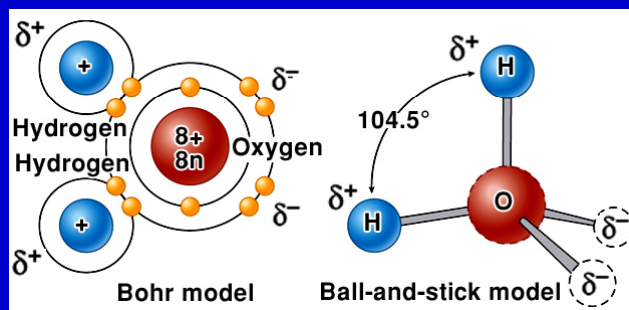


In water, the sharing is unbalanced. Oxygen is more "electron greedy" (electronegative) and has the electrons more often than does either hydrogen.



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The unequal sharing of electrons in a water molecule, makes the water molecules **polar**.

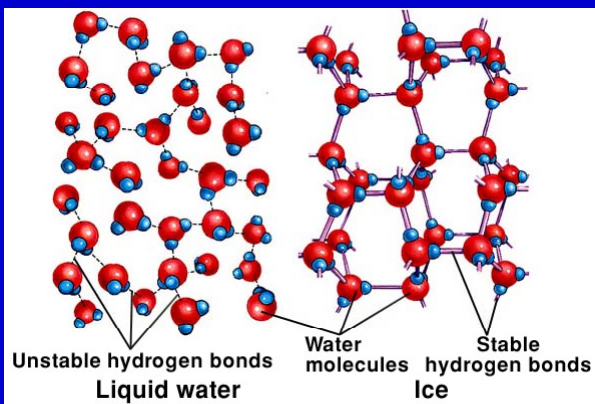


Oxygen carries a slight negative charge, and each hydrogen carries a slight positive charge.

14

**Hydrogen bonds** are the result of attractions between weak charge differences. They are weak bonds and easily broken.

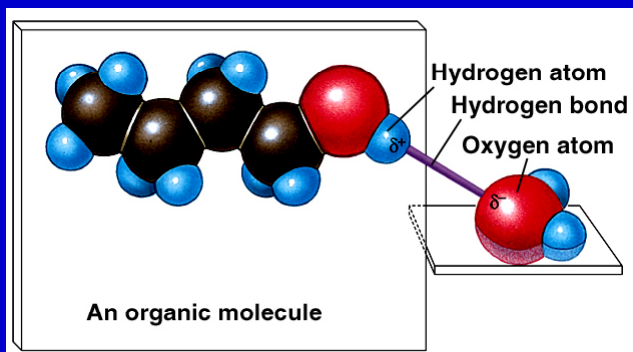
Hydrogen bonds can form between water molecules. They become stronger when water solidifies as ice.



Read about the properties of water (p 25-29). [?](#)

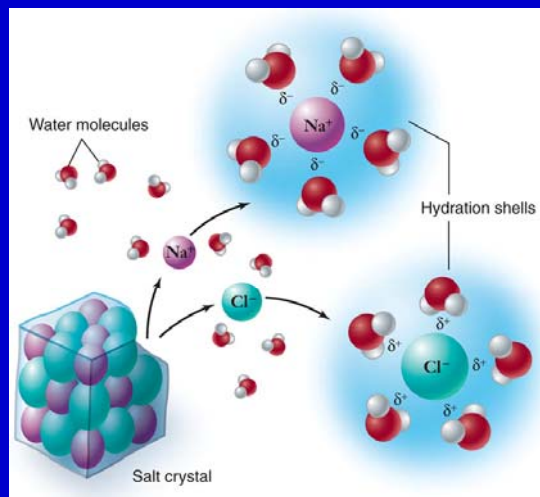
15

Other molecules can also be polar and form hydrogen bonds.



16

The polarity of water molecules makes water a **good solvent for other polar molecules** and ionic compounds. Ionic bonds dissociate readily in water because ions readily associate with water.



Water molecules form **hydration shells** around ions. The ionic bond between  $\text{Na}^+$  and  $\text{Cl}^-$  cannot be maintained in water.

17

Water molecules can also ionize.

2



### Acids, Bases, and Salts

An **acid** is any ionic substance that releases  $\text{H}^+$  (protons) water.



A **base** is any ionic substance that releases  $\text{OH}^-$  (hydroxyl ions) in water.



A **salt** is any ionic substance that contains an anion other than  $\text{OH}^-$  or  $\text{O}^{2-}$ . Salts are produced when acids and bases are mixed.



18

The strength of any acid or base depends on how readily it dissociates. HCl is a strong acid. Most of the HCl dissociates. NaOH is a strong base.

Carbonic acid:  $\text{H}_2\text{CO}_3$  is a weak acid



It is a weak acid because only a small proportion of the  $\text{H}_2\text{CO}_3$  in solution dissociates.

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pH is a measure of the acidity/alkalinity of a solution.

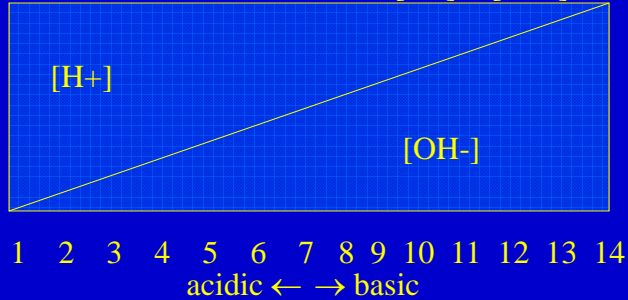
$$\text{pH} = -\log[\text{H}^+]$$

<u>[H<sup>+</sup>]</u> <u>M/l or g/l</u>	<u>log[H<sup>+</sup>]</u>	<u>pH</u>
0.1	-1	1
0.01	-2	2
0.0000001	-7	7
0.0000000001	-10	10

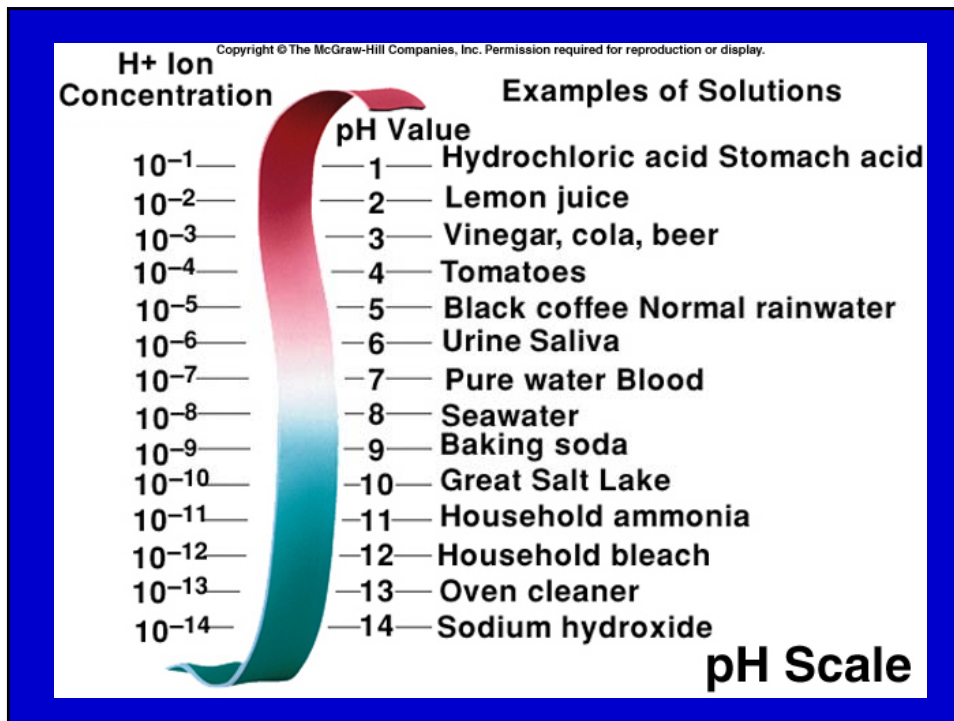
pH varies from about 1 to about 14

20

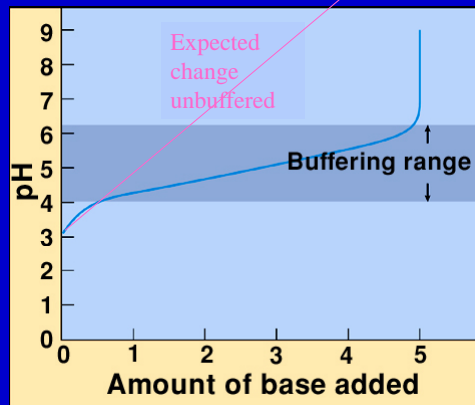
pH varies from about 1 to about 14.  
 Pure water dissociates into equal numbers of  $H^+$  and  $OH^-$  ions  
 and has a concentration of  $H^+$  ions of  $1 \times 10^{-7}$  g/l (pH = 7)  
 pH = 7 is considered neutral.  
 pH less than 7 is considered acidic  $[H^+] > [OH^-]$ .  
 pH greater than 7 is considered basic  $[H^+] < [OH^-]$ .



21

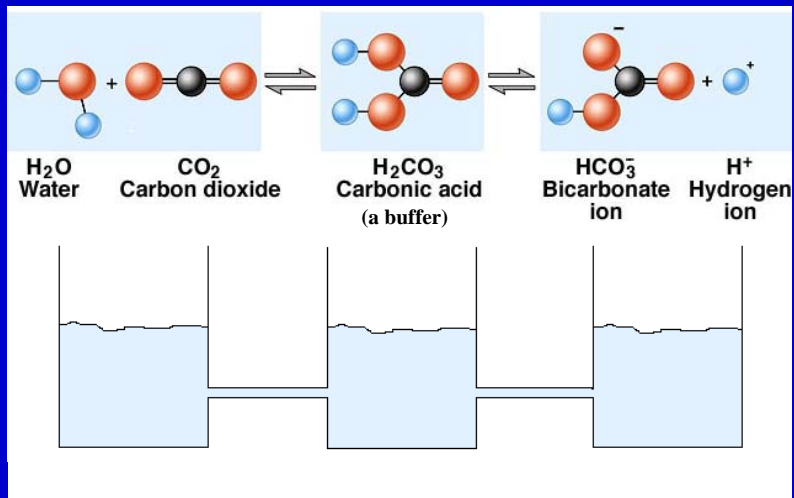


A **buffer** is a substance that when in solution stabilizes the pH of the solution within a range. The addition of small amounts of an acid or base change the pH of a buffered solution less than an unbuffered solution.



?

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Addition of acid ( $\text{H}^+$ ) will drive the reactions to the left.

Addition of base ( $\text{OH}^-$ ) will result in depletion of  $\text{H}^+$  (forming water) and reactions will be driven to the right.

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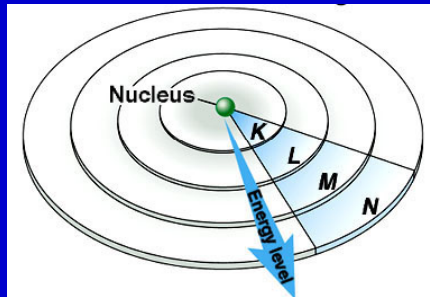
24

## Energy and Atoms

All matter contains energy. One form of energy that is useful to living things is the energy of electron position.

Electrons are found at different distances from the nucleus within an orbital. Those farther away have greater energy than those nearer the nucleus.

Electrons can accept energy from outside sources (e.g. light) and move farther away from the nucleus. They are called "**excited electrons**." The energy of excited electrons can be used for other energy demanding purposes.

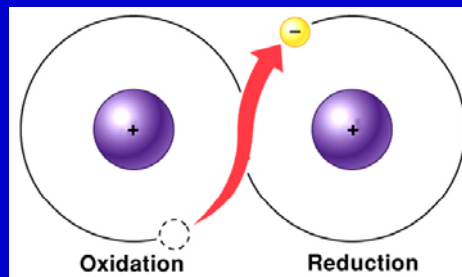


25

**Chemical reactions** involve the rearrangement of atoms within molecules, the breakage of chemical bonds, or the formation of chemical bonds.

One important class of chemical reactions for living things is the **oxidation-reduction reaction**. In oxidation-reduction reactions, an electron is transferred from one atom (or molecule) to another.

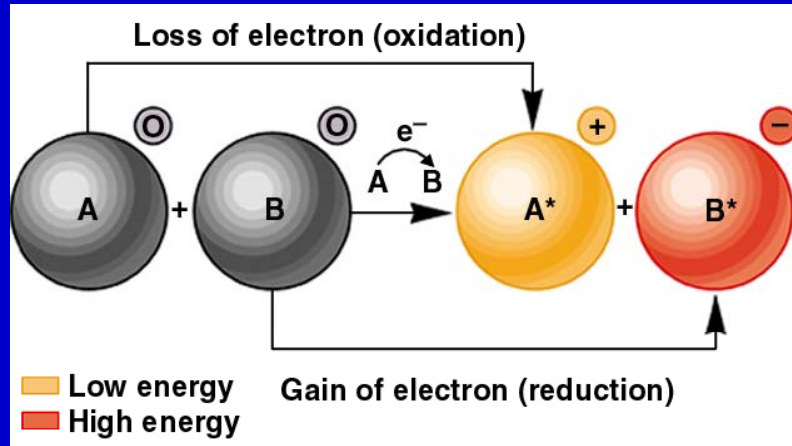
In **REDOX reactions**, the energy of the electron transferred is carried with the electron that is transferred.



The donating molecule becomes **oxidized**. The accepting molecule becomes **reduced**. The oxidized molecule loses electron energy. The reduced molecule gains electron energy

26

Oxidation-reduction (REDOX) reactions are the most important class of energy transfer reactions in living things.



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