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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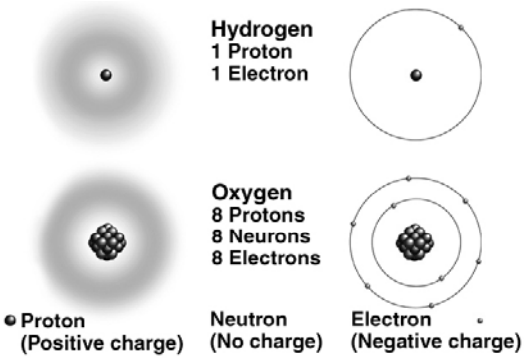
Chemistry - the study of the properties of matter

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

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Most atoms normally have an equal number of protons(+) and electrons(-) and carry no charge.

Some atoms can gain or loose electrons and become **ionized.**
Atoms that gain an electron are negatively charged **anions.**
Atoms that loose an electron are positively charged **cations.**

An **element** has a characteristic fixed number of protons. Atoms that have different numbers of protons are different **elements.**
Different elements have different chemical properties.

The **atomic mass** of an atom is equal to the combined mass of protons and neutrons in its nucleus.
Protons and neutrons have a mass of 1.009 daltons
Electrons have a mass of 0.0006 daltons
6.023×10^{23} daltons (602300000000000000000000) = 1 gram

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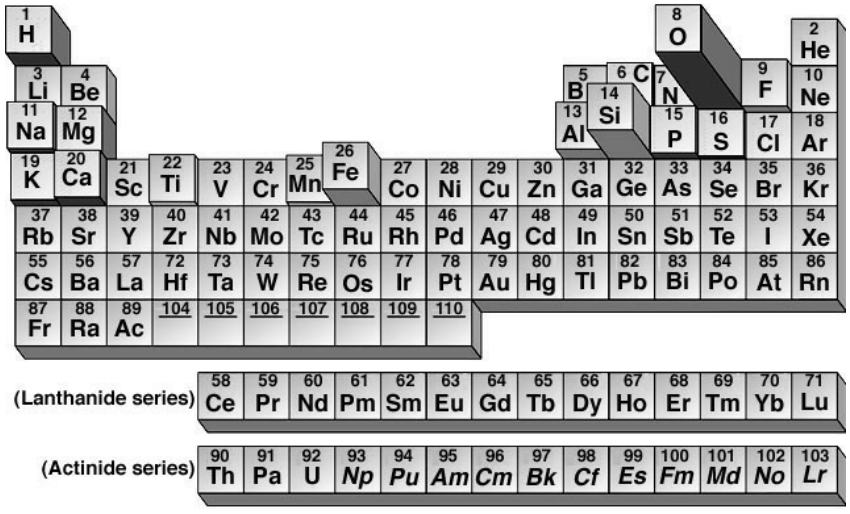
Periodic Table



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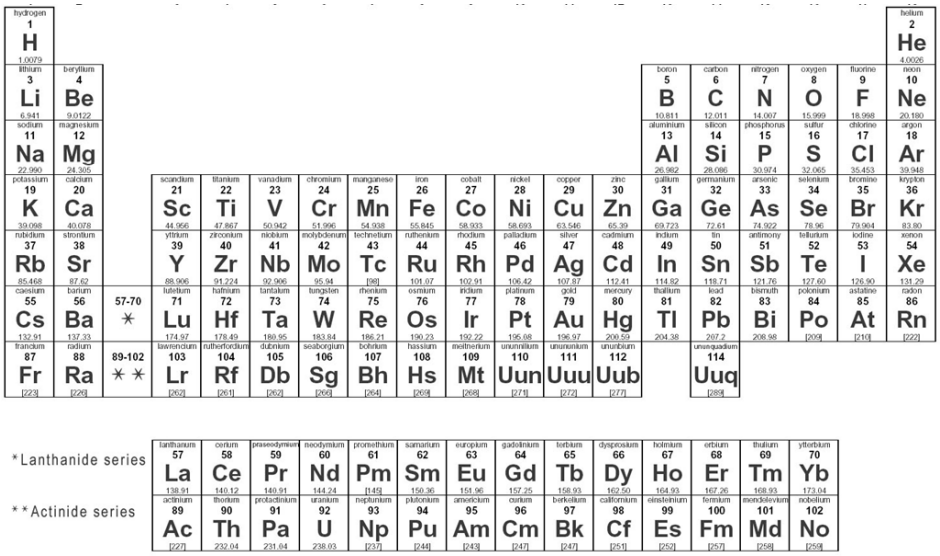

Within each element there is variation in the number of neutrons in the nucleus. Two atoms with the same number of protons and different numbers of neutrons are called **isotopes** of the element.

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

^{12}C

Carbon-13
6 Protons
7 Neutrons
6 Electrons

^{13}C

Carbon-14
6 Protons
8 Neutrons
6 Electrons

^{14}C

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

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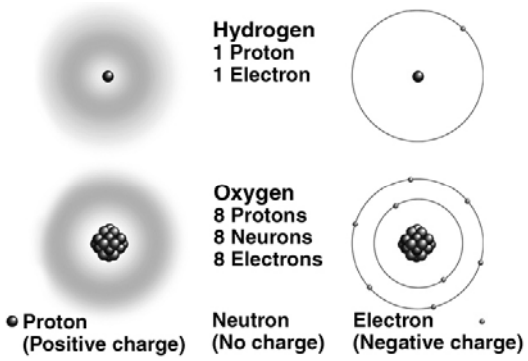
Progressing through the elements, as the number of protons increases so does the number of electrons in non-ionized atoms. As electrons increase they are **added to inner orbitals before outer orbitals.**



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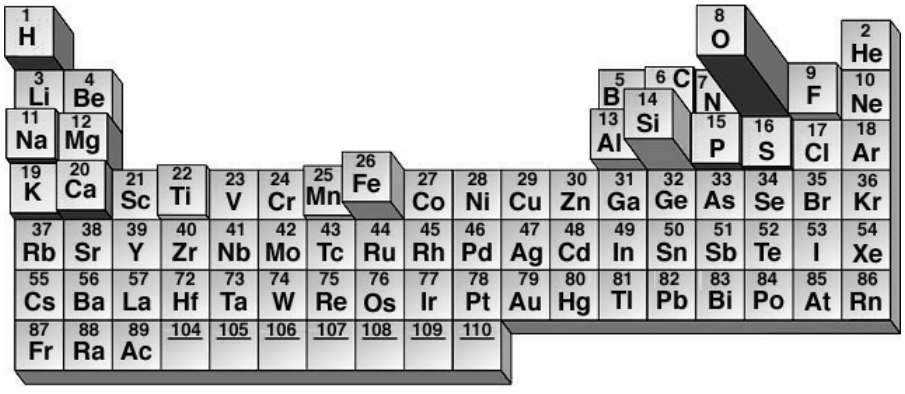

The periodic table is a representation of the electron configuration of the elements. The first row has 2 elements. The second and third have 8. The fourth has 18, etc.

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 ...

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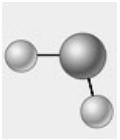
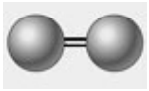
Atoms can form associations called **molecules**. A water molecule consists of an association of 2 hydrogen atoms and 1 oxygen atom. Oxygen gas (molecular oxygen) is an association of 2 oxygen atoms.





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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.

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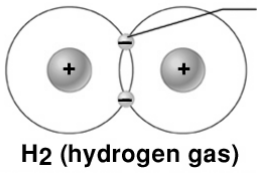
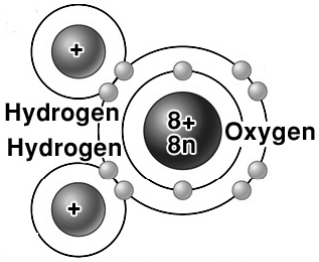
Hydrogen atoms will associate to share electrons. Each originally had one electron. After associating as a molecule of H_2 gas, each has 2 electrons part of the time.



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_2O).



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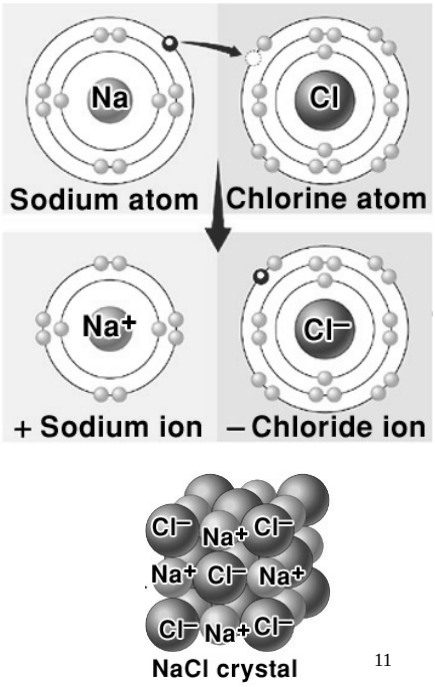
Sodium has one electron in its outer orbital. Donating that electron will leave it with an outer orbital that is full. It becomes Sodium ion (Na^+).

Chlorine has an outer orbital that has 7 electrons. Accepting 1 electron will give it a full outer orbital. It becomes Chloride ion (Cl^-)

Sodium and Chlorine associate to form Sodium Chloride (NaCl - table salt).

Na^+ is attracted to Cl^- and together they form NaCl crystals.



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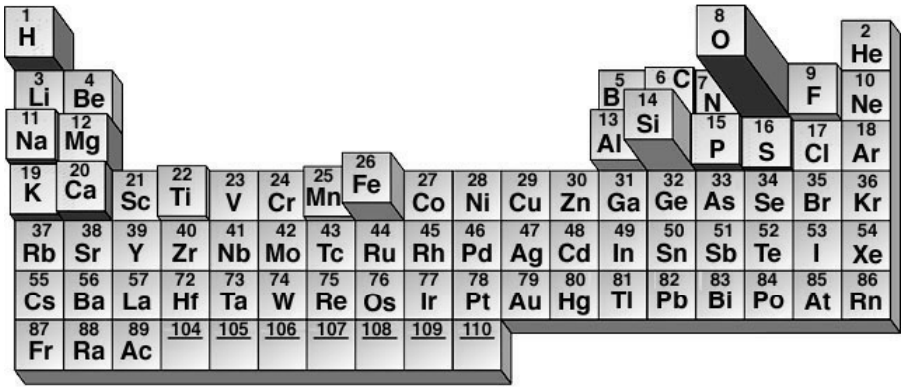
Elements on the far left of the periodic table are willing electron donators. Elements in the second to last column on the right are willing electron acceptors. Those two groups of elements associate to form **ionic compounds** (NaCl, KCl, LiBr, etc.)



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.

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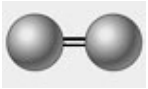
Chemical bonds

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

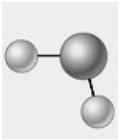
Ionic bonds are formed with atoms donate and accept electrons and the positive and negative charges attract each other. Ionic bonds are strong bonds, except in water. Ionic compounds like NaCl dissociate readily in water as Na^+ and Cl^- ions.

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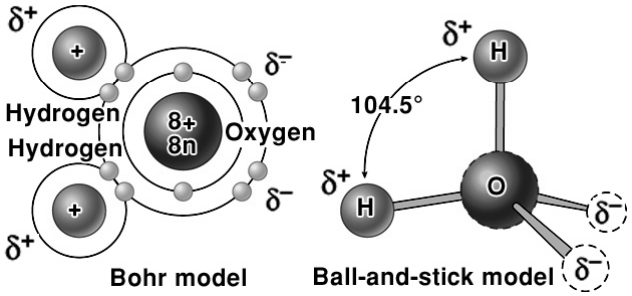
The unequal sharing of electrons in a water molecule, makes the water molecules **polar**.



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

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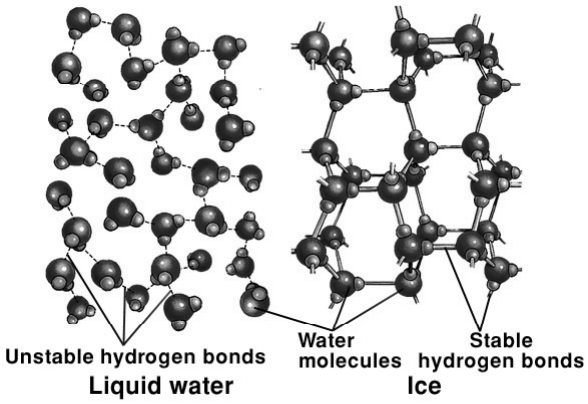
Hydrogen bonds are the result of attractions between weak charge differences. They are weak bonds and easily broken.

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



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

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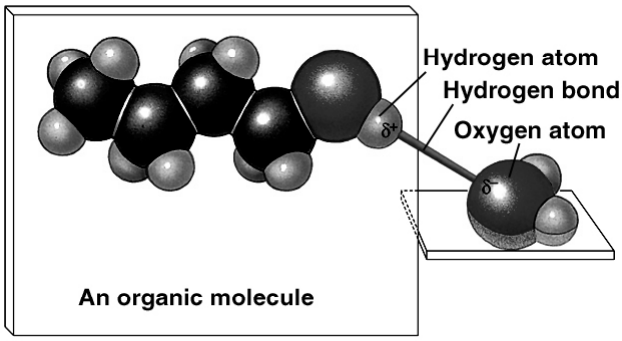
Other molecules can also be polar and form hydrogen bonds.



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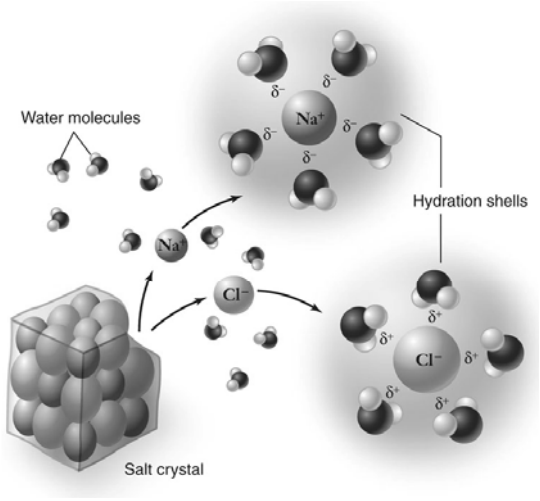
The polarity of water molecules makes water a **good solvent for other polar molecules** and ionic compounds. Ionic bonds dissociate readily in water because ions readily associate with water.



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

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Water molecules can also ionize. ?

$$H\text{-}O\text{-}H \rightarrow H^+ + OH^-$$

Acids, Bases, and Salts

An **acid** is any ionic substance that releases H^+ (protons) water.

e.g. (hydrochloric acid) $HCl \rightarrow H^+ + Cl^-$

A **base** is any ionic substance that releases OH^- (hydroxyl ions) in water.

e.g. (sodium hydroxide) $NaOH \rightarrow Na^+ + OH^-$

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

e.g. $HCl + NaOH \rightarrow NaCl + H_2O$

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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: H_2CO_3 is a weak acid

e.g. $H_2CO_3 \rightarrow H^+ + HCO_3^-$ (bicarbonate ion)

It is a weak acid because only a small proportion of the H_2CO_3 in solution dissociates.

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

$$pH = -\log[H+]$$

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

pH varies from about 1 to about 14

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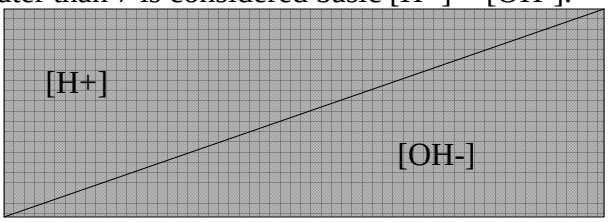
pH varies from about 1 to about 14.
Pure water dissociates into equal numbers of H^+ and OH^- ions and has a concentration of H^+ ions of 1×10^{-7} g/l (pH = 7)
pH =7 is considered neutral.
pH less than 7 is considered acidic [H+] > [OH-].
pH greater than 7 is considered basic [H+] < [OH-].



1 2 3 4 5 6 7 8 9 10 11 12 13 14
acidic ← → basic

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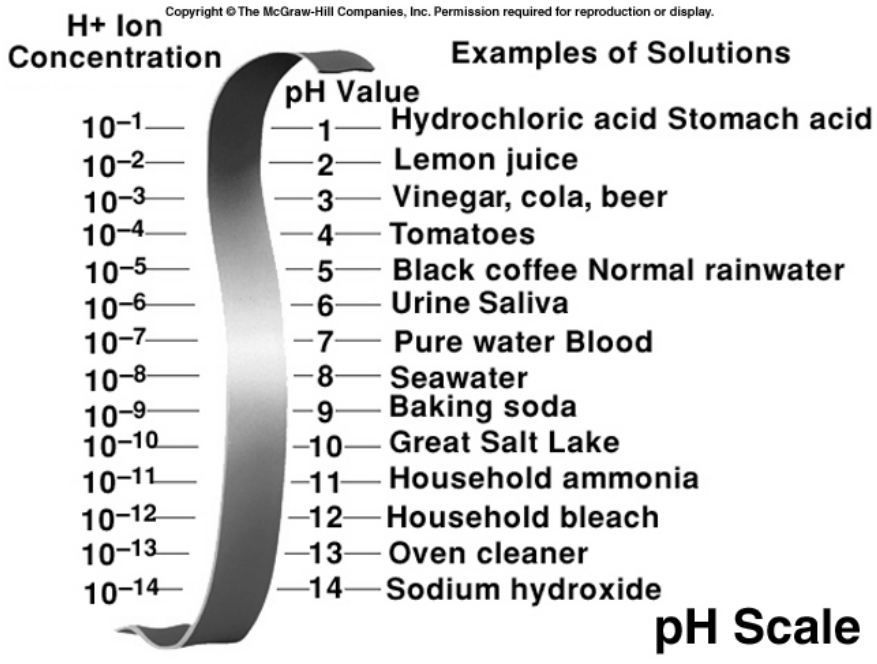
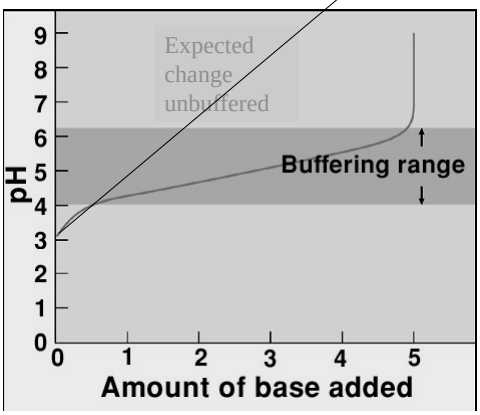


A **buffer** is a substance that when in solution stabilizes the pH of the solution within a range. The addition of small amounts of an acid or base change the pH of a buffered solution less than an unbuffered solution.



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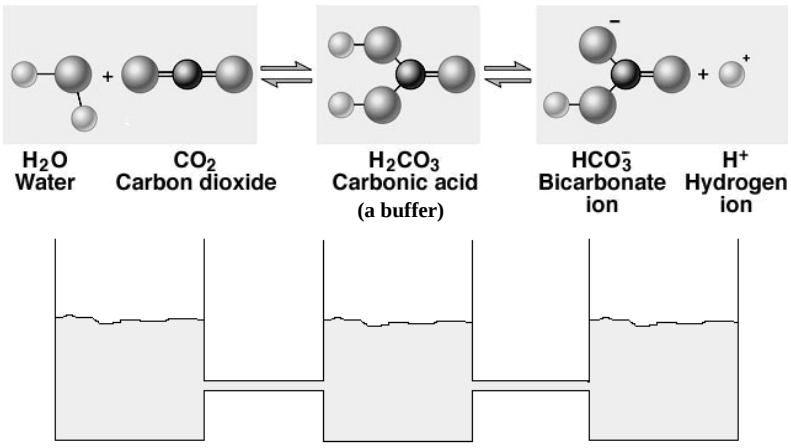

Addition of acid (H^+) will drive the reactions to the left.

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

?

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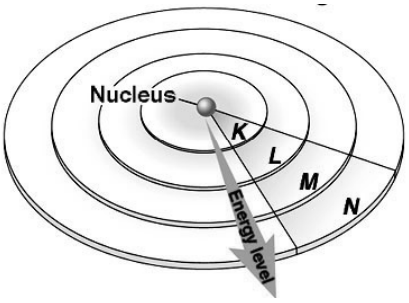
Energy and Atoms

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.



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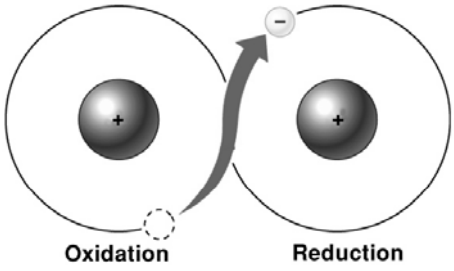
Chemical reactions involve the rearrangement of atoms within molecules, the breakage of chemical bonds, or the formation of chemical bonds.

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 looses electron energy. The reduced molecule gains electron energy

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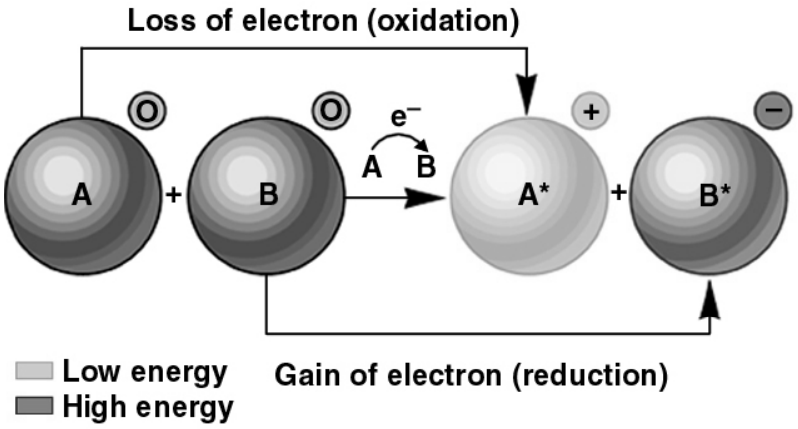
Oxidation-reduction (REDOX) reactions are the most important class of energy transfer reactions in living things.



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