BASIC CONCEPTS OF MODERN PHYSICS RELAVANT TO BIOLOGY

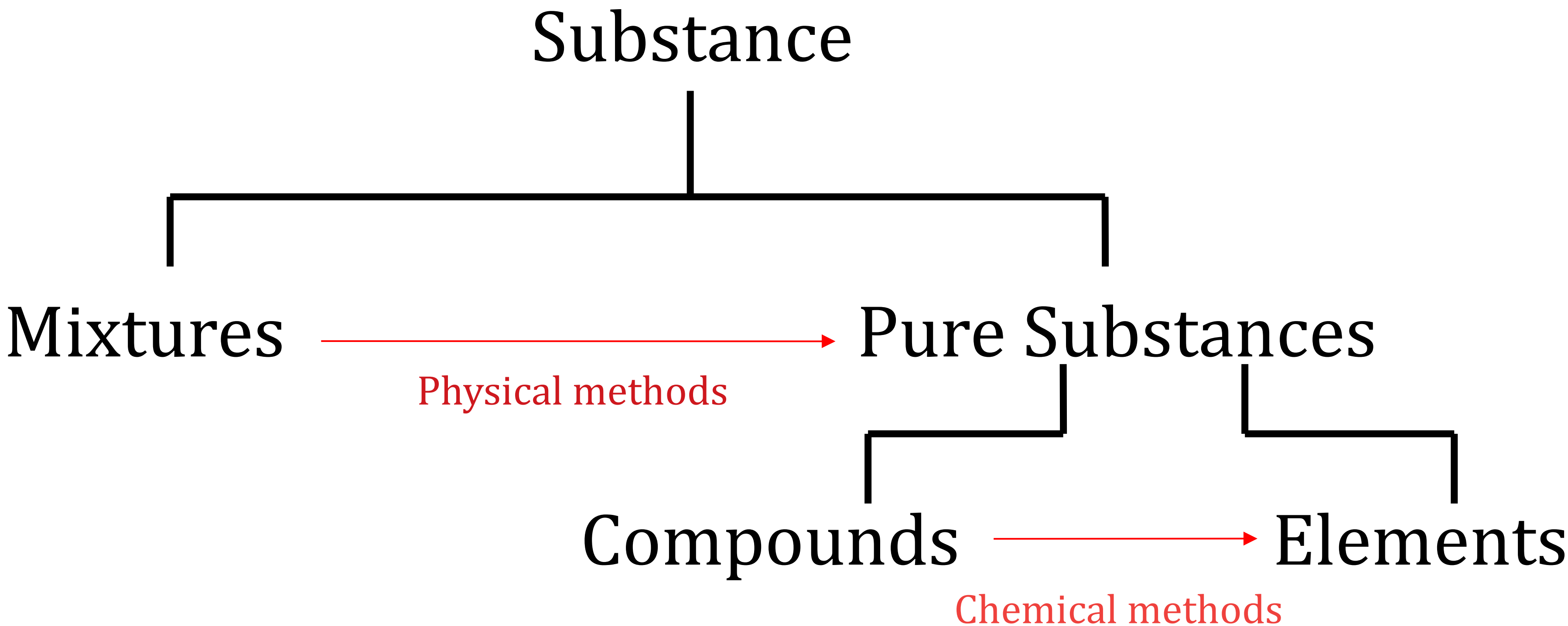
Yalçın İŞLER, PhD

Izmir Katip Celebi University

Department of Biomedical Engineering

islerya@yahoo.com

The molecular structure of living being



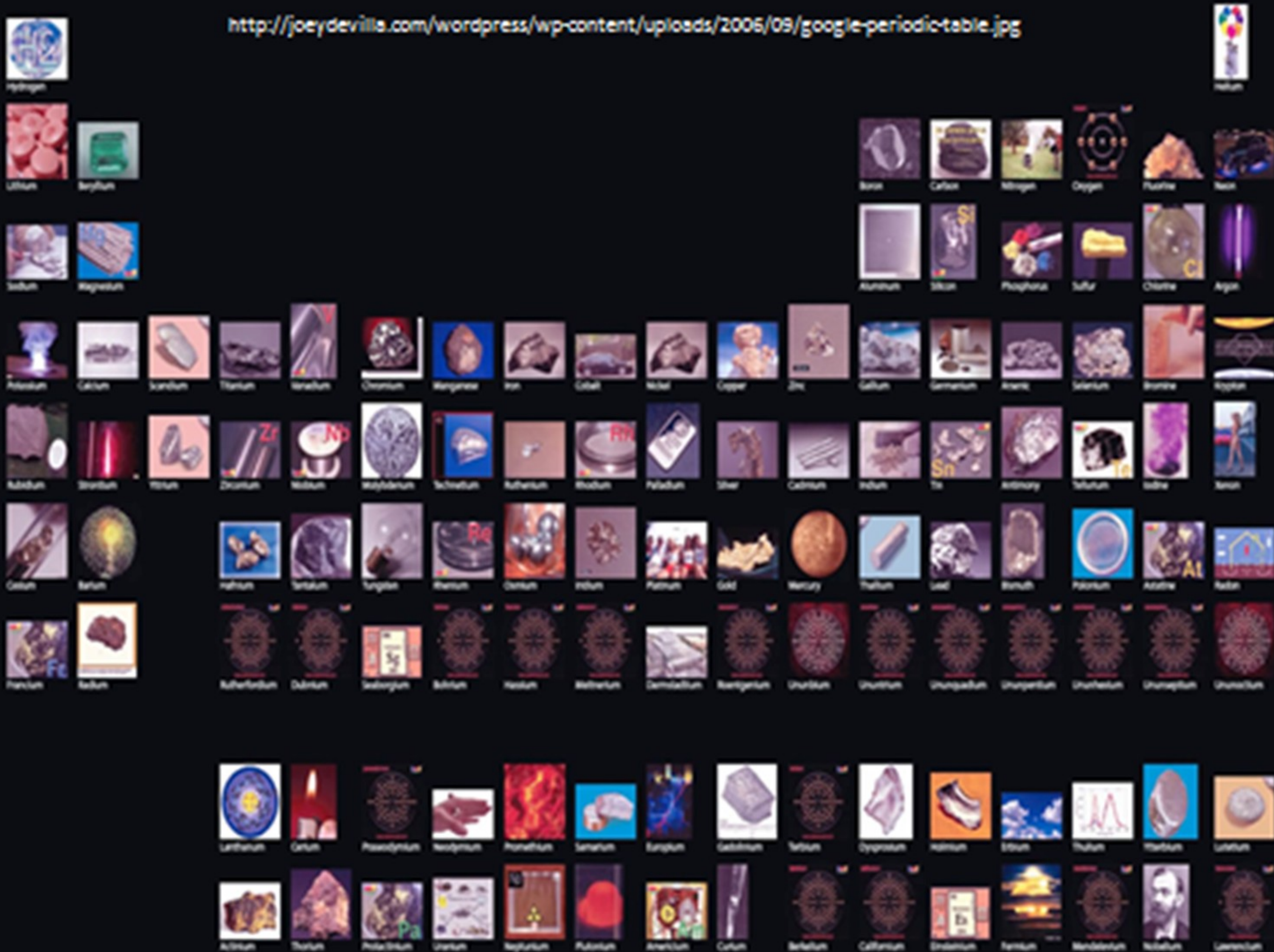
Pure Substances

http://powerlisting.wikia.com/wiki/List_of_Elemental_Abilities

- According to the Ancient Greeks, all substances on earth were composed of four elements; **Fire, Earth, Air and Water.**
- Objects in the sky are thought to be perfect and unchanging substance, so they were considered to occur from «Quintessence» *
- Quintessence was the fifth element.
- This Greek theory had dominated scientific thought for many years

*The essence in a thing that in its purest and most concentrated form

http://joeydevilla.com/wordpress/wp-content/uploads/2006/09/google-periodic-table.jpg



The 10 Most Abundant Elements in the Earth's Crust

Source: CRC Handbook of Chemistry and Physics, 77th Edition

Element	**Abundance** percent by weight	**Abundance** parts per million by weight
Oxygen	46.1%	461,000
Silicon	28.2%	282,000
Aluminum	8.23%	82,300
Iron	5.63%	56,300
Calcium	4.15%	41,500
Sodium	2.36%	23,600
Magnesium	2.33%	23,300
Potassium	2.09%	20,900
Titanium	0.565%	5,650
Hydrogen	0.14%	1,400

The Elements in the Human Body

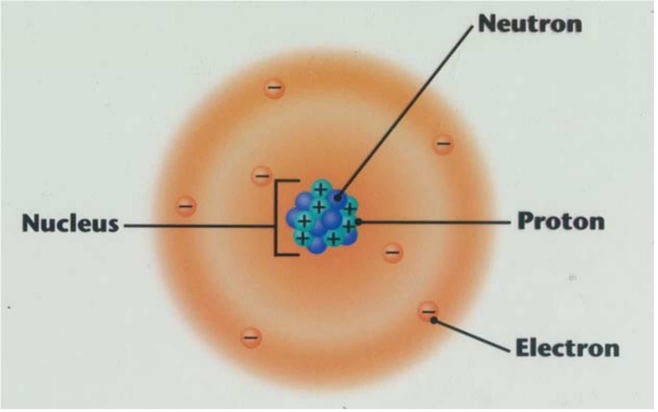
- Oxygen (65%)
- Carbon (18%)
- Hydrogen (10%)
- Nitrogen (3%)
- Calcium (1.5%)
- Phosphorus (1.0%)
- Potassium (0.35%)
- Sulfur (0.25%)
- Sodium (0.15%)
- Magnesium (0.05%)
- Copper, Zinc, Selenium, Molybdenum, Fluorine, Chlorine, Iodine, Manganese, Cobalt, Iron (0.70%)
- Lithium, Strontium, Aluminum, Silicon, Lead, Vanadium, Arsenic, Bromine (trace amounts)

Chemical Compounds

- Elements lose their properties in a compound
- Molecules are the smallest units
- Living things have moleculer structures
- intra- and inter- molecular interactions are directly related to the structure and functions of “biomolecules”

The Electronic Structure of Atoms

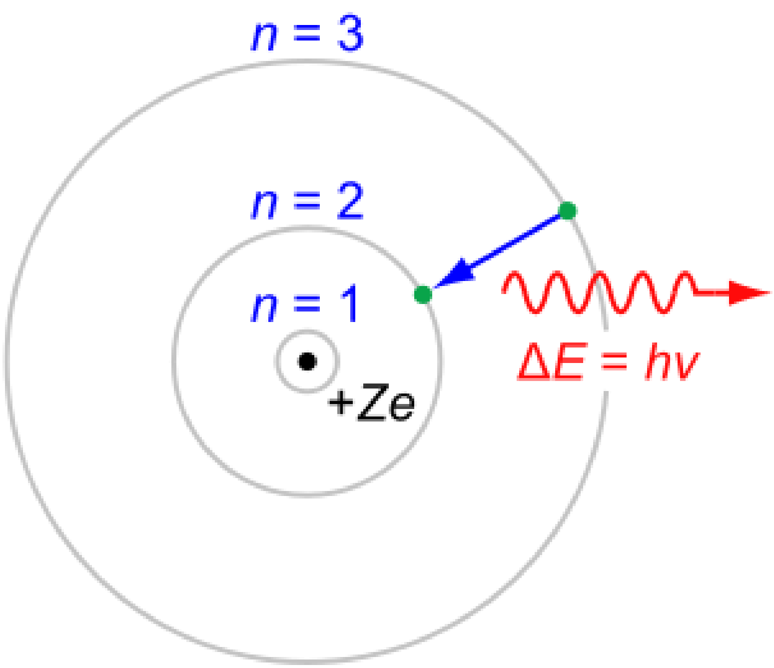
Particle	Symbol	Electric Charge	Mass (g)
Proton	p	1.6×10^{-19}	1.673×10^{-24}
Neutron	n	0	1.675×10^{-24}
Electron	e	-1.6×10^{-19}	9.11×10^{-28}



- The atom consists of a dense central nucleus surrounded by a cloud of negatively charged electrons
- The atomic nucleus contains positively charged protons and electrically neutral neutrons
- An atom containing an equal number of protons and electrons is electrically neutral
- it has a positive charge if there are fewer electrons
- negative charge if there are more electrons
- A positively or negatively charged atom is known as an ion

The Electronic Structure of Atoms

- Electrons revolve round the central nucleus, occupy only certain fixed orbitals
- These orbitals are called the stationary quantum states of the atom
- Radiation is emitted or absorbed only when electrons jump from one stationary state to another
- The difference in energy between two states is given by



$$\Delta E = h\nu = hc/\lambda$$

λ is the wavelength of the radiation, and c the velocity of light.

This equation determines the wavelength of the radiation emitted or absorbed.

Molecular Interactions

- The structure of a biological molecule determines its function.
- In turn, the forces between the atoms in a molecule determine its structure.
- The interactions between the atoms in the molecule are classified as strong or weak depending on whether or not the interaction can be disrupted by weak forces like thermal motion.
- The strength of an interaction is the energy required to disrupt it (bond energy).

Molecular Interactions

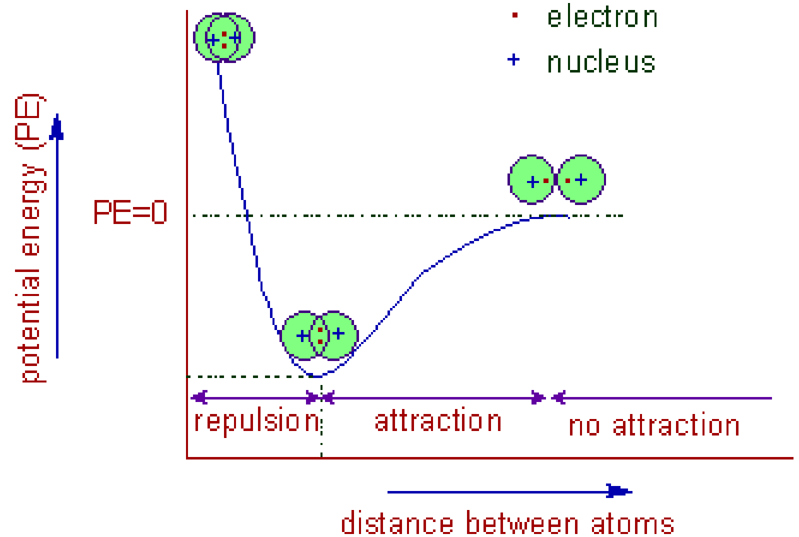
- Kinetic-molecular theory states that **the average kinetic energy of a mole of molecules** is proportional to absolute temperature, and the universal gas constant R

$$(1/2)MV^2 = (3/2)R\,T$$

For the body temperature	$RT \cong 2.5$ kJ/mol
Bond Energy > 2.5 kJ/mol	Strong interactions
Bond Energy ≤ 2.5 kJ/ mol	Weak interactions

- Strong interactions are implicated mainly in the formation of the chemical structure, and, to some extent, in the formation of the molecular structure.
- Weak interactions, not only help to determine the three-dimensional structure, but also are involved in the interactions between different molecules.

Bonding Forces and Energies



Potential energy between two atoms plotted as a function of the inter-nuclear distance

- When two atoms come close to each other a potential energy is associated with the system.

- This potential energy is minimum (largest negative value) when the force of attraction between the atoms equals the force of repulsion, and is zero when the two atoms are separated by an infinitely large distance.

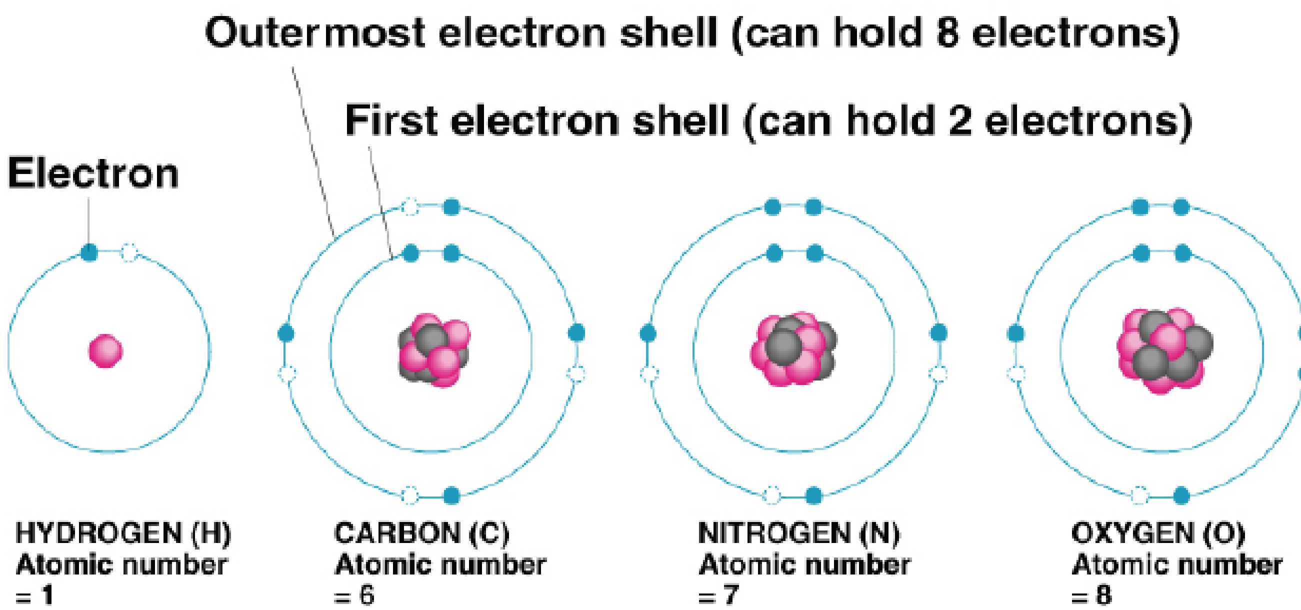
- The system as whole tries to attain an equilibrium minimum energy state and the final equilibrium distance between the two interacting atoms is a resultant of all the different forces, which act on each of them.

Strong Interactions

- **Ionic bonds** – electrostatic force between oppositely charge ions
- **Covalent bonds** - result from sharing electrons between the atoms
- **Metallic bonds** – attractive force holding pure metals together

The Octet Rule

- All inert gases (except He) have an s^2p^6 configuration
- Octet rule: atoms tend to gain, lose or share electrons until they have surrounded by 8 valence electrons (4 electron pairs)



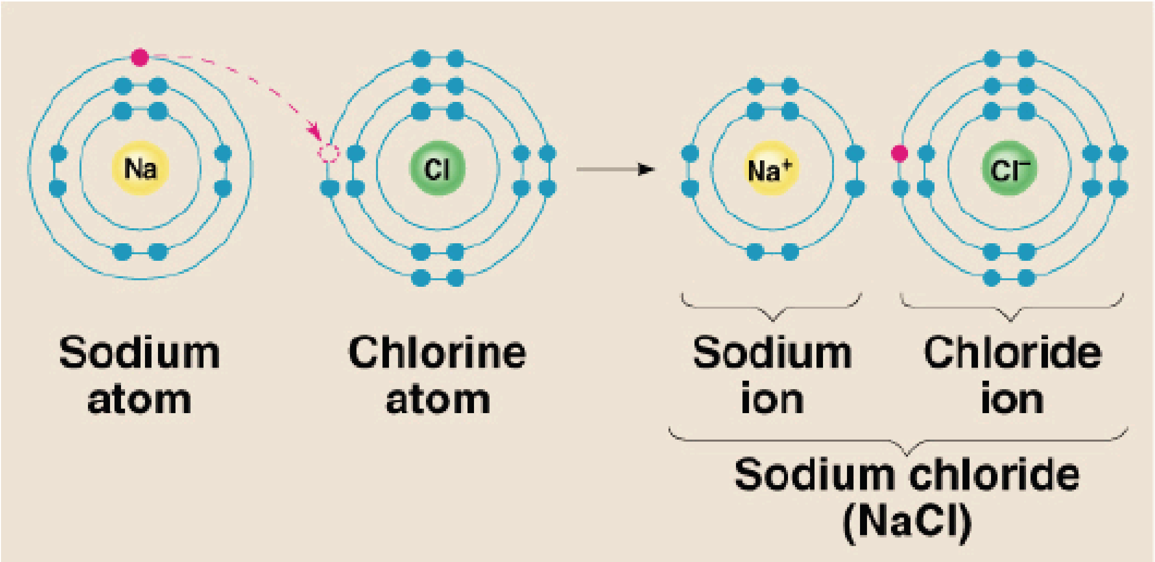
C would like to Gain 4 electrons

N would like to Gain 3 electrons

O would like to Gain 2 electrons

Ionic Bond

- formed due to electrostatic attraction between two oppositely charged ions
- formed by electron transfer
  - an electron is transferred from an electropositive to an electronegative element in order to achieve a stable electron configuration
- also known as electrovalent bond
- NaCl (sodium chloride)



Electron from Na is transferred to Cl.
Na becomes Na^+ and Cl becomes Cl^-

Most common ions in the human body

CATIONS

Sodium - Na^+

Potassium - K^+

Hydrogen - H^+

Calcium – Ca^{2+}

Magnesium – Mg^{2+}

ANIONS

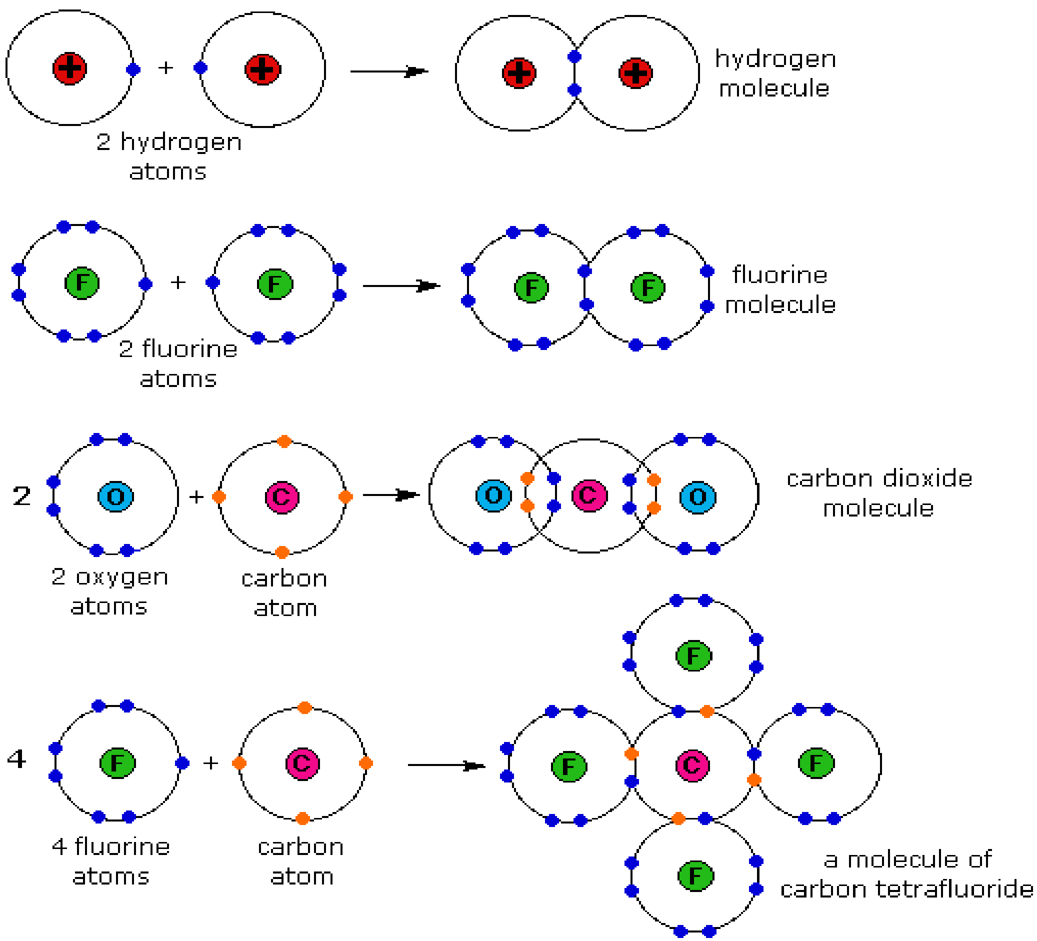
Chloride - Cl^-

Hydroxide - OH^-

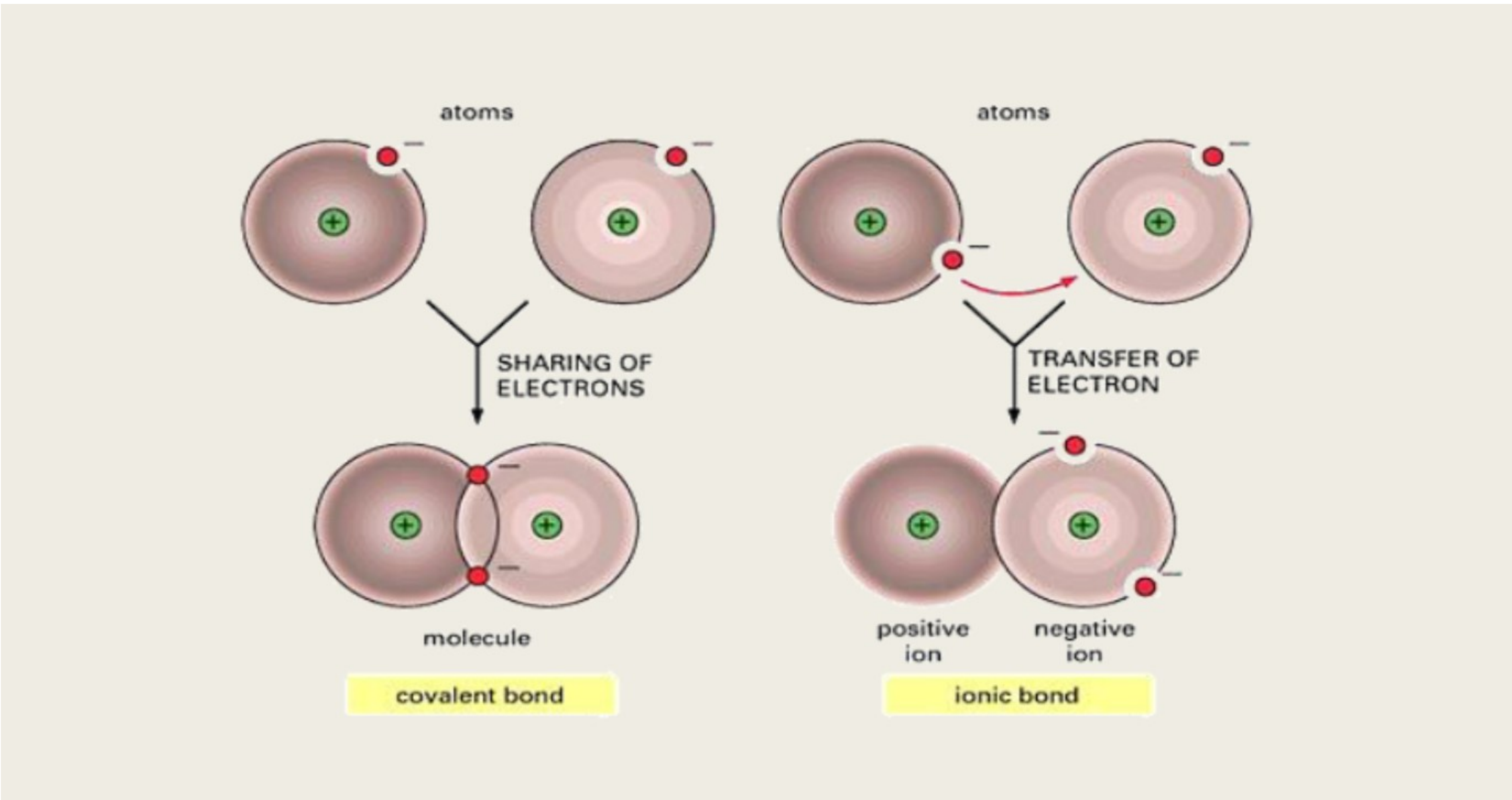
Bicarbonate - $HCO3^-$

Phosphate - $PO4^{3-}$

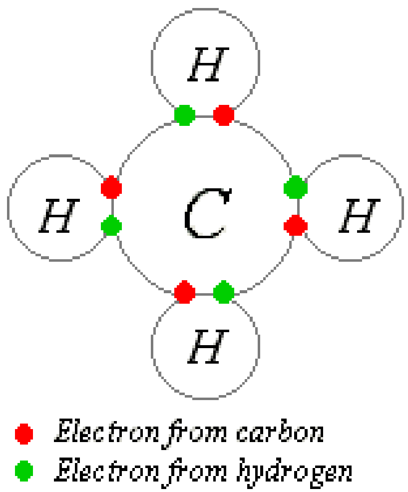
Covalent Bond



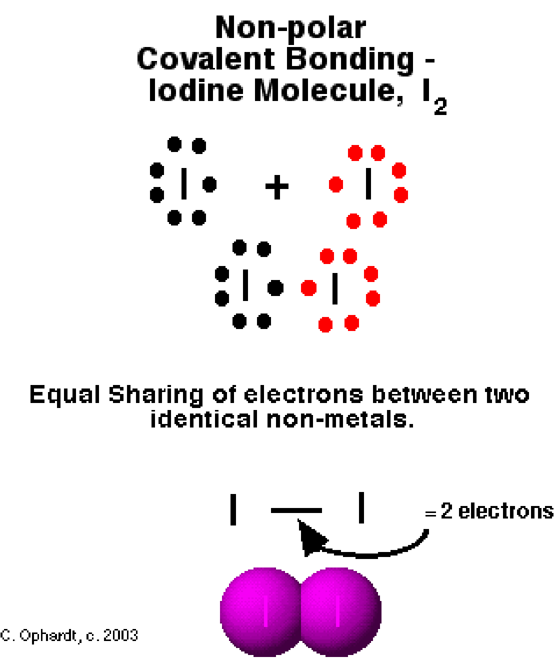
- A form of bonding that is characterized by the sharing of pairs of electrons between atoms
- The number of shared electrons depends on the number of electrons needed to complete the octet.
- Diatomic elements H_2, N_2, O_2, F_2 & Cl_2 have covalent bonds


atoms
SHARING OF ELECTRONS
molecule
covalent bond
atoms
TRANSFER OF ELECTRON
positive ion
negative ion
ionic bond

Nonpolar Covalent Bonds

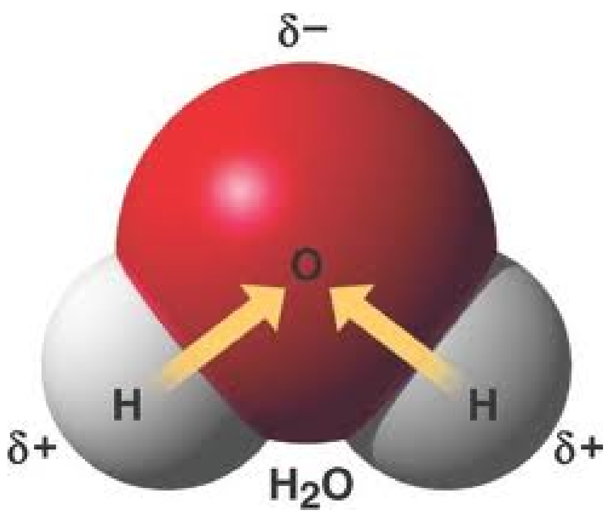


CH_4 (methane)



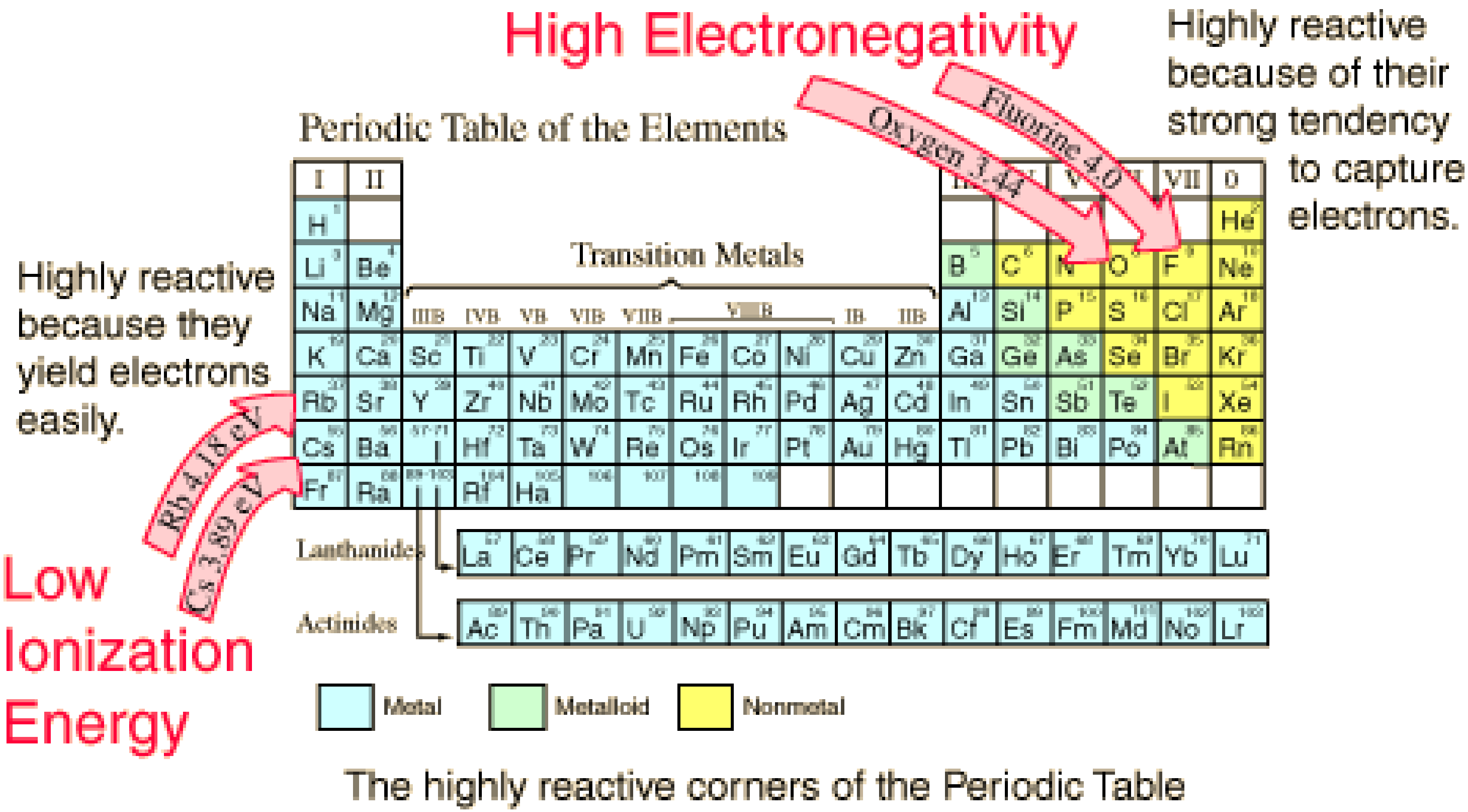
- Nonpolar covalent bonds– share electrons equally
  - Occurs when the shared pair of electrons are at an equal distance from both the atoms involved in bonding
  - The molecule is electrically neutral
- Iodine forms a diatomic non-polar covalent molecule.
  - The graphic on the left shows that iodine has 7 electrons in the outer shell. Since 8 electrons are needed for an octet, two iodine atoms <u>Equally</u> share 2 electrons

Polar Covalent Bonds



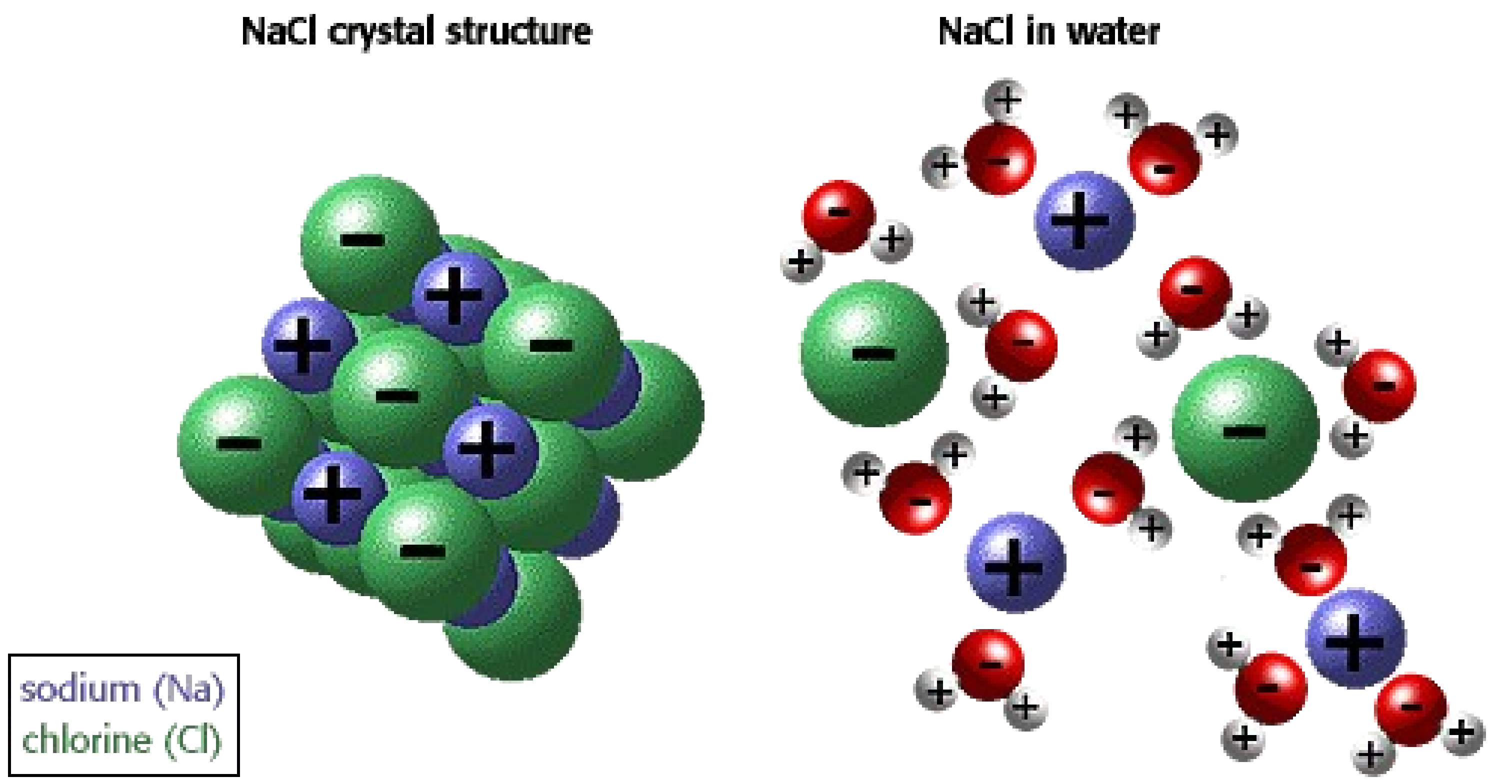
- Polar covalent bonds– do not share electrons equally
  - Occurs when the shared electron moves towards the electronegative atom
- In such a bond there is a charge separation with one atom being slightly more positive and the other more negative, i.e., the bond will produce a dipole moment.
- The ability of an atom to attract electrons in the presence of another atom is a measurable property called *electronegativity.*

Electronegativity



Electronegativity is a measure of the ability of an atom in a molecule to draw bonding electrons to itself.

Ion - Dipole Interactions



A molecular picture showing the ion-dipole interaction that helps a solid ionic crystal dissolve in water.

Electrostatic forces will arise between an ion and dipole molecule.

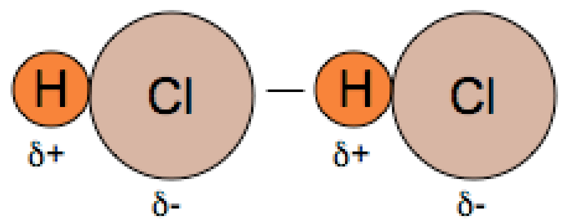
* Ions and polar molecules dissolve well in water.
  Water is a good solvent due to its polarity.

Weak Interactions

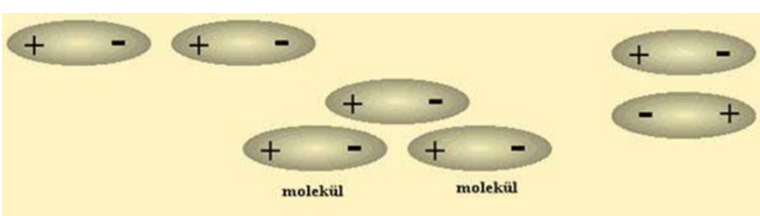
- Van der Waals interactions:
  - Van der Waals forces are basically electrostatic in nature
  - they involve interactions between electric dipoles
- Hydrogen bonds
  - generally found between two electronegative atoms
  - is stronger than a van der Waals interaction
  - occurs in both inorganic molecules such as water and organic molecules like DNA and proteins

Van der Waals Interactions
dipole-dipole interactions

- Interactions that occur between polar molecules
- There is an attractive force between opposite polars of dipole molecules.



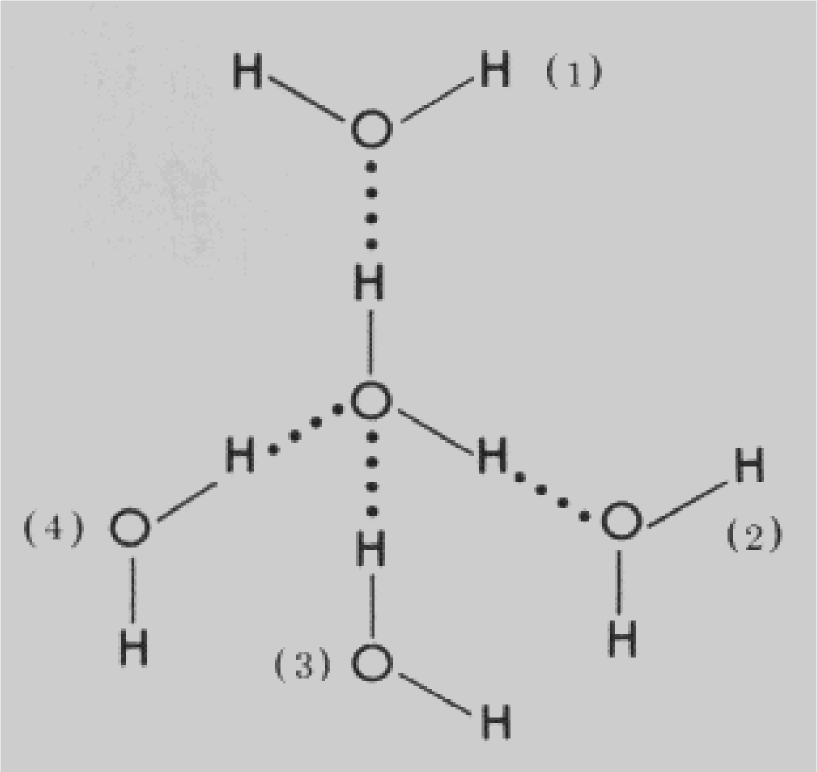
- HCl has a permanent dipole moment (It has a polar structure).
- Because Cl atom is more electronegative than H atom, it pulls electrons stronger than H.
- Between these dipole molecules electrostatic interactions occur.



- Each polar molecule affected by other polar molecules and therefore molecules will tend to move so as to maximize attractions and minimize repulsions.

Hydrogen Bonds

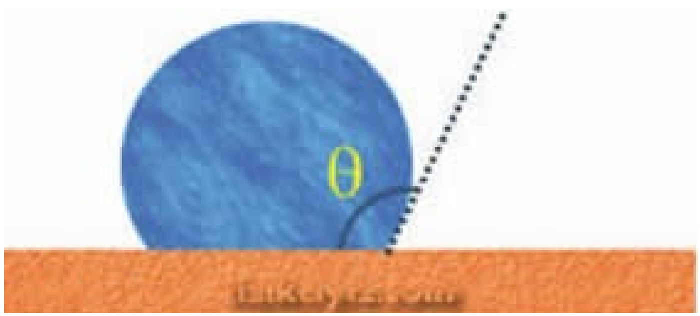
- If an electronegative atom bonded to a hydrogen atom, it draws the electron of the hydrogen atom towards it, leaving the latter with a residual positive charge.
- The *H* ion, with slightly positive charge, is now attracted by the electrons surrounding the second electronegative atom.
- This electronegative atoms are usually *flourine, oxygen* or *nitrogen.*

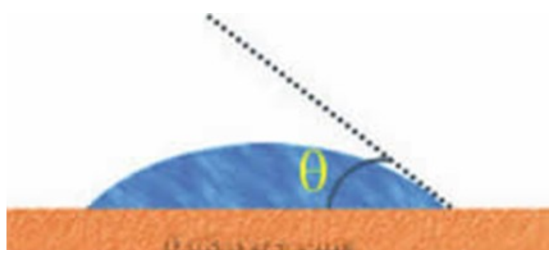


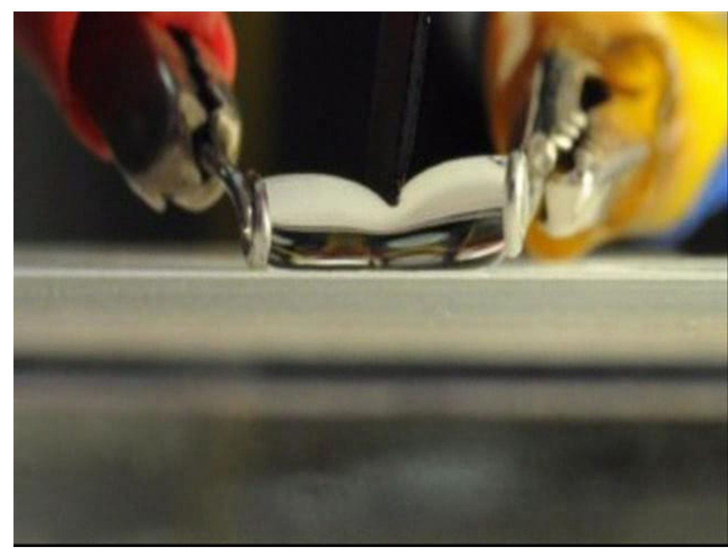
Each water molecule is hydrogen bonded to four others.

Hydrophobicity

- hydro, meaning water, phobos, meaning fear
- is the physical property of a molecule (known as a hydrophobe) that is repelled from a mass of water.
- Hydrophobic molecules in water often cluster together, forming micelles.
- Water on hydrophobic surfaces will exhibit a high contact angle.
- Examples of hydrophobic molecules include the alkanes, oils, fats, and greasy substances in general.







References

- Prof. Dr. Gürbüz Çelebi. Biyofizik. Tıp ve Diş Hekimliği Öğrencileri için. Barış Yayınları Fakülteler Kitabevi, Cilt I, III.Baskı, İzmir, 2005.
- Prof. Dr. Ferit Pehlivan. Biyofizik. Hacettepe Taş. 4. Tıpkı Basım, Ankara, 2009.
- Vasantha Pattabhi, N. Gautham. Biophysics. Kluwer Academic Publishers. 2002.
- http://www.deu.edu.tr/userweb/mehmet.kartal/dosyalar/KOVELENTBAG1.pdf
- http://kisi.deu.edu.tr/aytac.gokce/KF_4.pdf
- http://www.chem.ufl.edu/~itl/2045_s99/lectures/lec_g.html
- http://www.colorado.edu/physics/2000/elements_as_atoms/quantum_numbers2.html
- http://www.chemprofessor.com/imf.htm
- http://reich-chemistry.wikispaces.com/Burgess-Chrost.MMA.2010.atomichistory
- http://upload.wikimedia.org/wikipedia/commons/thumb/f/ff/Plum_pudding_atom.svg/2000px-Plum_pudding_atom.svg.png
- https://solbergsphyscience.wikispaces.com/The+Structure+of+the+Atom
- http://bdml.stanford.edu/twiki/bin/view/Rise/InvestigationOfVanDerWaalsForce.html

☺ Good Evening!