BIOCHEMISTRY

faculty of medicine - JU2017

ketone starch lipid protein amine carbohydrates isomers

◉ Sheet ○ Slides

Number

1

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What is BIOCHEMISTRY???

Biochemistry = understanding life

Chemical reactions are what makes an organism (An organism is simply atoms reacting with each other).

We will start by:

- knowing the chemical structures of biological molecules (building blocks).

- connecting it with the biological function of these molecules.

- Understanding the interaction and organization of different molecules within individual cells and whole biological systems (for example: why is a protein found in the plasma membrane in its specific structure, how do sugar molecules on a plasma membrane interact with proteins on a plasma membrane of another cell).

-understanding chemical reactions and the pathways of these reactions.

-Understanding bioenergetics (the study of energy flow in cells). Since life is actually energy, an organism that can't transfer energy is dead.

Biochemistry in medicine:

* Explains all disciplines, for example:

anatomy: why does a bone has its shape?

histology: why are these molecules found in this tissue?

pharmacology: explains the kinetics of drugs (pharmacokinetics and pharmacodynamics) and why the effect of a drug stops after 4 hours, meanwhile by adding chemicals a new generation of drugs would take days until it stops affecting. Why people differ in their response to the same drug even though they may have the same enzymes (because they have different metabolism). In blood tests they look for biochemical molecules (metabolites) for diagnosis.

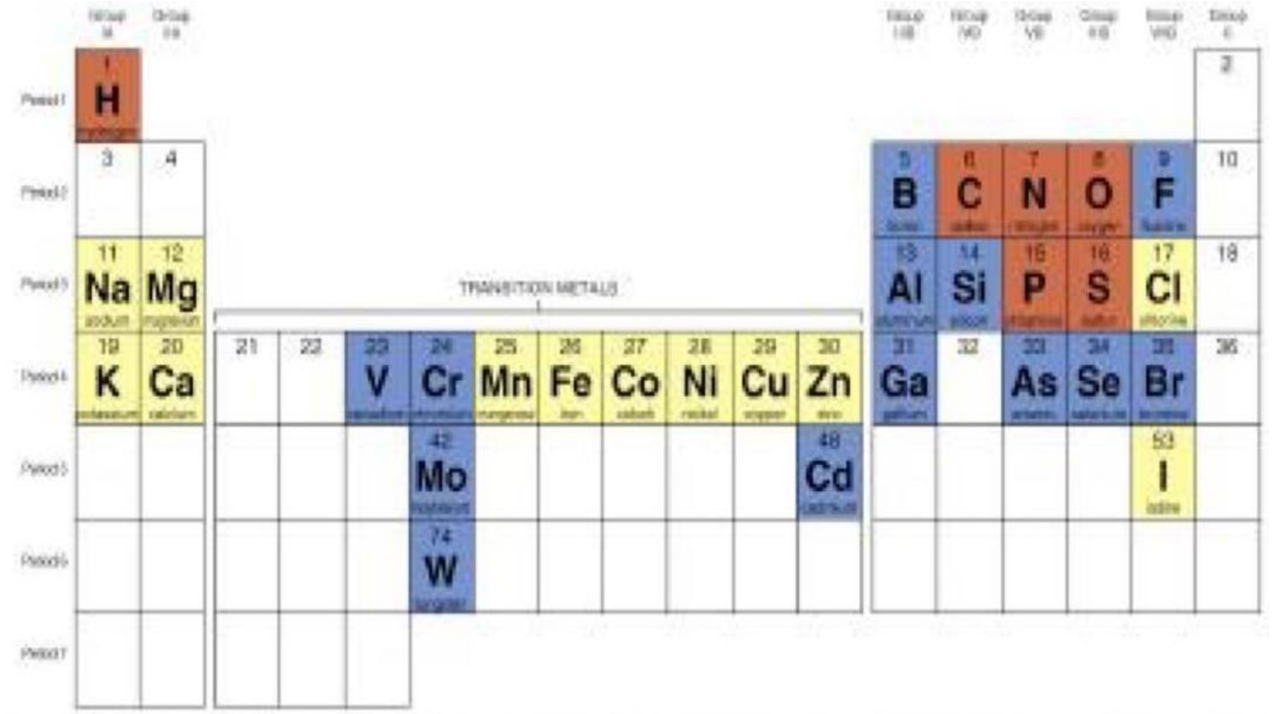
* diagnose and monitor diseases: for example, we never see cancer itself, but we see indicators of it, if we found the concentration of a certain protein high in a patient, we treat him to cancer even if we can't see cancer cells by our eyes, so if the concentration of this protein decreases after the treatment, it means that therapy is working, otherwise we have to change the therapy.

* design drugs (new antibiotics, chemotherapy agents): if we know the structure of an enzyme in our body we can make better drugs to affect it.

* understand the molecular basis of diseases.

NOW WE START,

Living organisms on earth are composed mainly of 31 elements, these elements are found in our bodies.



⟶ There are 4 primary elements (first tier) (Carbon, Hydrogen, Oxygen, Nitrogen) which are needed and found in high amounts (96.5% of an organism's weight).

⟶ The second group include Sulfur and Phosphorus which are needed in a lower amount (it's still high but lower than the primary 4 elements), because Phosphorus is found in the DNA and Sulfur is found in proteins (not all proteins contain Sulfur).

Second tier includes (Calcium, Magnesium, Chlorine, P, K, Na, S), which are needed in high amounts but less than first tier elements.

⟶ Third and fourth tiers include minor elements that are needed in minimal amounts, but they are very essential (mostly Metals).

⟶ Most biological compounds are made of only 6 elements

(C, H, O, N, P, S)

Element	Comment
First Tier	
Carbon (C) Hydrogen (H) Nitrogen (N) Oxygen (O)	Most abundant in *all organisms*
Second Tier	
Calcium (Ca) Chlorine (Cl) Magnesium (Mg) Phosphorus (P) Potassium (K) Sodium (Na) Sulfur (S)	Much less abundant but found in *all organisms*
Third Tier	
Cobalt (Co) Copper (Cu) Iron (Fe) Manganese (Mn) Zinc (Zn)	Metals present in small amounts in *all organisms* and essential to life
Fourth Tier	
Aluminum (Al) Arsenic (As) Boron (B) Bromine (Br) Chromium (Cr) Fluorine (F) Gallium (Ga) Iodine (I) Molybdenum (Mo) Nickel (Ni) Selenium (Se) Silicon (Si) Tungsten (W) Vanadium (V)	Found in or required by *some organisms* in trace amounts

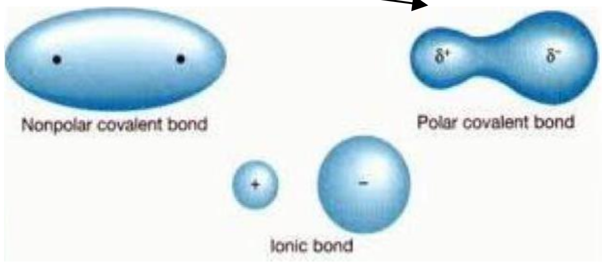
Important terms:

*** Electronegativity:** describes the tendency of an atom to attract a shared pair of electrons (electron density) towards itself.

*** Covalent bonds:** involves sharing of electron pairs between atoms.

It can be polar or non-polar / single or multiple (double or triple).

*** Non-covalent interactions:**

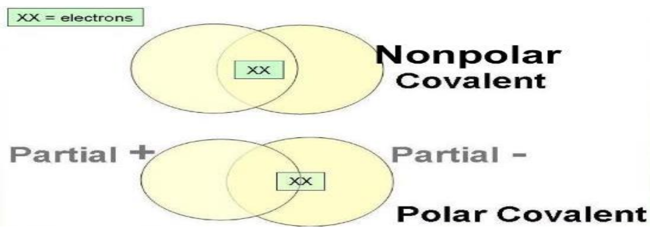


- electrostatic interactions

- hydrogen bonds (donor and acceptor)

- van der Waals interactions

xx- Hydrophobic interactions



*** Hydrophobic versus hydrophilic molecules**

Important properties of bonds:

Bond strength: amount of energy that must be supplied to break a bond (it determines the stability of molecules).

Bond length: the distance between two nuclei.

Bond orientation: bond angles determining the overall geometry of atoms.

The three-dimensional structures of molecules are specified by the bond angles and bond lengths for each covalent linkage, and therefore the three-dimensional structure of organisms.

Polarity of covalent bonds:

A covalent **bond** can be polar or non-polar depending on the electronegativity of the atoms, the higher the difference in electronegativity, the more polar the **bond**.

polar covalent bonds: Covalent bonds in which the electrons are shared unequally. **The bonds are known as "dipoles".**

Oxygen and nitrogen atoms are electronegative (have high electronegativity).

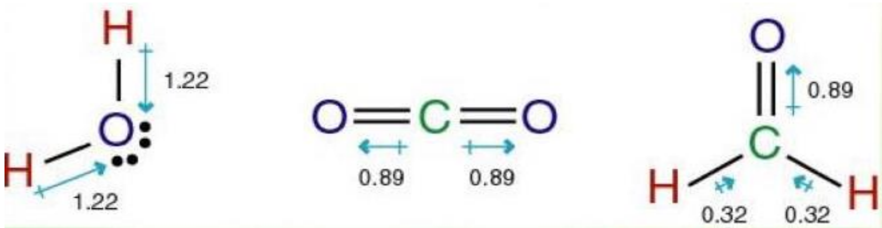
So, A bond between Oxygen and Hydrogen is polar (O has partial negative charge while H has partial positive charge because oxygen has a higher electronegativity)

A bond between Nitrogen and Hydrogen is polar.

A bond between Carbon and Hydrogen is non-polar because C and H have almost the same electronegativity (bonding electrons are distributed evenly).

We talked about the polarity of covalent **bond** by itself, but now the whole molecule can be polar or non-polar depending on both **the polarity of bonds** and **the angle (overall structure)**.

⟶ A molecule that contains polar covalent bonds can be polar such as H2O or non-polar such as CO2 (even if it contains polar bonds, the angle is 180 and the attraction of Oxygen for electrons in both directions is equal which cancels out).



Polar bond and polar molecule

Polar bond and nonpolar molecule

Polar bond and polar molecule

Non-covalent interactions (4 types)

Properties:

- Reversible (break and reform continuously)

- Relatively weak, 1-30 kj/mole vs. 350 kj/mole in C–C bond.

- Molecules interact and bind specifically.

- Noncovalent forces significantly contribute to the structure, stability, and functional competence of macromolecules in living cells.

- Can be either attractive or repulsive

Covalent vs Noncovalent bonds

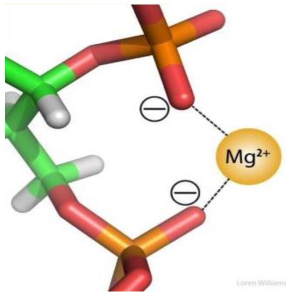
Table 2.3
Some Bond Energies

	Type of Bond	Energy (kJ mol^{-1})	Energy (kcal mol^{-1})
Covalent Bonds (Strong)	O—H	460	110
	H—H	416	100
	C—H	413	105
Noncovalent Bonds (Weaker)	Hydrogen bond	20	5
	Ion–dipole interaction	20	5
	Hydrophobic interaction	4–12	1–3
	Van der Waals interactions	4	1

- Involve interactions within both the biomolecule and between water of the surrounding environment and the biomolecule.

Types:

Electrostatic interactions, ionic interactions, salt bridges, you can also call it charge-charge interactions (real charges not partial):

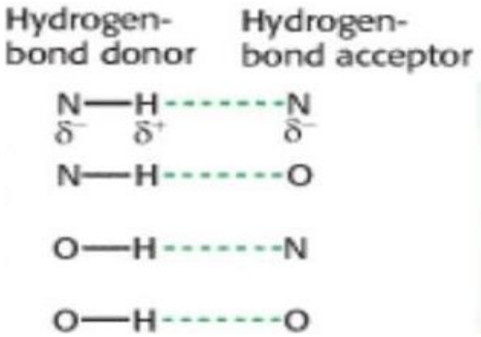


•They are formed between two oppositely charged particles.

•These forces are quite strong <u>in the absence of water.</u>

Hydrogen bonds

A hydrogen atom is partly shared between two relatively electronegative atoms (a donor and an acceptor).



H-bond is stronger if

X–H------A

A is O, N or F

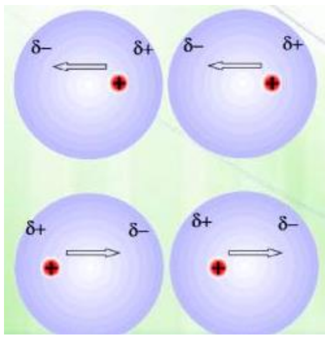
X is O, N or F

Hydrogen bond must contain a hydrogen atom which has a partial positive charge (polar bond to give it a +ve charge) which interacts with an atom that has a partial negative charge from <u>another molecule (O, F, N).</u>

Water molecules have hydrogen bonds between them (between H atom of one molecule and O atom of another molecule), that causes cohesion in plants (when water evaporates from leaves it pulls other water molecules upwards against gravity).

e.g. The two strands of the DNA helix. 10-30 kj/mole

Van der Waals interactions (London dispersion interactions)



Attractions between transient dipoles generated by the rapid movement of electrons of all neutral atoms.

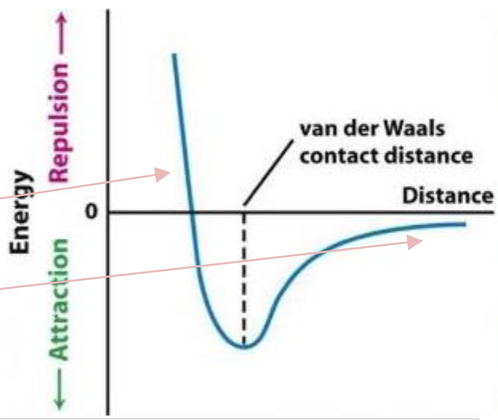
Unequal distribution of electric charge around an atom change with time (temporary).

They are the weakest forces, because they are so dynamic and electron movement is very fast. (1-5 kj/mole).

The strength of the attraction is affected by distance:

if molecules are very close they repulse

if they are far there will be no interaction.

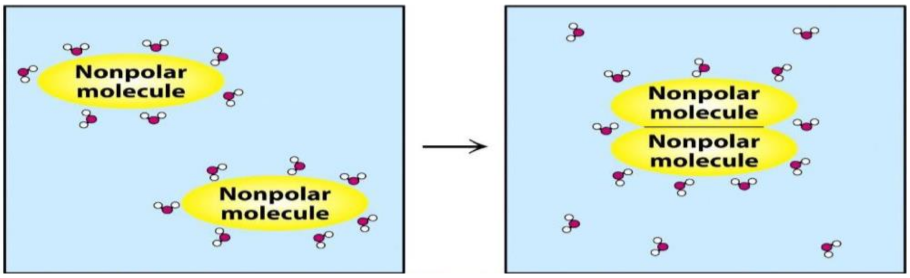


Hydrophobic interactions (hydro: water, phobia: fear):

- Not true bonds

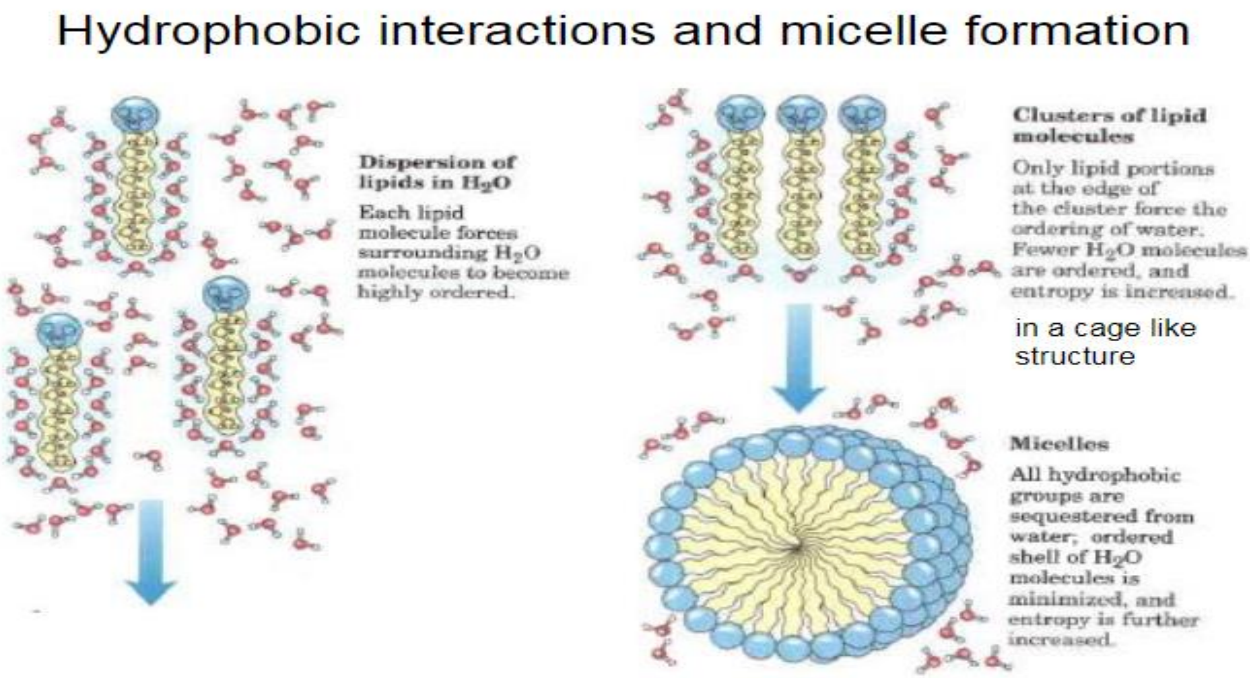
- Self-association of nonpolar compounds in an aqueous environment.

- Minimize unfavorable interactions between nonpolar groups and water by minimizing surface area.



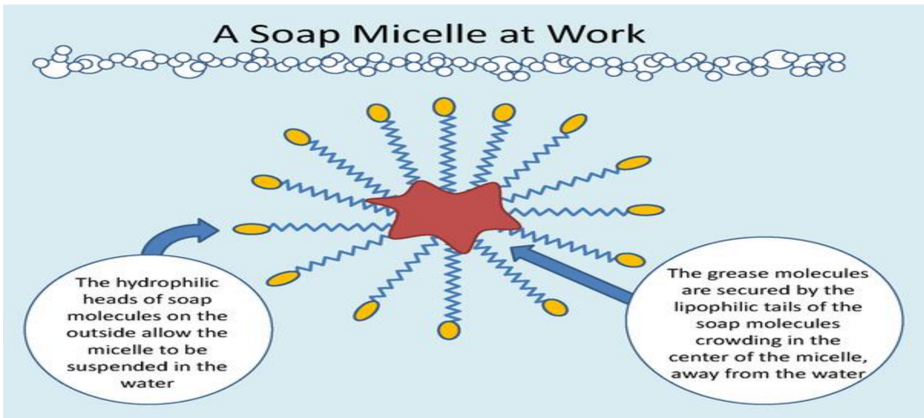
5-30 kj/mole

For example, if you put 2 drops of oil in water they will self-associate and become 1 droplet, they are trying to minimize the surface area that is exposed to water and therefore minimize unfavorable interactions.



Phospholipids are amphipathic, which means they have both hydrophilic and hydrophobic regions.

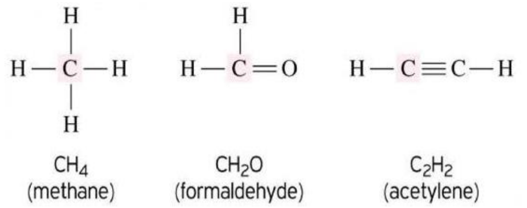
Micelles round structures formed to minimize the contact between the hydrophobic regions of phospholipids and water. And it's how a soap functions, the hydrophilic heads allow the contact and adhere to water, while the hydrophobic tails absorb oils and fats from your skin.



Carbon

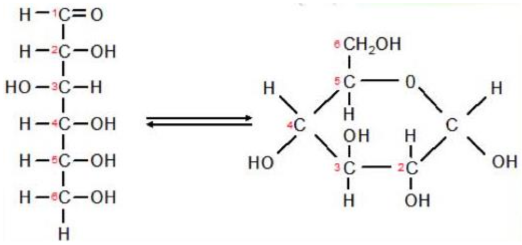
Properties of carbon:

* It can form four bonds which can bind with the same element such as methane CH4 or with 4 different elements, and it can also have single, double, or triple bonds (this causes high diversity of compounds).



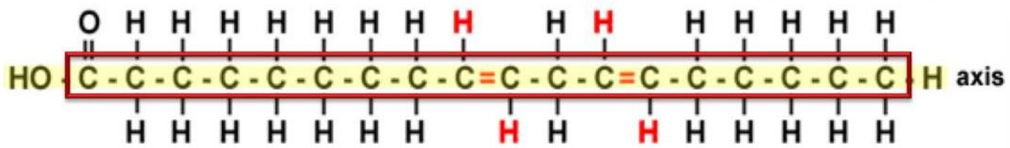
* Each bond is very stable.

strength of bonds: (triple > double > Single) we don't have triple bonds in our bodies, just single and double.

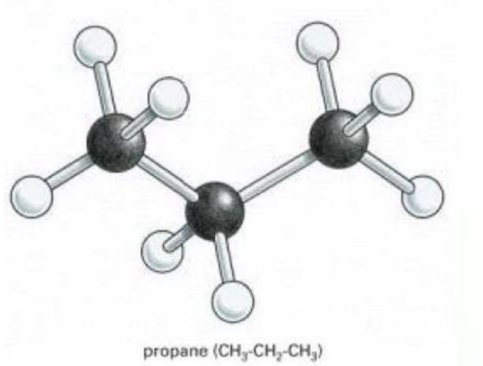


* C atoms can be linked together in chains or rings or a combination of both.

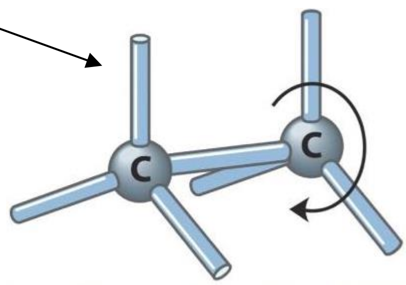
These serve as a backbone.



* Carbon bonds have angles giving the molecule three-dimensional structure.



* In a carbon backbone, some carbon atoms rotate around a single covalent bond producing molecules of different shapes (conformers).



* The electronegativity of carbon is not too high nor too low compared to other atoms. So, it can form polar and non-polar molecules.

* Pure carbon is not water soluble, but when carbon forms covalent bonds with other elements like O or N, the molecule makes the carbon compounds to be soluble.

((All these properties increase diversity))

Functional groups

(Groups of atoms attached to a carbon skeleton)

Class of Compound	General Structure[a]	Functional Group Structure	Functional Group Name	Example
Alkane	$RCH_2{-}CH_3$	$-\underset{H}{\overset{\mid}{C}}-\underset{H}{\overset{\mid}{C}}-$	Carbon–carbon and carbon–hydrogen single bonds	$H_3C{-}CH_3$
Alkene	$RCH{=}CH_2$	$>C{=}C<$	Carbon–carbon double bond	$H_2C{=}CH_2$
Alcohol	ROH	$-OH$	Hydroxyl group	CH_3OH
Thiol	RSH	$-SH$	Thiol or sulfhydryl group	CH_3SH
Ether	$R{-}O{-}R$	$-O-$	Ether group	$CH_3{-}O{-}CH_3$
Amine[b]	RNH_2, R_2NH, R_3N	$-N<$	Amino group	$H_3C{-}NH_2$
Imine[b]	$R{=}NH$	$>C{=}N{-}H$	Imino group	$(H_3C)_2C{=}NH$
Aldehyde	$R-\overset{O}{\overset{\|}{C}}-H$	$-\overset{O}{\overset{\|}{C}}-H$	Carbonyl group	$CH_3C(=O)H$
Ketone	$R-\overset{O}{\overset{\|}{C}}-R$	$-\overset{O}{\overset{\|}{C}}-$	Carbonyl group	$CH_3\overset{O}{\overset{\|}{C}}CH_3$
Carboxylic acid[b]	$R{-}COOH$	$-\overset{O}{\overset{\|}{C}}-OH$	Carboxyl group	$CH_3C(=O)OH$
Ester	$R-\overset{O}{\overset{\|}{C}}-OR$	$-\overset{O}{\overset{\|}{C}}-OR$	Ester group	$CH_3\overset{O}{\overset{\|}{C}}-OCH_3$
Amide	$R-\overset{O}{\overset{\|}{C}}-NH_2$	$-\overset{O}{\overset{\|}{C}}-N(H)H$	Amide group	$CH_3\overset{O}{\overset{\|}{C}}-NH_2$
Phosphoric acid[b]	$HO-\underset{OH}{\overset{O}{\overset{\|}{P}}}-OH$	$HO-\underset{OH}{\overset{O}{\overset{\|}{P}}}-OH$	Phosphoric acid group	$HO-\underset{OH}{\overset{O}{\overset{\|}{P}}}-OH$
Phosphoric acid ester[b]	$R-O-\underset{OH}{\overset{O}{\overset{\|}{P}}}-OH$	$-O-\underset{OH}{\overset{O}{\overset{\|}{P}}}-OH$	Phosphoester group or phosphoryl group	$CH_3O\underset{OH}{\overset{O}{\overset{\|}{P}}}-OH$
Phosphoric acid anhydride[b]	$R-O-\underset{OH}{\overset{O}{\overset{\|}{P}}}-O-\underset{OH}{\overset{O}{\overset{\|}{P}}}-OH$	$-O-\underset{OH}{\overset{O}{\overset{\|}{P}}}-O-\underset{OH}{\overset{O}{\overset{\|}{P}}}-OH$	Phosphoric anhydride group	$CH_3O-\underset{OH}{\overset{O}{\overset{\|}{P}}}-O-\underset{OH}{\overset{O}{\overset{\|}{P}}}-OH$
Carboxylic acid–phosphoric acid mixed anhydride[b]	$R-\overset{O}{\overset{\|}{C}}-O-\underset{OH}{\overset{O}{\overset{\|}{P}}}-OH$	$-\overset{O}{\overset{\|}{C}}-O-\underset{OH}{\overset{O}{\overset{\|}{P}}}-OH$	Acyl-phosphoryl anhydride	$CH_3\overset{O}{\overset{\|}{C}}-O-\underset{OH}{\overset{O}{\overset{\|}{P}}}-OH$

[a] R refers to any carbon-containing group.
[b] These molecules are acids or bases and are able to donate or accept protons under physiological conditions. They may be positively or negatively charged.

Water

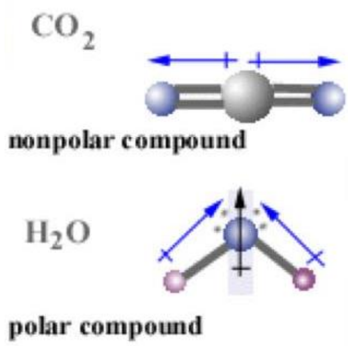
Properties of water:

a. Water is a polar molecule as a whole because of:

-the different electronegativity between Hydrogen and oxygen.

-It is angular.

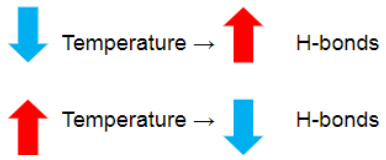
b. Water is highly cohesive.

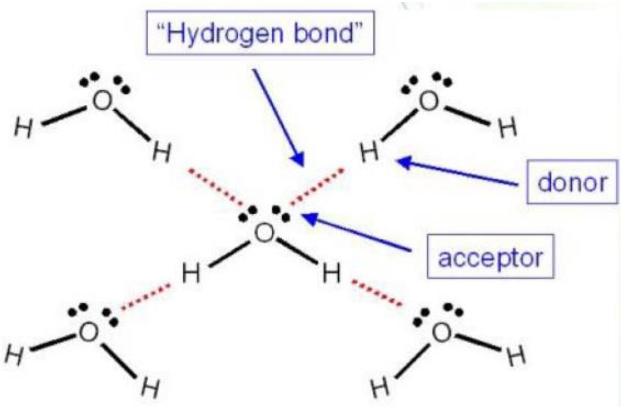


c. Water molecules produce a network (each water molecule can make 4 Hydrogen bonds).

((**Average** number of H-bond in liquid water at 10ºC is 3.4 while in ice crystals is 4))

Number of H-bonds decreases with higher temperatures





*** H-bonding gives water its unusual properties**

-Higher melting and boiling points

-Heat of vaporization

-Higher freezing point

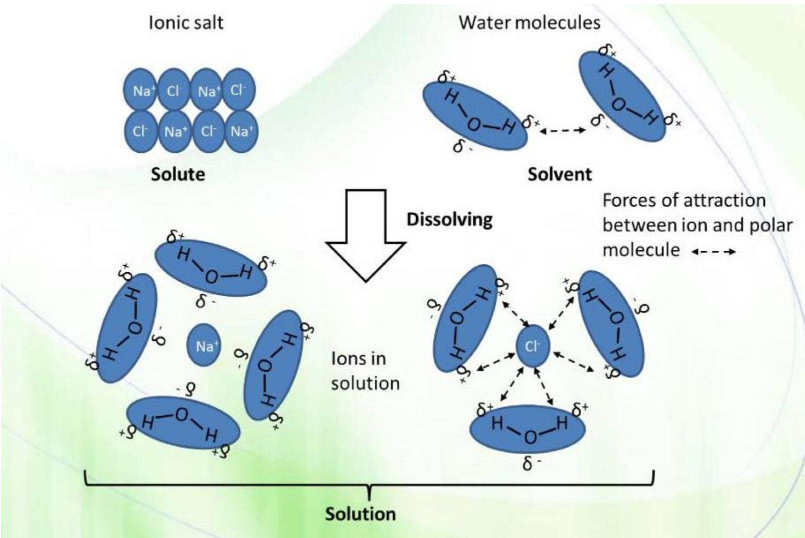
-Surface tension

*** H-bond has: A bond energy of 20 kj/mole and Life time 1x 10^{-9} second**

d. Water is an excellent solvent because It is small and has polar bonds and structure, so it weakens electrostatic forces and hydrogen bonding between polar molecules.

(Forms H-bonds with other polar molecules, thus acts as a solvent)

e. Water is electrically neutral (net charge is zero)



f. Bent geometry → dipole

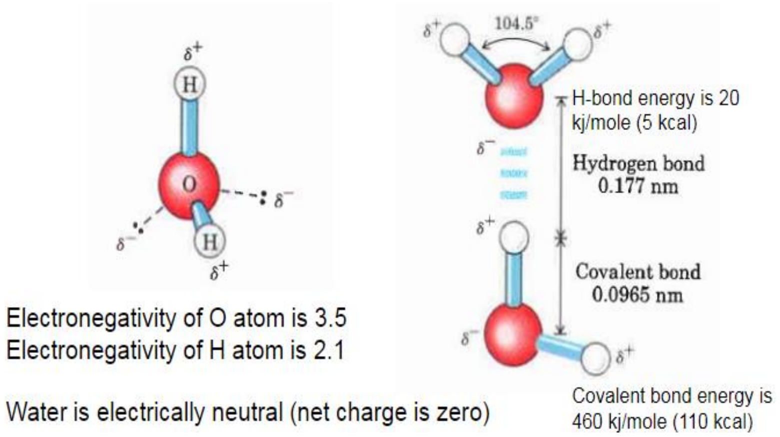
g. It is reactive because it is a nucleophile

Water and Thermal Regulation:

Water structure resists sudden and large temperature changes because:

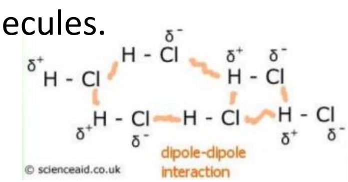
High thermal conductivity thus, facilitates heat dissipation from high energy consumption areas into the body water pool.

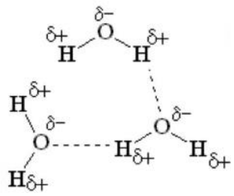
High heat of fusion, so a large drop in temperature is needed to convert liquid water to ice.



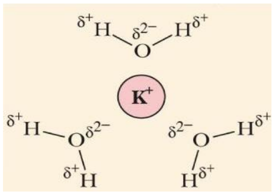
High heat capacity and heat of vaporization; when liquid water (sweating) is converted to a vapor. As a result of evaporation from the skin, we feel a cooling effect (water absorbs heat from our skin as it evaporates).

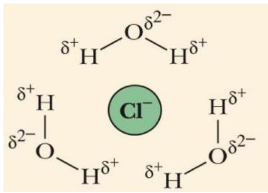
Dipole-dipole interaction: between polar molecules.



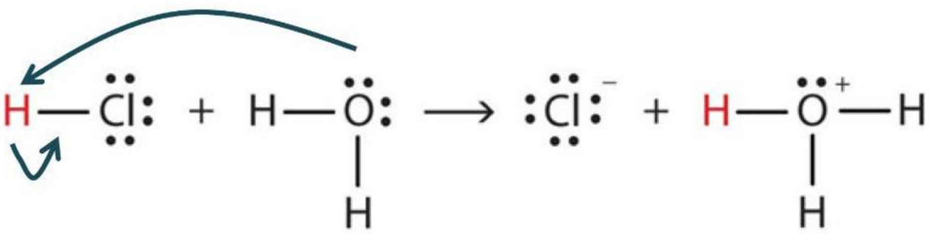


Dipole-charge interaction: interaction between real charge and partial charge.





- A nucleophile is an electron-rich molecule (likes protons (nucleus)) that is attracted to positively-charged or electron-deficient species (electrophiles).



h. Water molecules are ionized to become a positively-charged hydronium ion (simplified as proton but in reality, its H3O$^+$), and a negatively charged hydroxide ion (real charges).

$$H_2O + H_2O \rightleftharpoons H_3O^{\oplus} + OH^{\ominus}$$