INTRODUCTION TO BIOCHEMISTRY

QMA MEDICAL TEAM

Done by: Abdelhadi Okasha
WhatsApp: 00962792868475

تشمل كلام الدكتور مأمون والدكتورة ديالا

Summary for the whole lecture

1- Introduction

→ Biochemistry is the science concerned with studying various molecules that occur in living cells and organisms as well as their chemical reactions.
→ Why we study biochemistry? Know the chemical structures of biological molecules/ their interactions and organization/ their function/ understand bioenergetics
→ Biochemistry in medicine:
- Explains all disciplines
- diagnose and monitor diseases
- design drugs
- understand the molecular bases of diseases

2- Chemical elements in living creatures

→ Living organisms on Earth are composed mainly of 31 elements
→ Most abundant: C ,N,O,H
→ Less abundant: Ca,P
→ Those 6 elements forms most of body weight

3- Types of bonds

A- Covalent bonds

A1: **Important properties**
- Bond strength (amount of energy that must be supplied to break a bond)
- Bond length: the distance between two nuclei
- Bond orientation: bond angles determining the overall geometry of atoms (And it's length as well)
- have a lot of types ,such as single, double, and triple covalent/ Double bonds are stronger, shorter, and more orientally rigid than single bonds.

A2: **Polarity**
- polar covalent bonds (dipoles):
- electronegativity: The strength of attracting electrons
- The element which attracts the electrons gets a partial negative charge, while the one that partially loses its electrons gets a partial positive charge.
- e.g. Water, unlike CO_2, is an excellent example of a polar molecule because it is made up of O-H bonds which have a difference in electronegativity. Also, their orientation is not exactly opposite due to the presence of unshared electron pairs. Even though CO_2 has a difference in electronegativity, its 2 CO bonds are on directly opposite sides causing them to cancel out (linear or 180- degree angle).

B- Non-covalent bonds

B1: **Important properties**
- Reversible & Relatively weak. (10 times less than covalent)
-Molecules interact and bind specifically (they require special conditions for interactions to occur). Ex: Molecules should be properly oriented and close enough to each other for any interaction to occur, and for ionic interactions to occur, molecules should possess similar or different charges.
-Non covalent forces, even though weak, but the presence of large quantities significantly contribute to the structure stability, and functional competence of macromolecules in living cells.
-Can be either attractive or repulsive (ionic interactions between different charges are attractive and repulsive between similar charges)
-Involves interactions both within the biomolecule (ex: hydrogen bonds in large molecules), and between it and water in the surrounding environment (ex: hydrophobic interactions).

B2: **Types**
1st - Electrostatic interactions (charge-charge interactions):
- They are formed between two charged particles.
- These forces are quite strong in the absence of water

2nd -Hydrogen bonds A hydrogen atom is partly shared between two relatively electronegative atoms (a donor and an acceptor).
3rd - van der Waals interactions Unequal distribution of electronic charge around an atom changes with time. The strength of the attraction is affected by distance.
4th -Hydrophobic interactions: Self-association of nonpolar compounds in an aqueous environment

4- Carbon

It can form four bonds, which can be single, double, or triple bonds/ They link C atoms together in chains and rings. These serve as a backbones./ bonds have angles giving molecules three-dimensional structure./ In a carbon backbone, some carbon atoms rotate around a single covalent bond / The electronegativity of carbon is between other atoms. /Pure carbon is not water soluble

5- Properties of water (see slide 15)

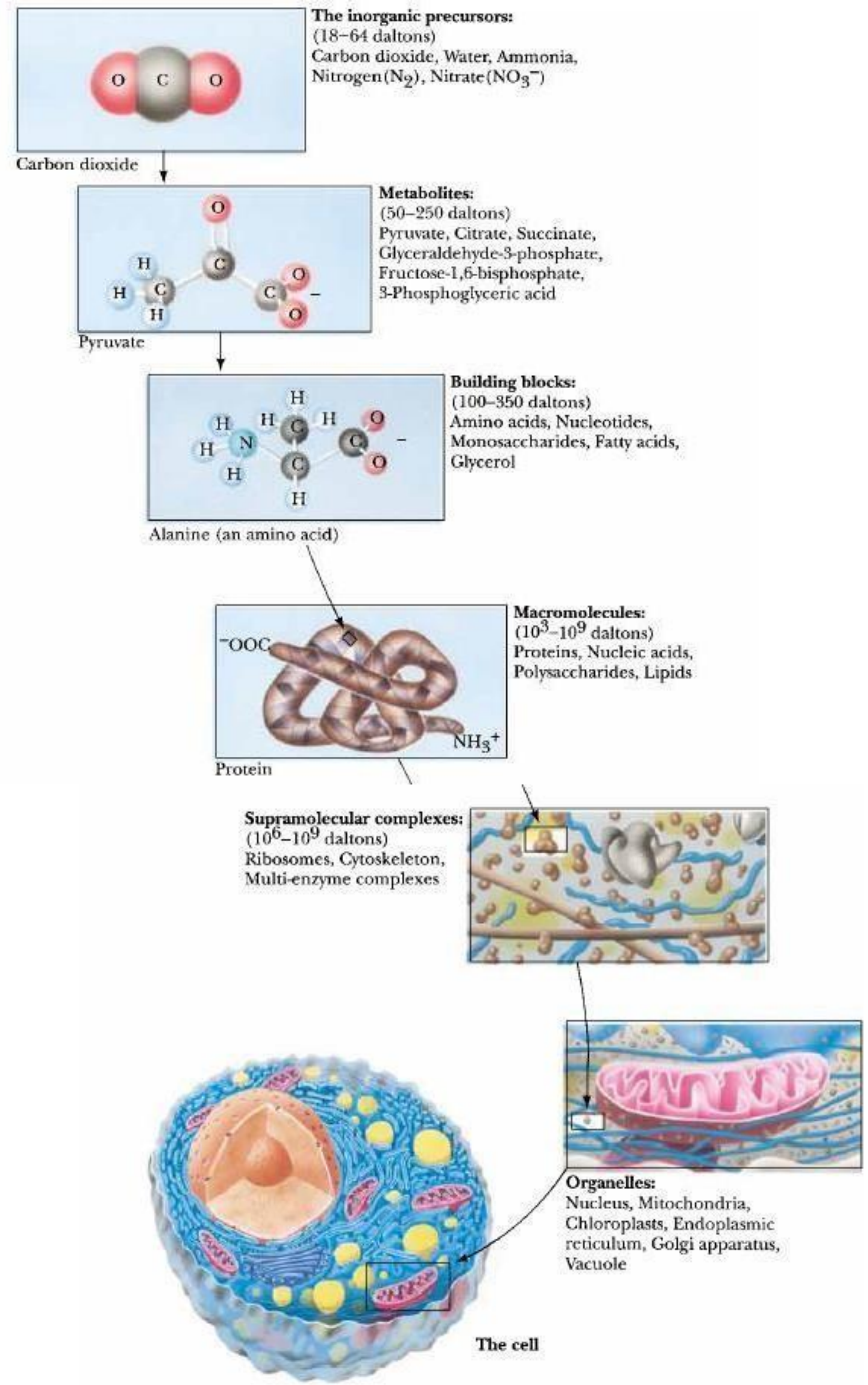
6- Acids and bases (See slide 18)

1- INTRODUCTION

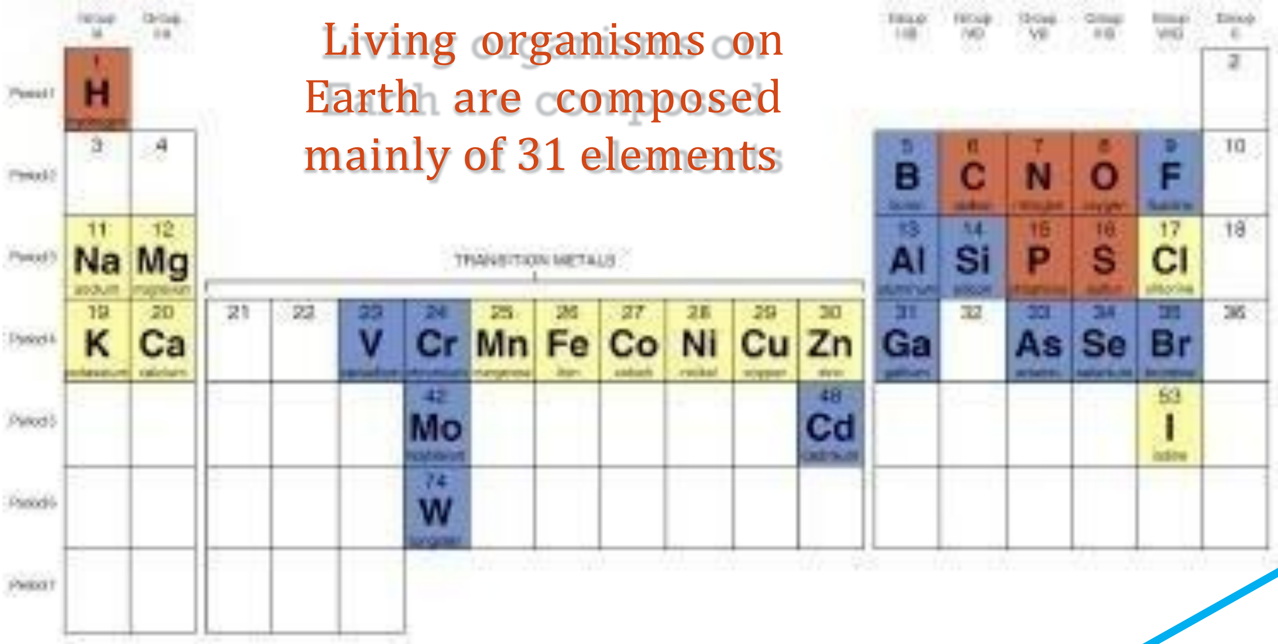
- What is Biochemistry?

  Biochemistry is the science concerned with studying various molecules that occur in living cells and organisms as well as their chemical reactions.

- For clarification: Biochemistry studies molecules and their relationships and interactions between each other in different biological systems (Plants, Animals, Human beings, etc…), but we will be focusing on human beings during this course.



1- INTRODUCTION



Living organisms on Earth are composed mainly of 31 elements

2- CHEMICAL ELEMENTS IN LIVING CREATURES

1st tier: Four primary elements (Most abundant elements in all organisms): Carbon, Hydrogen, Oxygen, and Nitrogen.
→ 96.5% of an organism's weight.

3rd: are minor, but essential, elements Mostly metals

Forms most of the organism weight:

C,Ca,P,N,H,O

2st tier: includes calcium and phosphorus
→ Less abundant but still very important

4th: minor amounts, but essential in **some organisms**

3- TYPES OF BONDS

A- Covalent bonds

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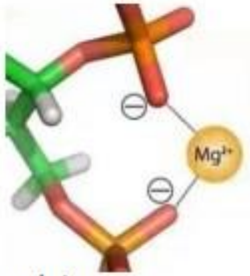
4th -Hydrophobic interactions: Self-association of nonpolar compounds in an aqueous environment

There are different types of non-covalent interactions:

1. **Electrostatic interactions** (charge-charge interactions) also called Ionic interactions.

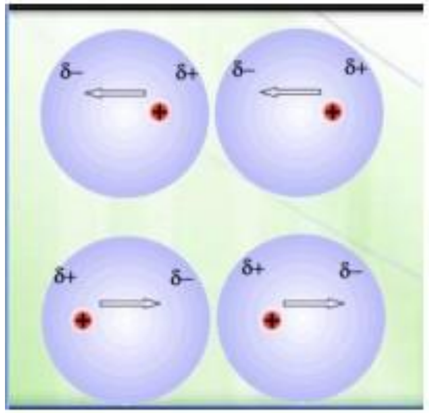
They are interactions between charged particles whether they have full or partial charge, different charges attract while similar charges repel. These forces are quite strong in the absence of water.



The larger the charges of the particles are, the larger the attraction and repulsion forces according to Coulomb's law. $F = k\frac{q_1 q_2}{r^2}$

3. **Van der Waals interactions**:

This interaction results from the movement of electrons present in orbits around the nuclei of an atom. At a specific time, electrons will move to a certain point making it relatively more negative, while other sides will be relatively more positive. When two or more atoms come closer to each other, the local negative areas in some atoms will be attracted to the local positive areas in other atoms.

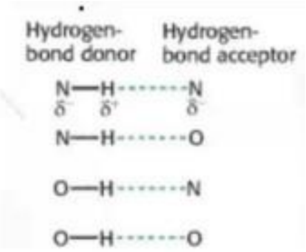


Weaker than the previous two types

Note: In chemistry, a nucleophile is a chemical species that forms bonds by donating an electron pair. While an electrophile is a chemical species that forms bonds with nucleophiles by accepting an electron pair.

2. **Hydrogen bonds:**

a special type of Electrostatic interactions (it's considered electrostatic because there are partial charges involved) also it can be considered as an independent type of interactions

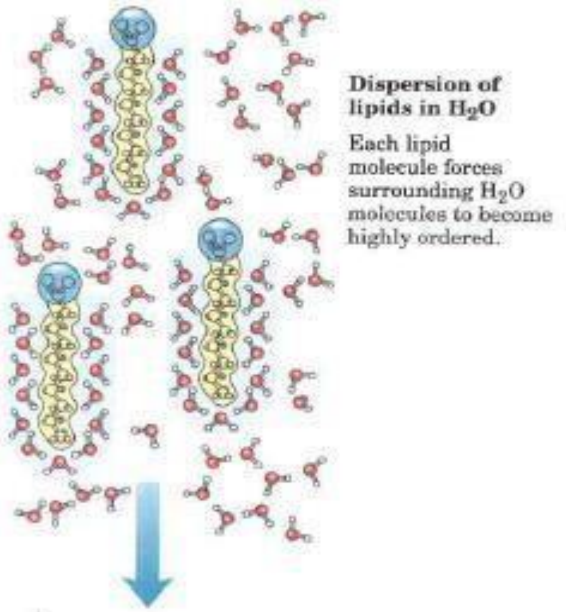


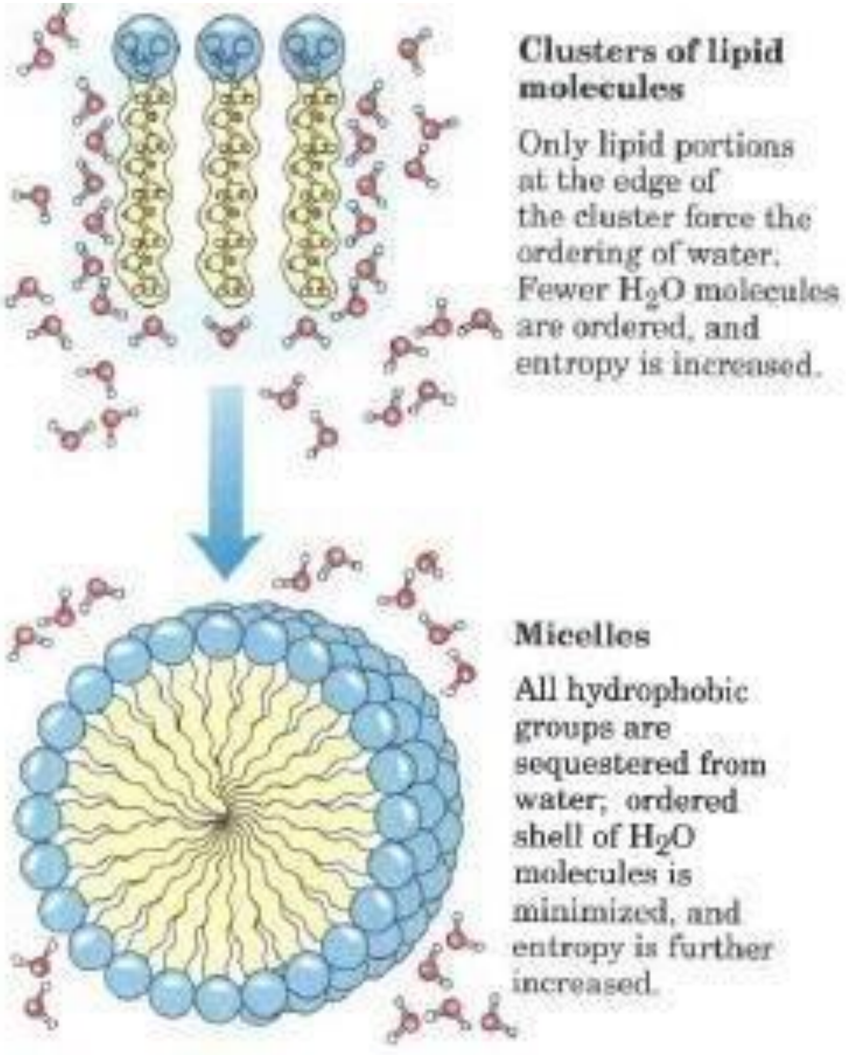
A hydrogen atom is partly shared between two relatively electronegative atoms (a donor and an acceptor). Hydrogen bond forms between a Hydrogen atom connected to a highly electronegative atom (hydrogen becomes + charged) and a negatively charged atom on another molecule.

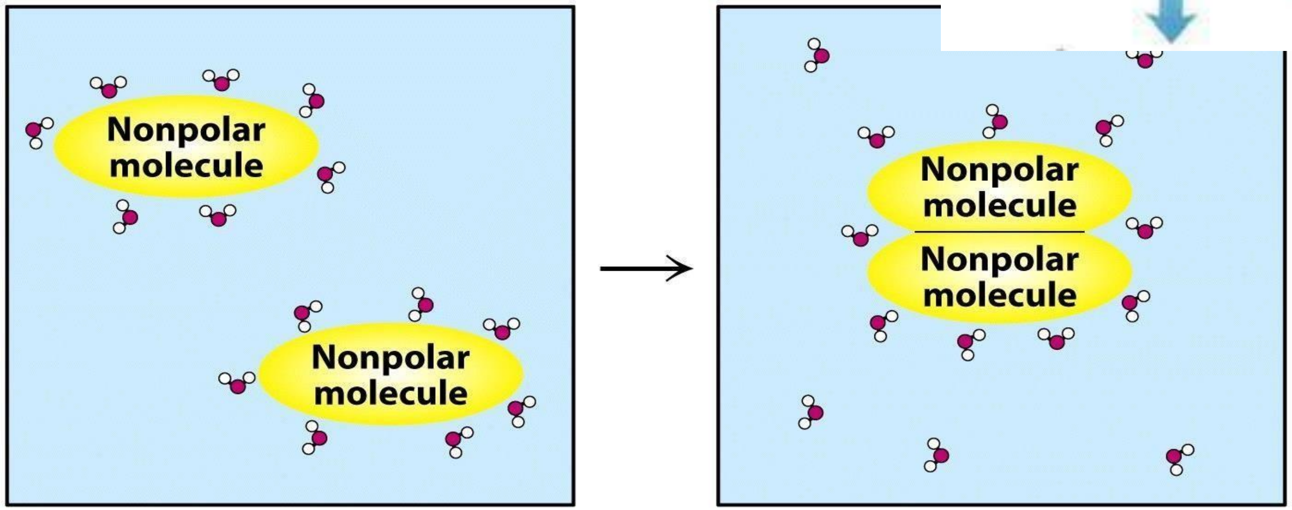
The donor partially donates the hydrogen atom and the acceptor accepts the hydrogen partially.

4- Hydrophobic interactions:

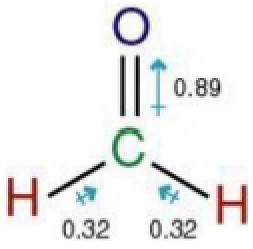
- Not true interactions
- Self-association of nonpolar compounds in an aqueous environment
- Minimize unfavorable interactions between nonpolar groups and water





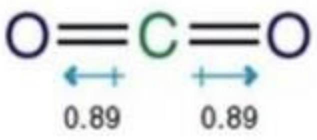


Examples of polarity in covalent bonds:



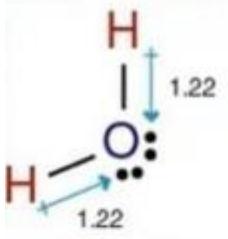
so, if we look at this example, we notice that there's a high difference in electronegativity between C & O, and since the electronegativity of Oxygen is much higher, the bond electrons will be closer to O rather than to C, so the O is going to get partial –ve charge (δ-) and the C is going to get partial +ve charge (δ+).

The bond between C-H is considered to be non-polar covalent, since the difference in electronegativity between them is so small (one third the difference between C-O), so there won't be any δ- or δ+ at all.



The geometry plays an important role in the molecule polarity, notice that the C-O bonds in the molecule are polar, but the whole molecule is NOT, why?

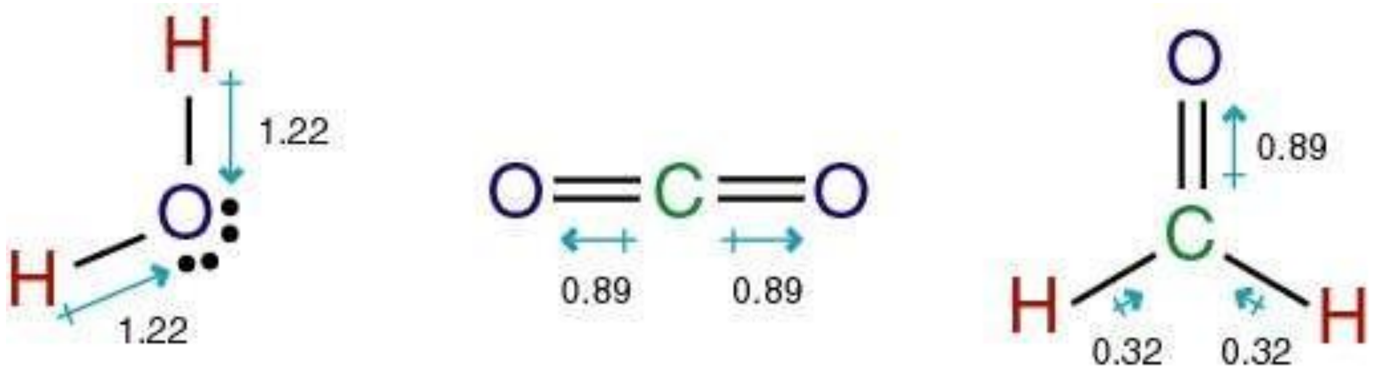
Because the best way to distribute O atoms around C atom and maintaining them as far as possible is linearly(180°).According to this, 2 oxygen atoms of equal electronegative pull the electron density from carbon from either direction. Thus, net pulling =0.



lone pair of electrons on the Oxygen atom are going to repulse due to negative charges. To prevent this, molecule bents which gives them more space, which means that molecule is not linear and H atoms don't oppose each other. According to this, pulling forces are not canceled and molecule is polar.

- Covalent bonds in which the electrons are shared unequally in this way are known as polar covalent bonds. The bonds are known as “dipoles”.
  - Oxygen and nitrogen atoms are electronegative
  - Oxygen and hydrogen
  - Nitrogen and hydrogen
  - Not carbon and hydrogen

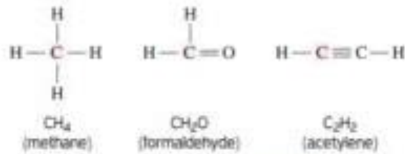
Water is an excellent example of polar molecules, but not CO_2.



4- CARBON

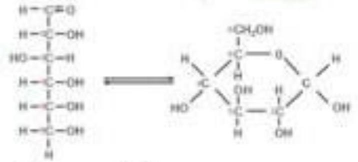
Carbon and its properties.

-It can form four bonds, which can be single, double, or triple bonds (each of which have different lengths, strengths ,etc…).



-Each bond Is very stable.

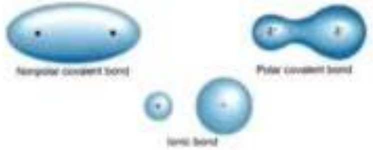
-The bonds link C atoms together in chains (linear array) and rings (they serve as the backbone of organic molecules).



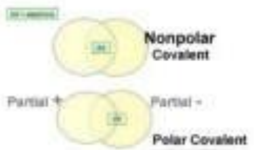
-Carbon bonds have angles giving molecules three-dimensional structures [the angle depends on the type of bond (single, double, triple) and the presence of unshared electrons].

-In a carbon backbone, some carbon atoms rotate around single covalent bonds producing molecules of different shapes (isomers).

-The electronegativity of carbon is between other atoms (it can form polar AND non-polar molecules).



-Pure carbon is not water soluble, but when carbons form covalent bonds with other elements like O or N, the resulting molecule becomes soluble.



Class of Compound	General Structure[a]	Functional Group Structure	Functional Group Name	Example
Alkane	RCH_2-CH_3	$-\underset{H}{\overset{\vert}{\underset{\vert}{C}}}-\underset{H}{\overset{\vert}{\underset{\vert}{C}}}-$	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	$\begin{matrix}H_3C\\ H_3C\end{matrix}>C=NH$
Aldehyde	$R-\overset{O}{\overset{\Vert}{C}}-H$	$-\overset{O}{\overset{\Vert}{C}}-H$	Carbonyl group	$CH_3C\begin{matrix}{/\!\!/}O\\ \backslash H\end{matrix}$
Ketone	$R-\overset{O}{\overset{\Vert}{C}}-R$	$-\overset{O}{\overset{\Vert}{C}}-$	Carbonyl group	$CH_3\overset{O}{\overset{\Vert}{C}}CH_3$
Carboxylic acid[b]	$R-COOH$	$-\overset{O}{\overset{\Vert}{C}}-OH$	Carboxyl group	$CH_3C\begin{matrix}{/\!\!/}O\\ \backslash OH\end{matrix}$

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]	$HO-\overset{O}{\overset{\|}{P}}(OH)-OH$	$HO-\overset{O}{\overset{\|}{P}}(OH)-OH$	Phosphoric acid group	$HO-\overset{O}{\overset{\|}{P}}(OH)-OH$
Phosphoric acid ester[b]	$R-O-\overset{O}{\overset{\|}{P}}(OH)-OH$	$-O-\overset{O}{\overset{\|}{P}}(OH)-OH$	Phosphoester group or phosphoryl group	$CH_3O\overset{O}{\overset{\|}{P}}(OH)-OH$
Phosphoric acid anhydride[b]	$R-O-\overset{O}{\overset{\|}{P}}(OH)-O-\overset{O}{\overset{\|}{P}}(OH)-OH$	$-O-\overset{O}{\overset{\|}{P}}(OH)-O-\overset{O}{\overset{\|}{P}}(OH)-OH$	Phosphoric anhydride group	$CH_3O-\overset{O}{\overset{\|}{P}}(OH)-O-\overset{O}{\overset{\|}{P}}(OH)-OH$
Carboxylic acid–phosphoric acid mixed anhydride[b]	$R-\overset{O}{\overset{\|}{C}}-O-\overset{O}{\overset{\|}{P}}(OH)-OH$	$-\overset{O}{\overset{\|}{C}}-O-\overset{O}{\overset{\|}{P}}(OH)-OH$	Acyl-phosphoryl anhydride	$CH_3\overset{O}{\overset{\|}{C}}-O-\overset{O}{\overset{\|}{P}}(OH)-OH$

[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.

5- PROPERTIES OF WATER

1- Water is a polar molecule as a whole because of:

a) The different electronegativity between hydrogen and oxygen

b) It is angular because of two unshared pairs of electrons

2- Water is highly cohesive and can form a network due to the formation of hydrogen bonds

5- Water molecules are ionized to become a positively-charged hydronium ion (or proton), and a hydroxide ion

3Water is an excellent solvent because It is small and it weakens electrostatic forces and hydrogen bonding between polar molecules. (O with positive ions and H with negative ones)

(H-bond is stronger if X—H A

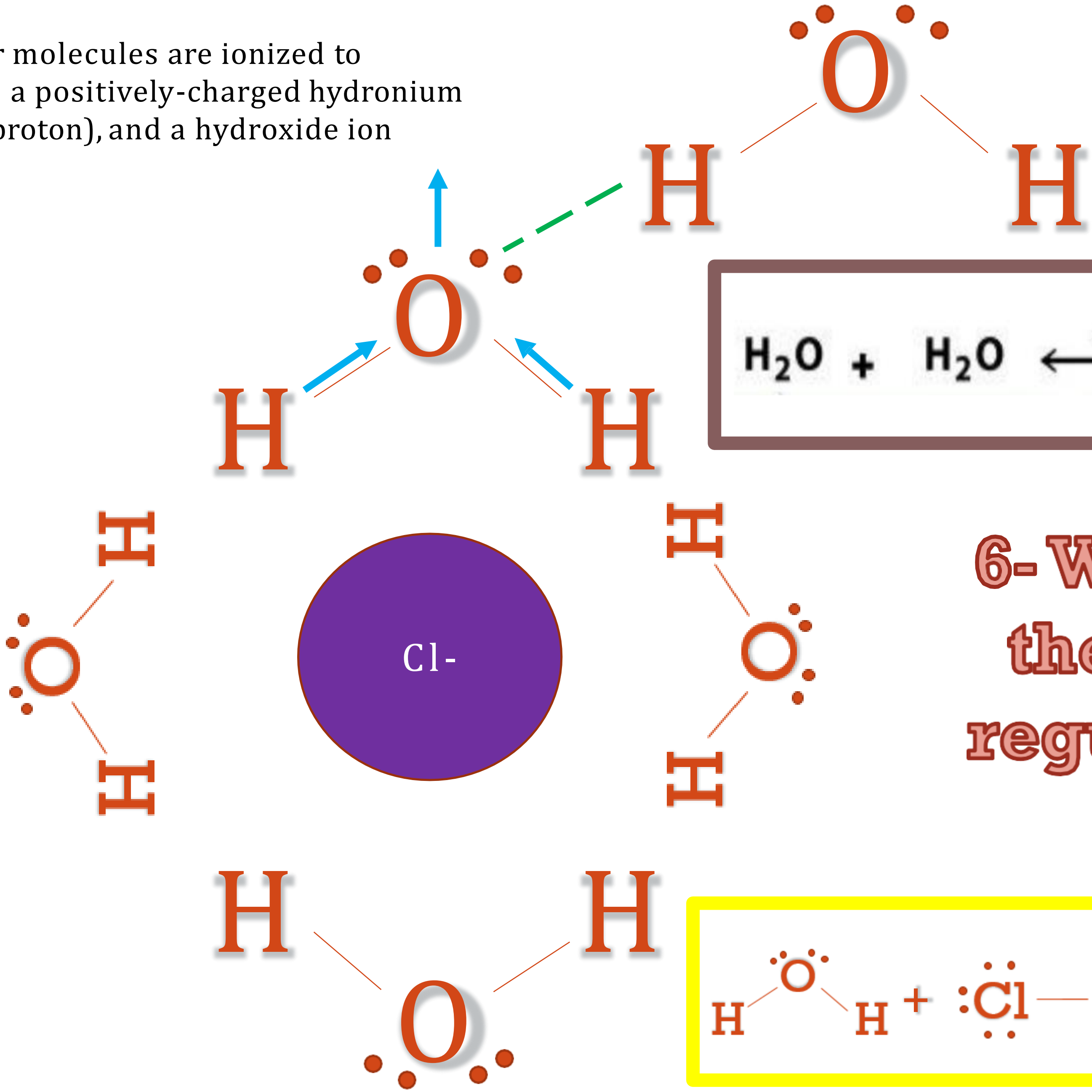
A is O, N or

F X is O, N or F

Average number of H-bond in liquid water at 10°C is 3.4 in ice crystals is 4

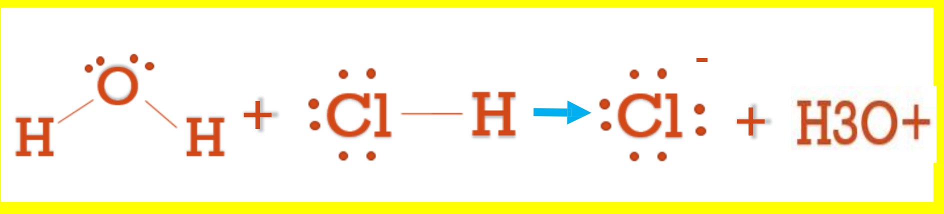
Number of H-bonds decrease with higher temperatures)

4It is reactive because it is a nucleophile. A nucleophile is an electron-rich molecule that is attracted to positively-charged or electron-deficient species (electrophiles)



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

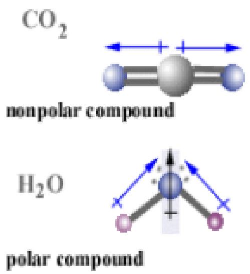
6- Water & thermal regulation



1- Water is a polar molecule as a whole because of:

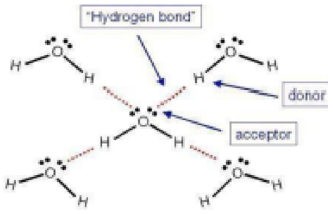
a) The different electronegativity between hydrogen and oxygen

b) It is angular(As said before, water molecules have two unshared pairs of electrons that causes the bending of the molecule and results in an angle between the hydrogen and oxygen, leading to the formation of a polar molecule because the forces are not completely in opposite directions so they don't cancel out.



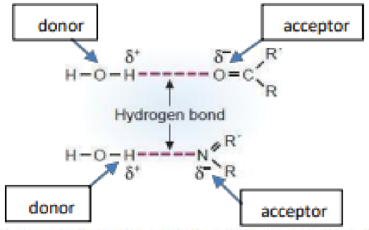
2- Water is highly cohesive due to the formation of hydrogenbonds which causes point 3.

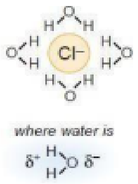
3- Water molecules produce a network (in this case, the oxygen atom is the hydrogen acceptor, and the hydrogen itself acts as a hydrogen donor).

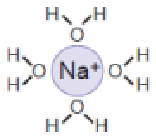


4- Water is an excellent solvent because it is small and it weakens electrostatic forces and hydrogen bonding between polar molecules

*Dissolution is a process of hydrogen bond formation between water molecules and a different type of solute with water acting as a doner and solute as acceptor.

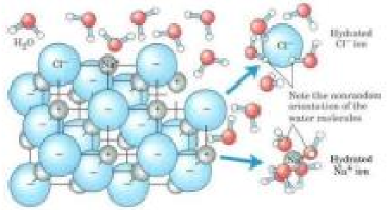




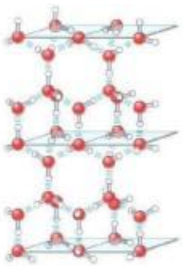


Dissolution of ionic compounds like NaCl, we start with a solid organized crystal in water, water molecules will start to interweave in between the Na+ and Cl- causing them to dissolve away from the crystal, which result in ionizing them. Then water molecules will form hydration shells around both ions, that have different sizes and shapes.

Oxygen (which has a partial negative charge) is going to be close to the Na+ whereas Hydrogen (which has a partial positive charge) would be closer to the Cl-.



Hydrogen bonds between water molecules:



Average number of H-bonds in liquid water at 10°C is 3.4, while in ice crystals it's 4.

***What do we mean by a 3.4 hydrogen bond?**

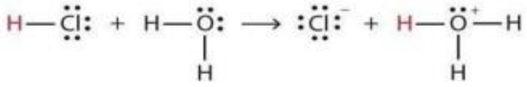
There is no 0.4 hydrogen bond. Hydrogen bonds form and breaks all the time in a nanosecond; however, each water molecule is surrounded by 3.4 hydrogen bonds as an average in liquid state.

*As temperature increases, molecules will gain more energy (kinetic energy will increase), therefore, molecules will move faster and get away from each other so, **the distance increases** in between , thereby making the formation of hydrogen bonds harder whereas in lower temperature, the water molecules are organized in crystals so they have little to no mobility which causes the formation of many hydrogen bonds. (More temperature=less hydrogen bonding)

5- It is reactive because it is a nucleophile

As we said before, water molecules may contribute as a participant in reaction, they act as **nucleophile**

A nucleophile is an electron-rich molecule that is attracted to positively-charged or electron-deficient species (electrophiles). (Nucleo: derived from nucleus, Phile: likes)



*A water molecule has two unshared pairs of electrons making it highly electron-rich and nucleophilic, causing it to attack **positively charged** atoms or molecules such as hydrogen.

6- water molecules are ionized to become a positively charged hydronium ion (or proton),and a hydroxide ion:

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

Ionizing one water molecule will gives off OH- and H+ (if 2 water molecules are ionized, it gives off OH- and H3O+)

This will be important when we talk about acids and bases in later lectures.

water's structure allows it to resist sudden and large temperature changes.

The thermal regulation and resistance are due to:
1- high thermal conductivity thus, water facilitates heat dissipation from high energy consumption areas into the body water pool. The heat doesn't just stay in small heatedareas in your body, it's conducted and shared by all the water in your body).

2- high heat of fusion, so large drop in temperature is needed to convert liquid water to ice. (Not only does water resist an increase in temperature, but it also resists a decreasein temperature and crystallization into ice).

3- high heat capacity and heat of vaporization; large amount of energy is absorbed when liquid water (sweating) is converted to a gas and evaporates from the skin, that's why we feel a cooling effect

Specific heat is the amount of energy required to raise/decrease the temperature of 1g of a substance by 1 degree Celsius.

Heat of vaporization is the amount of energy required to convert 1g of water from the liquid state to the gas state.

Example: if you go outside and it is 50 degrees Celsius your body will not reach that temperature because much of it is going to get dissipated to raise the temperature of the water in the body by a very small amount of increase (water inside the body requires large quantities of heat to change its temperature).
furthermore, when you're sweating, water which is a major constituent of sweat absorbs a very large amount of heat on your skin and evaporates leaving a cooling effect.

6- Acids and bases

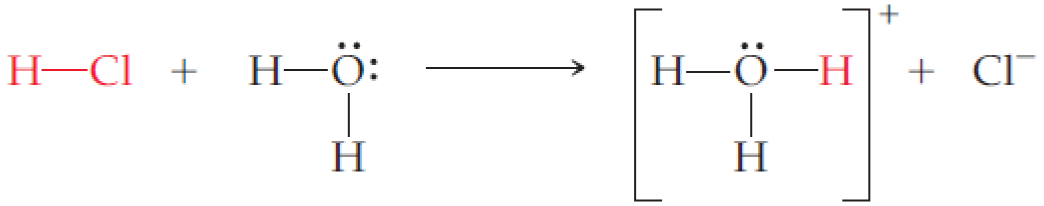
Acid: a substance that produces H^+ when dissolved in water
Base: a substance that produces OH^- when dissolved in water.

The Brønsted-Lowry acid: any substance (proton donor) able to give a hydrogen ion or a proton (H^+) to another molecule.
Brønsted-Lowry base: any substance that accepts a proton (H^+) from an acid.

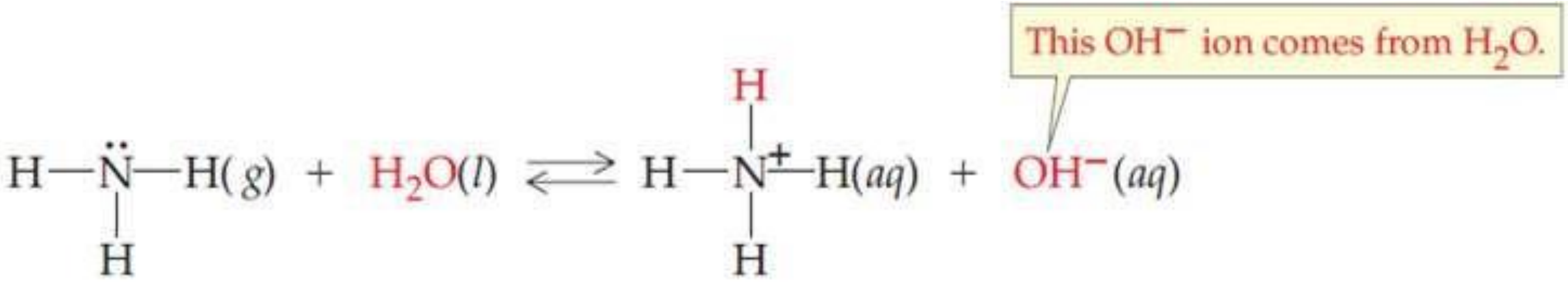
Water is amphoteric, it acts sometimes as an acid and sometimes as a base

Brønsted-Lowry acids and bases

- Acid: a substance that produces H^+ when dissolved in water
  - H^+ Reacts with water producing hydronium ion (H_3O^+).



- Base: a substance that produces OH^- when dissolved in water.



Types of acids and bases

- The Brønsted-Lowry acid: any substance (proton donor) able to give a hydrogen ion or a proton (H^+) to another molecule.
  - Monoprotic acid: HCl, HNO_3, CH_3COOH
  - Diprotic acid: H_2SO_4
  - Triprotic acid: H_3PO_3
- Brønsted-Lowry base: any substance that accepts a proton (H^+) from an acid.
  - $NaOH$, NH_3, KOH

Water = amphoteric

- Substances that can act as an acid in one reaction and as a base in another are called **amphoteric substances.**
  - **Example: water**
- With ammonia (NH_3), water acts as an acid because it donates a H^+ to NH_3.

$$NH_3 + H_2O \leftrightarrow NH_4^+ + OH^-$$

- With hydrochloric acid, water acts as a base.

$$HCl + H_2O \rightarrow H_3O^+ + Cl^-$$

Ampho = 'both' or 'dual'

Acid/base strength

- Acids differ in their ability to release protons.
  - Strong acids dissociate 100%.
- Bases differ in their ability to accept protons.
  - Strong bases have a strong affinity for protons.
- For multi-protic acids (H_2SO_4, H_3PO_4), each proton is donated at different strengths.