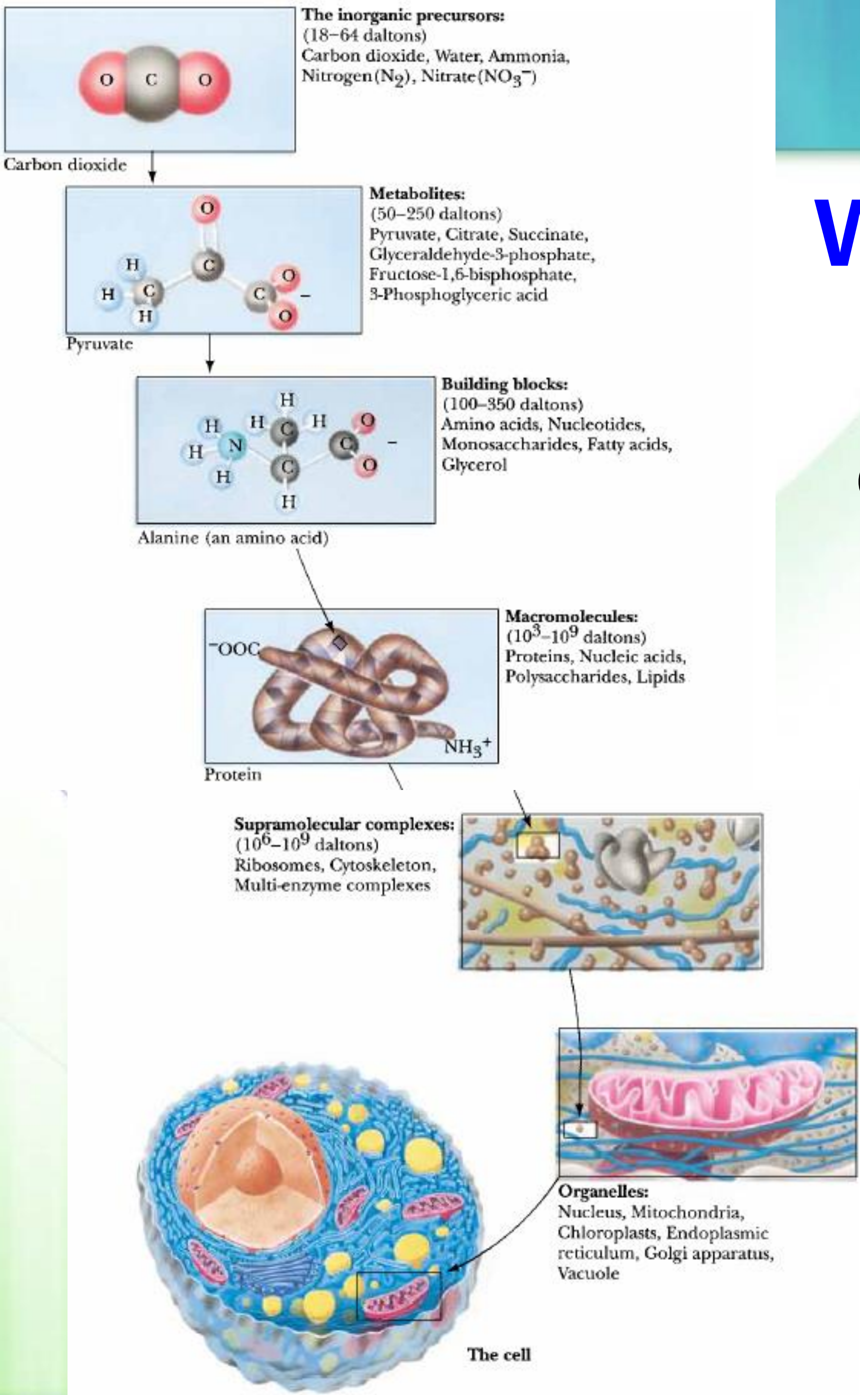
Introduction to Biochemistry



What is Biochemistry?

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

Garret *et al*

Biochemistry = understanding life

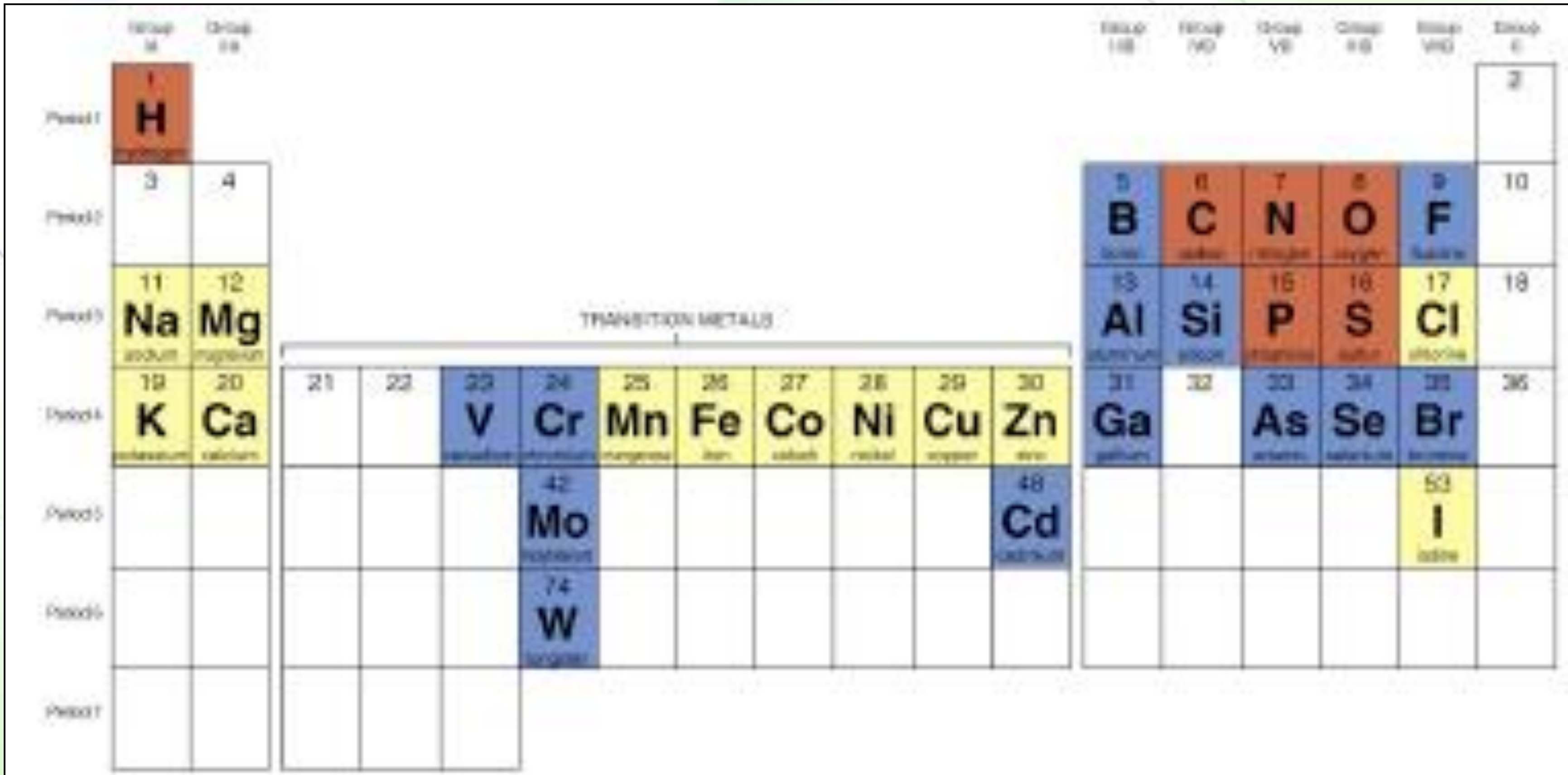
- Know the chemical structures of biological molecules
- Understand the biological function of these molecules
- Understand interaction and organization of different molecules within individual cells and whole biological systems
- Understand bioenergetics (the study of energy flow in cells)

Biochemistry in medicine:

- ***Explains all disciplines***
- ***diagnose and monitor diseases***
- ***design drugs (new antibiotics, chemotherapy agents)***
- ***understand the molecular bases of diseases***

Chemical elements in living creatures

- Living organisms on Earth are composed mainly of 31 elements



Abundant elements

- Four primary elements: carbon, hydrogen, oxygen, and nitrogen
  - 96.5% of an organism's weight
- The second groups includes sulfur and phosphorus
- Most biological compounds are made of only SIX elements: C, H, O, N, P, S
- Others are minor, but essential, elements
  - Mostly metals

Element	Comment
First Tier	
Carbon (C)	Most abundant in *all* organisms
Hydrogen (H)	
Nitrogen (N)	
Oxygen (O)	
Second Tier	
Calcium (Ca)	Much less abundant but found in *all* organisms
Chlorine (Cl)	
Magnesium (Mg)	
Phosphorus (P)	
Potassium (K)	
Sodium (Na)	
Sulfur (S)	
Third Tier	
Cobalt (Co)	Metals present in small amounts in *all organisms* and essential to life
Copper (Cu)	
Iron (Fe)	
Manganese (Mn)	
Zinc (Zn)	
Fourth Tier	
Aluminum (Al)	Found in or required by *some* organisms in trace amounts
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)	

Important properties of bonds

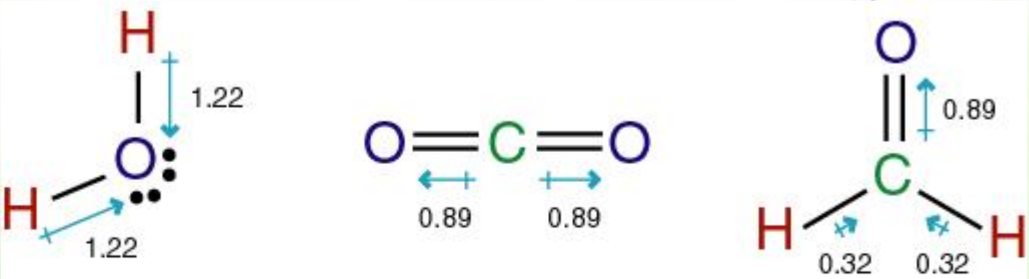
- *Bond strength* (amount of energy that must be supplied to break a bond)
- Bond length: the distance between two nuclei
- Bond orientation: bond angles determining the overall geometry of atoms

The three-dimensional structures of molecules are specified by the bond angles and bond lengths for each covalent linkage

Polarity of covalent bonds

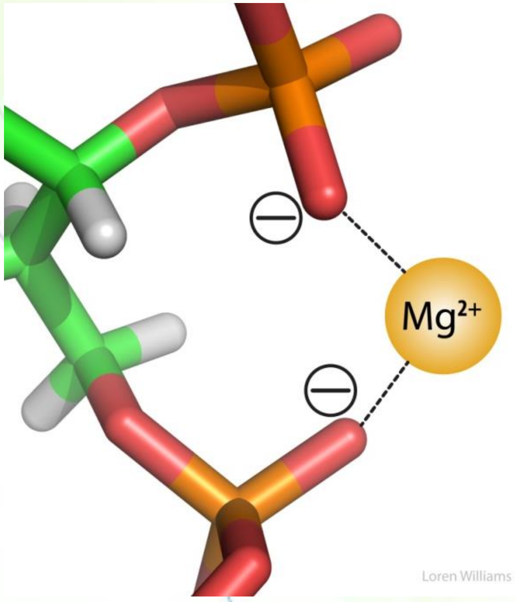
- Covalent bonds in which the electrons are shared unequally in this way are known as polar covalent bonds. The bonds are known as “dipoles”.
  - Oxygen and nitrogen atoms are electronegative
  - Oxygen and hydrogen
  - Nitrogen and hydrogen
  - Not carbon and hydrogen

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



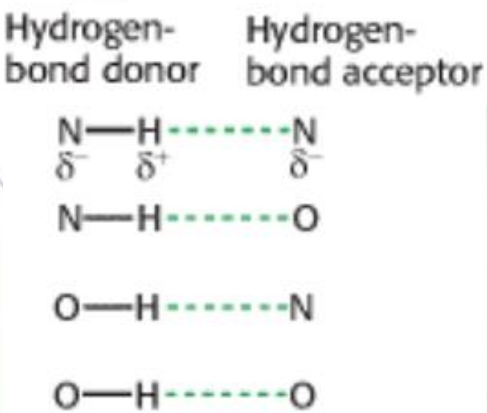
Non-covalent interactions

- They are reversible and relatively weak.



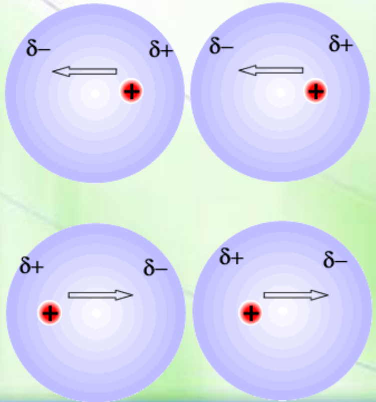
Electrostatic interactions **(charge-charge interactions):**

- **They are formed between two charged particles.**
- **These forces are quite strong in the absence of water .**



Hydrogen bonds

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



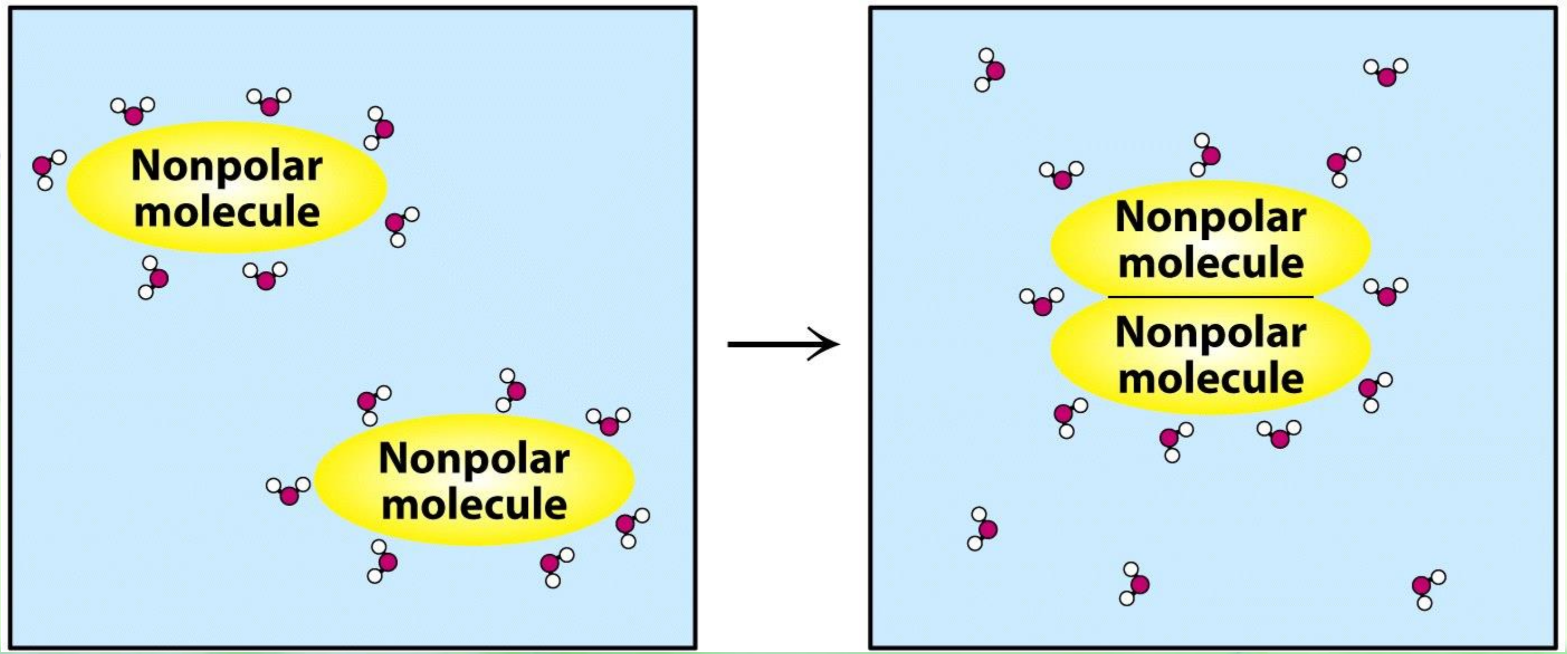
van der Waals interactions

Unequal distribution of electronic charge around an atom changes with time.

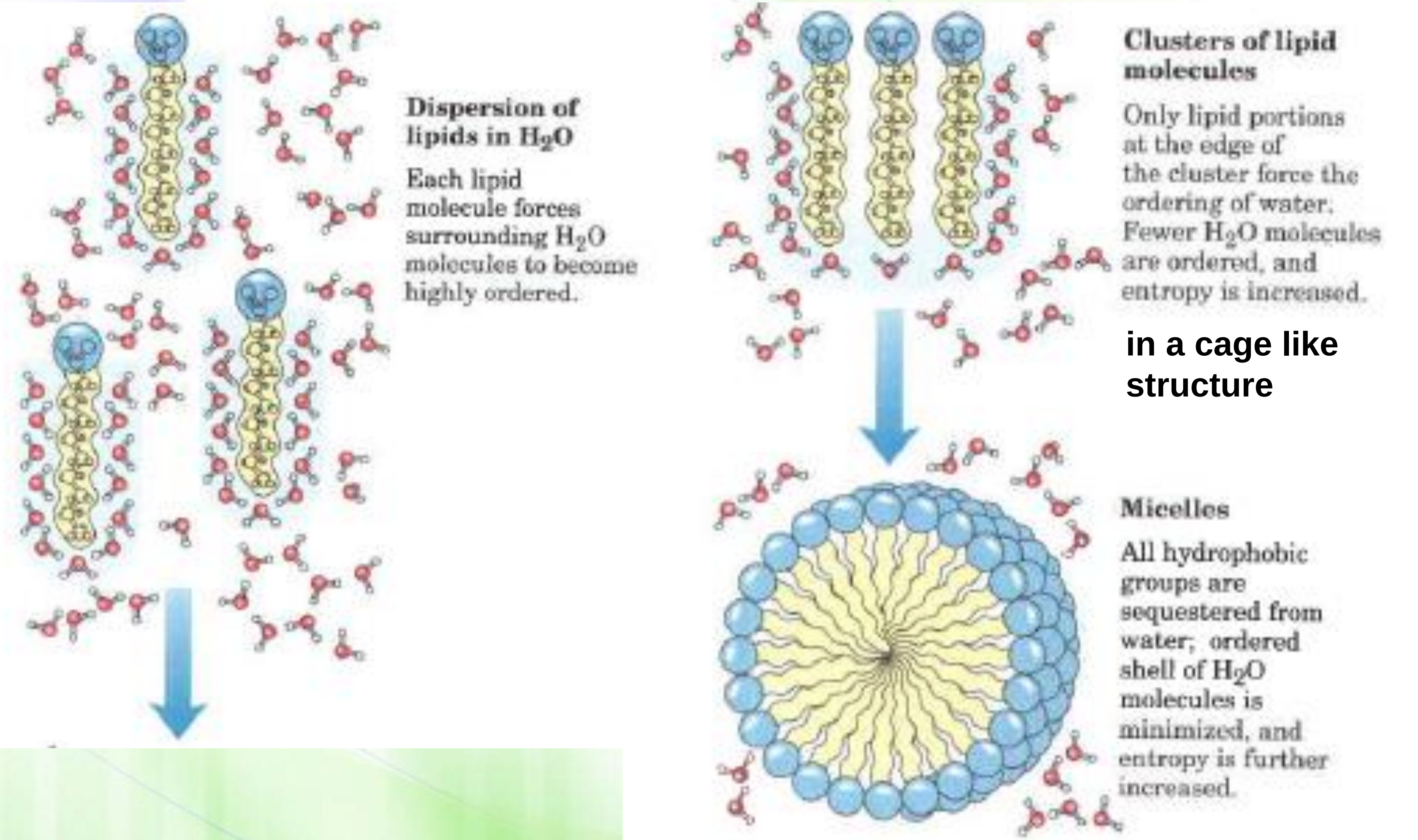
The strength of the attraction is affected by distance.

Hydrophobic interactions

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



Hydrophobic interactions and micelle formation



in a cage like structure

Properties of non covalent Interactions

- Reversible
- 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.

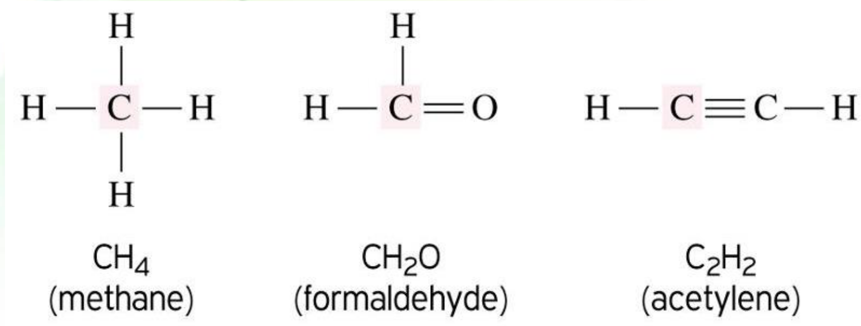
- Can be either attractive or repulsive
- Involve interactions both within the biomolecule and between it and the water of the surrounding environment.

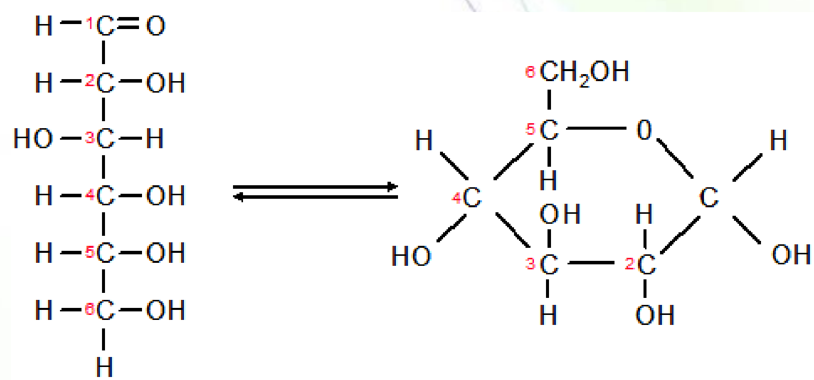
Carbon

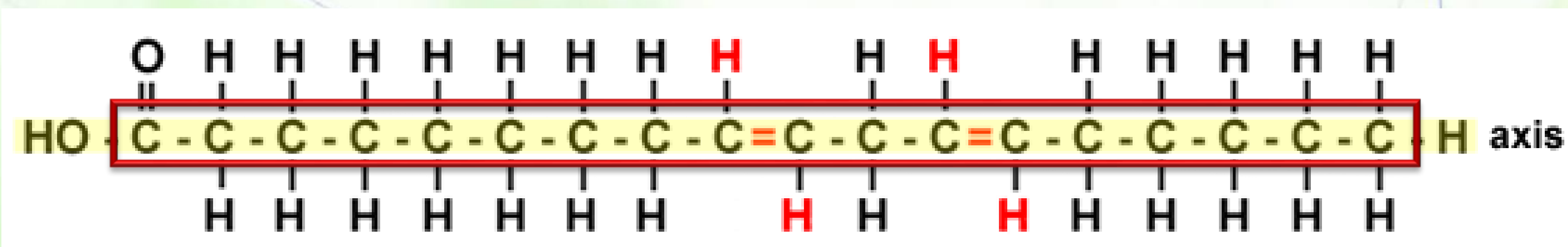
The road to diversity and stability

Properties of carbon (1)

- It can form four bonds, which can be single, double, or triple bonds.
- Each bond is very stable.
  - strength of bonds: triple > double > Single)
- They link C atoms together in chains and rings.
  - These serve as a backbones.



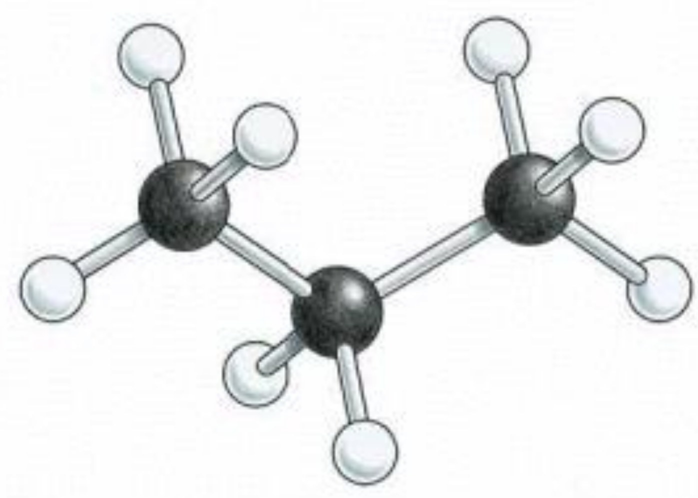




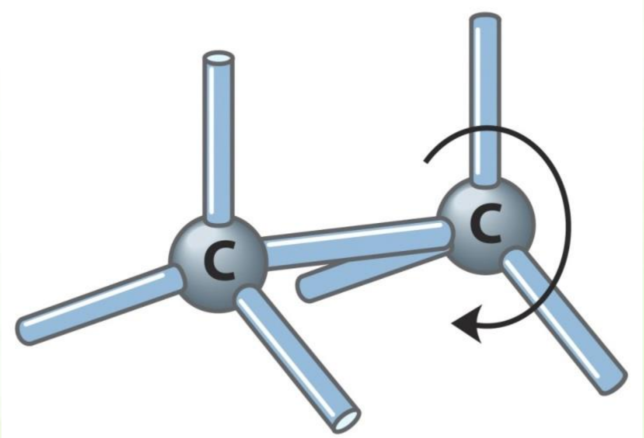
Properties of carbon (2)

- Carbon bonds have angles giving molecules three-dimensional structure.

- In a carbon backbone, some carbon atoms rotate around a single covalent bond producing molecules of different shapes.

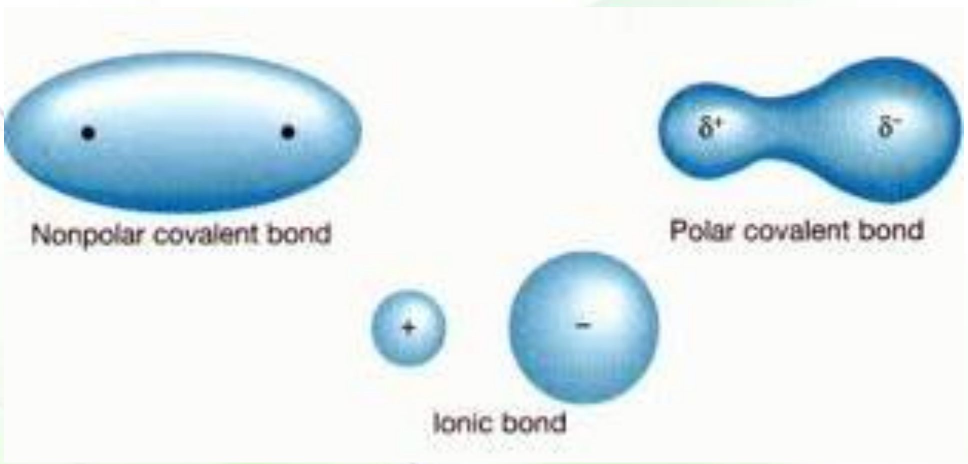


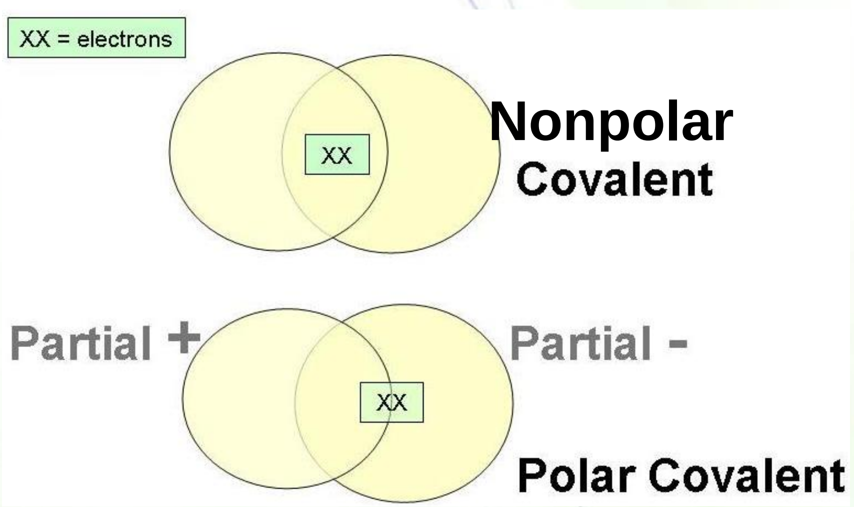
propane (CH_3-CH_2-CH_3)



Properties of carbon (3)

- The electronegativity of carbon is between other atoms.
  - 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 that makes carbon compounds to be soluble.





Functional groups (Groups of atoms attached to a carbon skeleton)

Class of Compound	General Structure[a]	Functional Group Structure	Functional Group Name	Example
Alkane	$RCH_2—CH_3$	—C(H)—C(H)—	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—C(=O)—H	—C(=O)—H	Carbonyl group	$CH_3C(=O)H$
Ketone	R—C(=O)—R	—C(=O)—	Carbonyl group	$CH_3C(=O)CH_3$
Carboxylic acid[b]	R—COOH	—C(=O)—OH	Carboxyl group	$CH_3C(=O)OH$

Ester	$R-C(=O)-OR$	$-C(=O)-OR$	Ester group	$CH_3C(=O)-OCH_3$
Amide	$R-C(=O)-NH_2$	$-C(=O)-N(H)H$	Amide group	$CH_3C(=O)-NH_2$
Phosphoric acid[b]	$HO-P(=O)(OH)-OH$	$HO-P(=O)(OH)-OH$	Phosphoric acid group	$HO-P(=O)(OH)-OH$
Phosphoric acid ester[b]	$R-O-P(=O)(OH)-OH$	$-O-P(=O)(OH)-OH$	Phosphoester group or phosphoryl group	$CH_3OP(=O)(OH)-OH$
Phosphoric acid anhydride[b]	$R-O-P(=O)(OH)-O-P(=O)(OH)-OH$	$-O-P(=O)(OH)-O-P(=O)(OH)-OH$	Phosphoric anhydride group	$CH_3O-P(=O)(OH)-O-P(=O)(OH)-OH$
Carboxylic acid–phosphoric acid mixed anhydride[b]	$R-C(=O)-O-P(=O)(OH)-OH$	$-C(=O)-O-P(=O)(OH)-OH$	Acyl-phosphoryl anhydride	$CH_3C(=O)-O-P(=O)(OH)-OH$

[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.

Water

Why <u>water</u> is important to our bodies?

1. ~60% of our body is water, 70-85% of the weight of a typical cell

2. A solvent of many substances our bodies need such as glucose, ions, etc.

3. Acts as a medium in which acids and bases release their chemical groups to maintain a constant cellular environment or homeostasis.

4. Essential buffer that maintain pH

5. Temperature regulation- high specific heat capacity.

6. A participant in many biochemical reactions.

Water distribution in body compartments

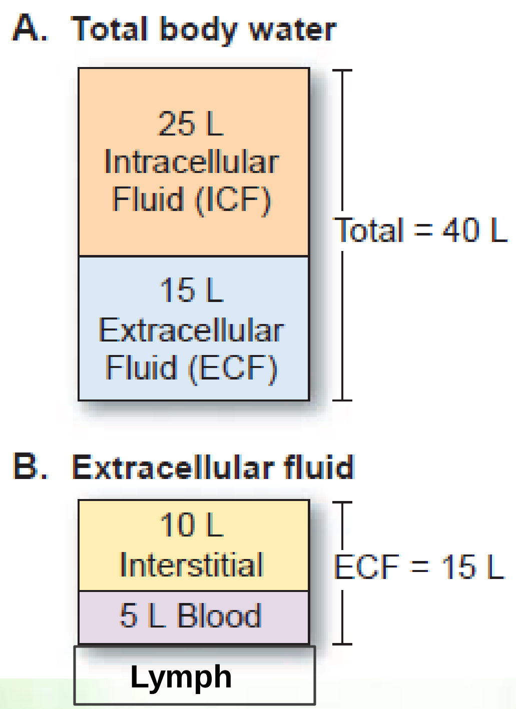
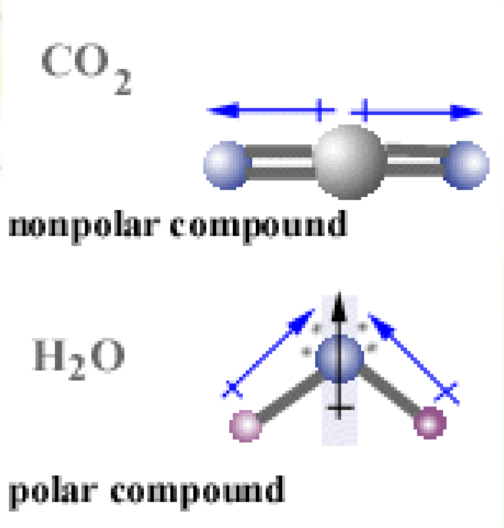


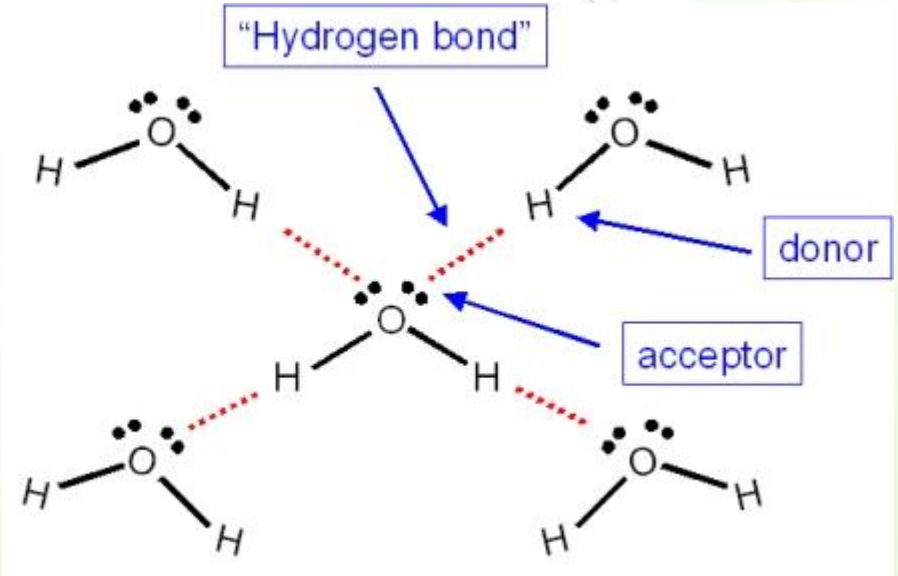
FIG. 4.2. Fluid compartments in the body based on an average 70-kg man.

Mark's 2012

Properties of water (1)

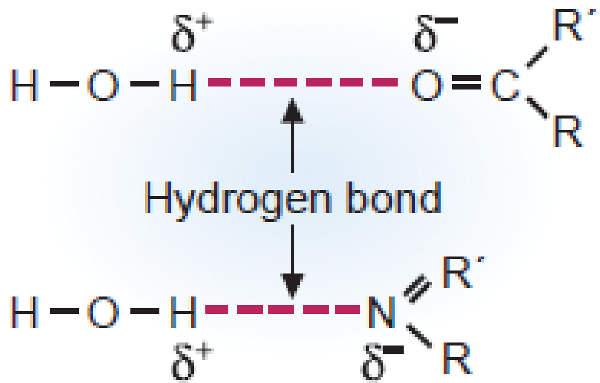
- Water is a polar molecule as a whole because of:
  - the different electronegativitiy between Hydrogen and oxygen,
  - It is angular.
- Water is highly cohesive.
- Water molecules produce a network.



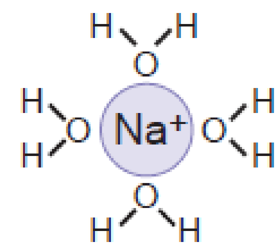


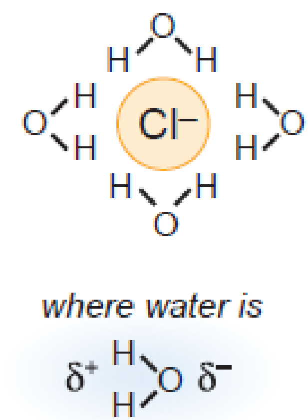
Properties of water (2)

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

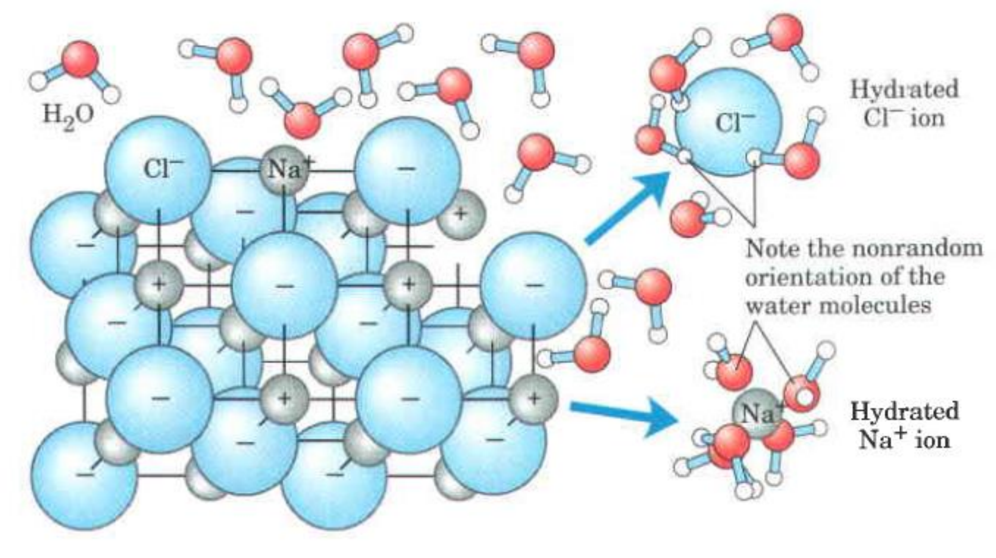


H-bonds between water and polar molecules. *R denotes additional atoms*.





Hydration shells surrounding anions and cations.



Hydrogen Bonds (H-bonds) between Water Molecules

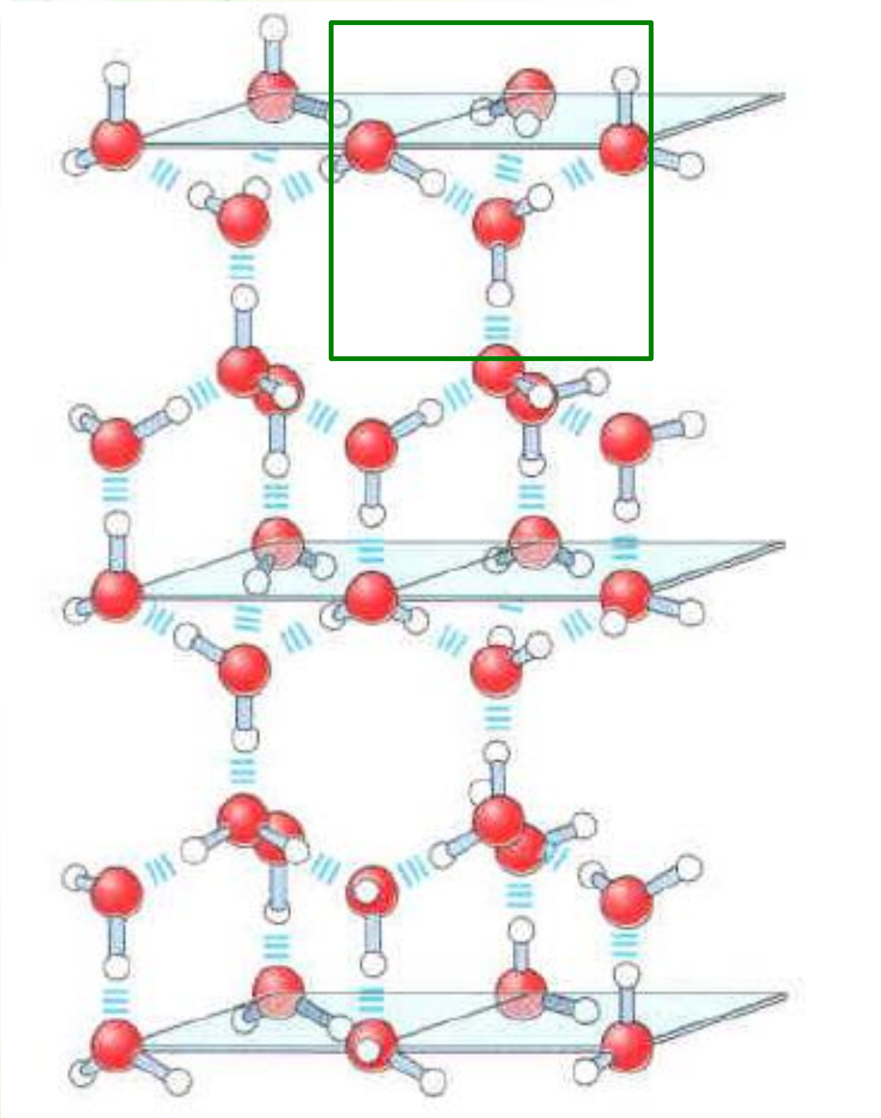
H-bond is stronger if

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



Lehninger 5th edition

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.

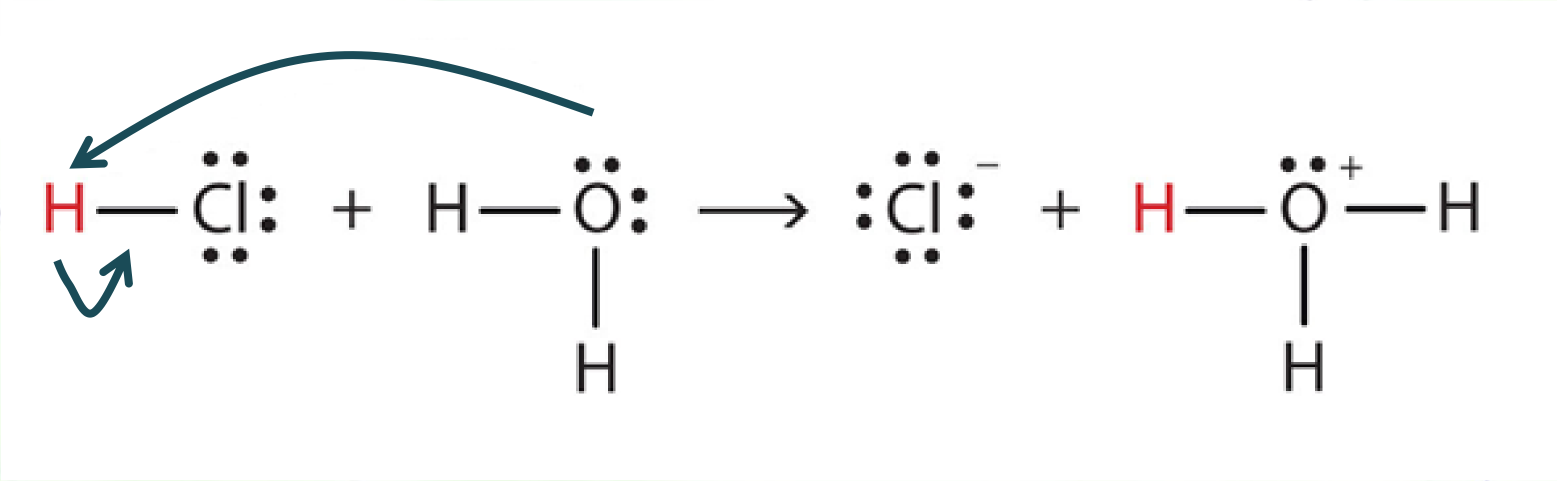
High heat capacity and heat of vaporization; when liquid water (sweating) is converted to a gas and evaporates from the skin, we feel a cooling effect.

↓ **Temperature →** ↑ **H-bonds**

↑ **Temperature →** ↓ **H-bonds**

Properties of water (3)

- It 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).



Properties of water (4)

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

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