

Chemical Bonds and Biochemical Properties of Water

Tishk International University,
Education Faculty, Biology Dept,
Biochemistry, 1st Semester/W1

Outline

- What is the biochemistry?
- Principles of Biochemistry,
- What is the matter?
- Chemical bonds,
- Properties of water,
- pH and Buffer

What is Biochemistry?

- Biochemistry is the chemistry of the living cell.
 - It describes in molecular terms the structures, mechanisms, function and chemical processes shared by all living organisms.
 - It provides fundamental understanding of the molecular basis for the function of living things.
 - It provides a broad understanding of the molecular basis of life.
 - It explains what goes wrong to produce a disease.
- Examples:
 - The chemical structures of biomolecules.
 - Interactions leading to formation of supermacro-molecules , cells, multi-cellular tissues, and organisms.
 - Bioenergetics of the reactions in the cell.
 - Storage and transmission of information.
 - Chemical changes during reproduction, aging, and death of cells.
 - Regulation of chemical reactions inside living cells.

Principal Areas of Biochemistry

- **Structure-function relationship:**
 - Structural Chemistry for proteins, carbohydrates, DNA/RNA, lipids, and every other component in the cell.
 - Functions of these components
 - Relationship between structure and function.
- **Metabolism:**
 - Catabolism: Pathways of chemical reactions leading to the breakdown of molecules
 - Anabolism: pathways of chemical reactions leading to synthesis of molecules.
 - Bioenergetics of reaction as well as management of cellular Energy.
- **Cellular communication**
 - Storage, transmission, and expression of genetic information
 - DNA replication and protein synthesis.
 - Cell-cell communication & interaction
 - Signal transduction

What is the matter?

- **The matter** is anything that has mass and volume (occupies space).
 - In chemical point of view matter is made up of atoms.
 - Atoms are formed from nucleus (having protons and neutrons) and circulating negatively charges electrons.
 - Atoms having specific numbers of protons form elements
 - There are 118 elements on the periodic table 92 of them are natural.
 - All living and non-living matter are made of elements.
 - Group of elements can form **molecules** of compounds.

In biochemistry, we are interested in the chemical structure and reactions in living cells.

So, the introduction for biochemistry is the study of the living cell.

The origin of Life

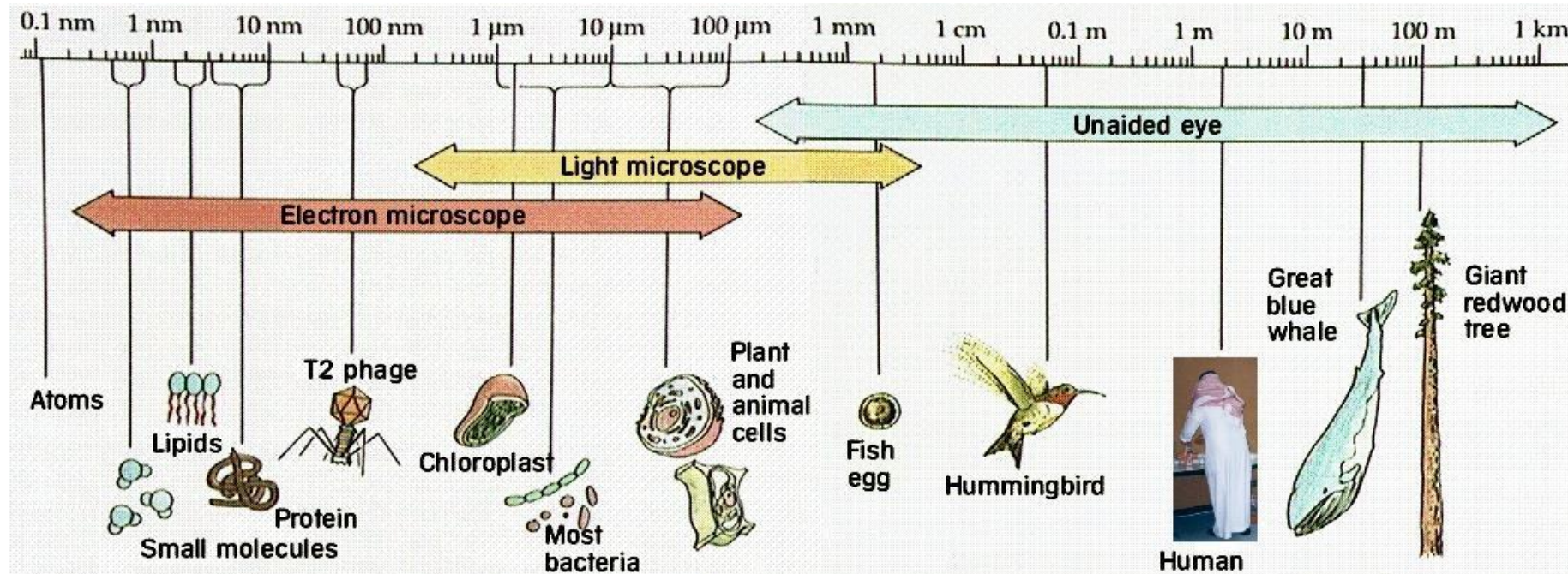
- Living matter consists of some chemical **elements**.
- Those elements bind together to form **molecules**.
- Most of compounds in Biological systems are **organic compounds** (have Carbon)
- Chemical compounds have **reactive functional groups** that participate in biological structure and biochemical reactions.
- **Polymerization** of organic molecules form more complex structure by the mean of **condensation** reaction with the removal of water.
- The key of origin of living matter is the formation of **membranes** that separate the critical molecules required for replication and energy capture.
- Larger polymers of molecules form **macromolecules** that all together provide biological specificity of the living matter. E.g. carbohydrates, proteins, lipids, genetic material (DNA and RNA) etc.

Biological Hierarchies

- Biological Hierarchy: Simple Molecules are used to Build Complex Structures

Elements → Molecule → Cell → Tissue → Organ → Organism → Population → Species → Biosphere

- Relative sizes (or ranges) for some biological things, and the resolving power of available tools!
 - Note that the scale is logarithmic.
 - Remember: $1 \text{ m} = 10 \text{ dm} = 100 \text{ cm} = 1000 \text{ mm} = 10^6 \mu\text{m} = 10^9 \text{ nm} = 10^{10} \text{ \AA}$

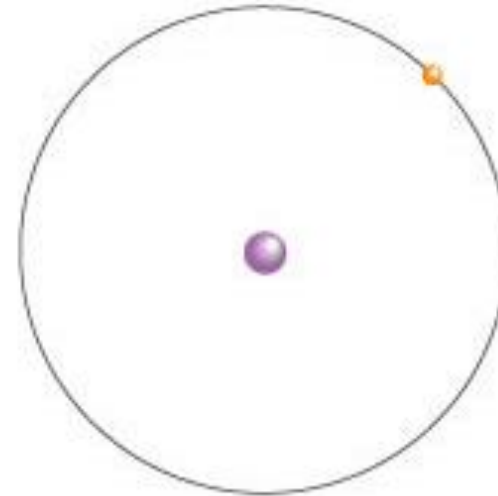


- **Everything is made of matter**
- **Matter is made of atoms**



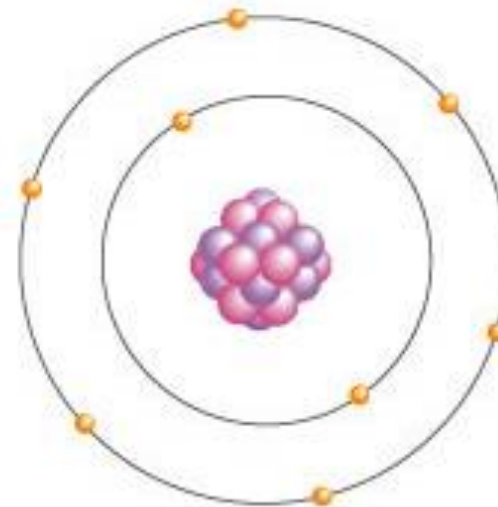
Hydrogen

1 proton
1 electron



Oxygen

8 protons
8 neutrons
8 electrons



Proton  +

Neutron  0

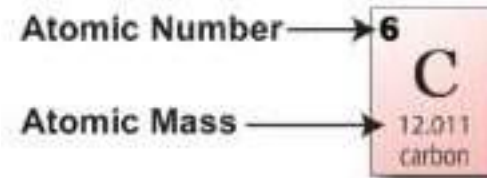
Electron  -

The matter versus element and molecule?

- The atomic number of each element represent the number of protons in its nucleus.

For example,

- the element that has 6 protons in its atom is CARBON
- The atom that has 7 protons is NITROGEN
- The atom that has 8 protons is OXYGEN
- **Molecule** is a group of two or more elements.



Periodic table of elements

group 1		metals										nonmetals						group 18									
		alkali metals					alkaline earth metals					transition metals		rare earth metals		other metals		halogens						noble gases		other nonmetals	
												metalloids															
		group 3		group 4	group 5	group 6	group 7	group 8	group 9	group 10	group 11	group 12	group 13	group 14	group 15	group 16	group 17	group 18									
1 H 1.0079 hydrogen																		2 He 4.0026 helium									
3 Li 6.941 lithium	4 Be 9.0122 beryllium																	5 B 10.811 boron	6 C 12.011 carbon	7 N 14.007 nitrogen	8 O 15.999 oxygen	9 F 18.998 fluorine	10 Ne 20.180 neon				
11 Na 22.990 sodium	12 Mg 24.305 magnesium																	13 Al 26.982 aluminum	14 Si 28.086 silicon	15 P 30.974 phosphorous	16 S 32.065 sulfur	17 Cl 35.453 chlorine	18 Ar 39.948 argon				
19 K 39.098 potassium	20 Ca 40.078 calcium	21 Sc 44.956 scandium	22 Ti 47.867 titanium	23 V 50.942 vanadium	24 Cr 51.996 chromium	25 Mn 54.938 manganese	26 Fe 55.845 iron	27 Co 58.933 cobalt	28 Ni 58.693 nickel	29 Cu 63.546 copper	30 Zn 65.38 zinc	31 Ga 69.723 gallium	32 Ge 72.61 germanium	33 As 74.922 arsenic	34 Se 78.96 selenium	35 Br 79.904 bromine	36 Kr 83.80 krypton										
37 Rb 85.468 rubidium	38 Sr 87.62 strontium	39 Y 88.906 yttrium	40 Zr 91.224 zirconium	41 Nb 92.906 niobium	42 Mo 95.96 molybdenum	43 Tc (90) technetium	44 Ru 101.07 ruthenium	45 Rh 102.91 rhodium	46 Pd 106.42 palladium	47 Ag 107.87 silver	48 Cd 112.41 cadmium	49 In 114.82 indium	50 Sn 118.71 tin	51 Sb 121.76 antimony	52 Te 127.60 tellurium	53 I 126.90 iodine	54 Xe 131.29 xenon										
55 Cs 132.91 cesium	56 Ba 137.33 barium	71 Lu 174.97 lutetium	72 Hf 178.49 hafnium	73 Ta 180.95 tantalum	74 W 183.84 tungsten	75 Re 186.21 rhenium	76 Os 190.23 osmium	77 Ir 192.22 iridium	78 Pt 195.08 platinum	79 Au 196.97 gold	80 Hg 200.59 mercury	81 Tl 204.38 thallium	82 Pb 207.2 lead	83 Bi 208.98 bismuth	84 Po (209) polonium	85 At (210) astatine	86 Rn (222) radon										
87 Fr (223) francium	88 Ra (226) radium	103 Lr (262) lawrencium	104 Rf (267) rutherfordium	105 Db (268) dubnium	106 Sg (271) seaborgium	107 Bh (272) bohrium	108 Hs (270) hassium	109 Mt (276) meitnerium	110 Ds (281) darmstadtium	111 Rg (280) roentgenium	112 Uub (285) ununbium	113 Uut (284) ununtrium	114 Uuq (289) ununquadium	115 Uup (288) ununpentium	116 Uuh (293) ununhexium			118 Uuo (294) ununoctium									

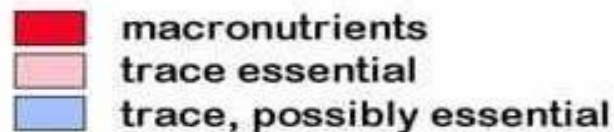
57 La 138.91 lanthanum	58 Ce 140.12 cerium	59 Pr 140.91 praseodymium	60 Nd 144.24 neodymium	61 Pm (145) promethium	62 Sm 150.36 samarium	63 Eu 151.96 europium	64 Gd 157.25 gadolinium	65 Tb 158.93 terbium	66 Dy 162.50 dysprosium	67 Ho 164.93 holmium	68 Er 167.26 erbium	69 Tm 168.93 thulium	70 Yb 173.06 ytterbium
89 Ac (227) actinium	90 Th 232.04 thorium	91 Pa 231.04 protactinium	92 U 238.03 uranium	93 Np (237) neptunium	94 Pu (244) plutonium	95 Am (243) americium	96 Cm (247) curium	97 Bk (247) berkelium	98 Cf (251) californium	99 Es (252) einsteinium	100 Fm (257) fermium	101 Md (258) mendelevium	102 No (259) nobelium

Elements in living cells

There are many classifications of elements regarding its distribution in living cells. The most used one is as follow:

- **Macronutrients** are elements that are most abundant in the cell, (**C, H, N, O, P, S**)
- **Essential elements** are found in small amounts, but essential (**Na, Mg, K, Ca, Mn, Fe, Co, Ni, Zn, Cu, Cl, I**).
- **Trace Possibly Essential elements**: some are common, others are less common (**V, Cr, Mo, B, Al, Si, As, Se, Br**).

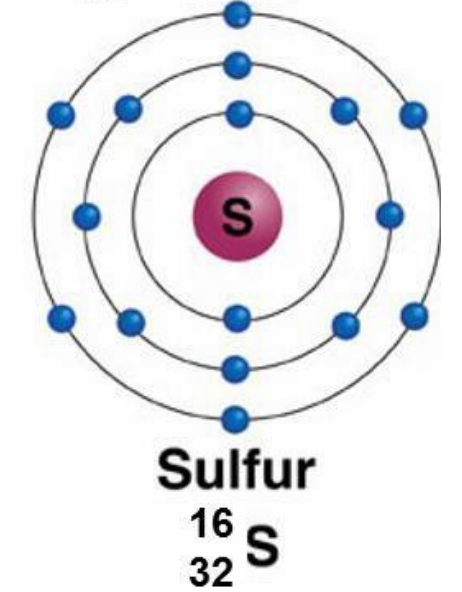
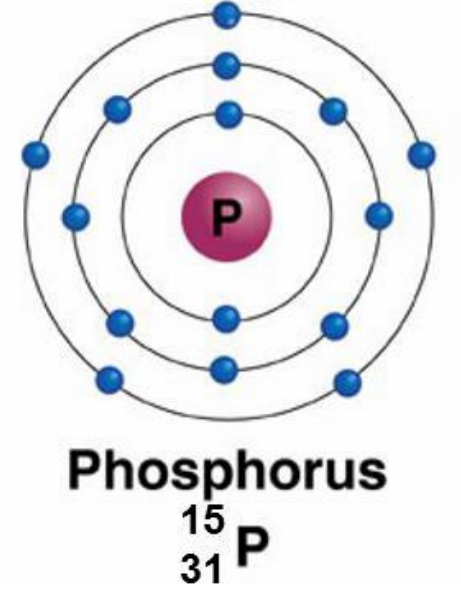
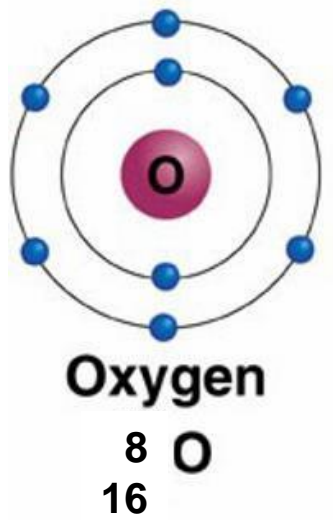
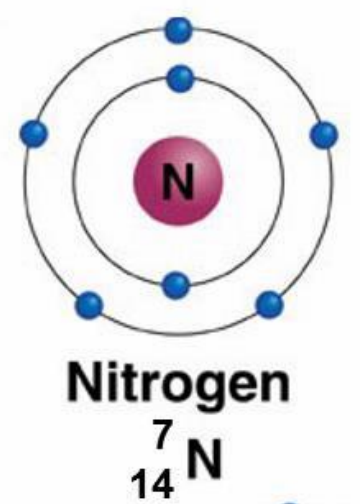
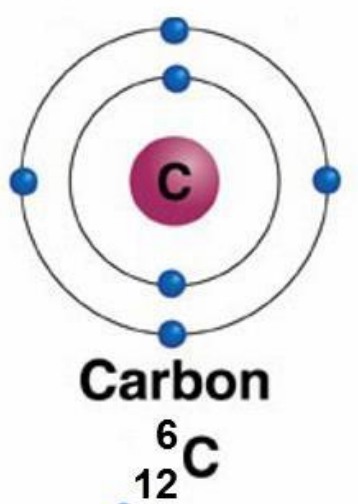
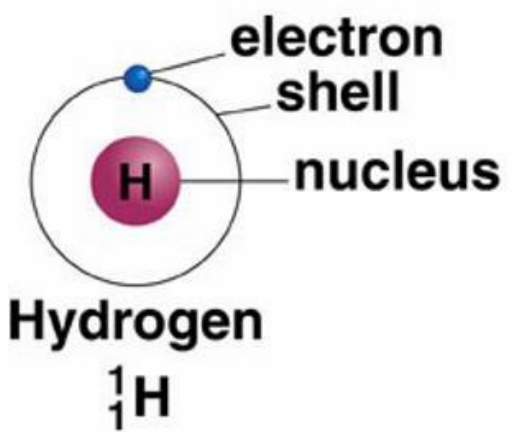
	IA	IIA											IIIA	IVA	VA	VIA	VIIA	VIIIA	
1	H																	He	
2	Li	Be											B	C	N	O	F	Ne	
3	Na	Mg	IIIB	IVB	VB	VIB	VIB	VIB	VIII	VIII	VIII	IB	IIB	Al	Si	P	S	Cl	Ar
4	K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr	
5	Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe	
6	Cs	Ba	La	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn	



Chemical Elements of Life

- **C H N O P S**: are the most abundant elements in cell.
 - They account for more than 99% of atoms in the human body
- **H, O, N** and **C** have **common properties** that are important to the chemistry of life.
 - They all:
 - have relatively low atomic numbers
 - capable of forming **one**, **two**, **three** and **four** bonds (for **H**, **O**, **N** and **C**, in order).
 - form the strongest covalent bonds in general.

Write the atomic number and the atomic mass of each element (CHNOPS)



Chemistry Review

To truly understand biochemistry, we need to understand chemical bonding. We review here the types of chemical bonds that are important for biochemical and their transformation.

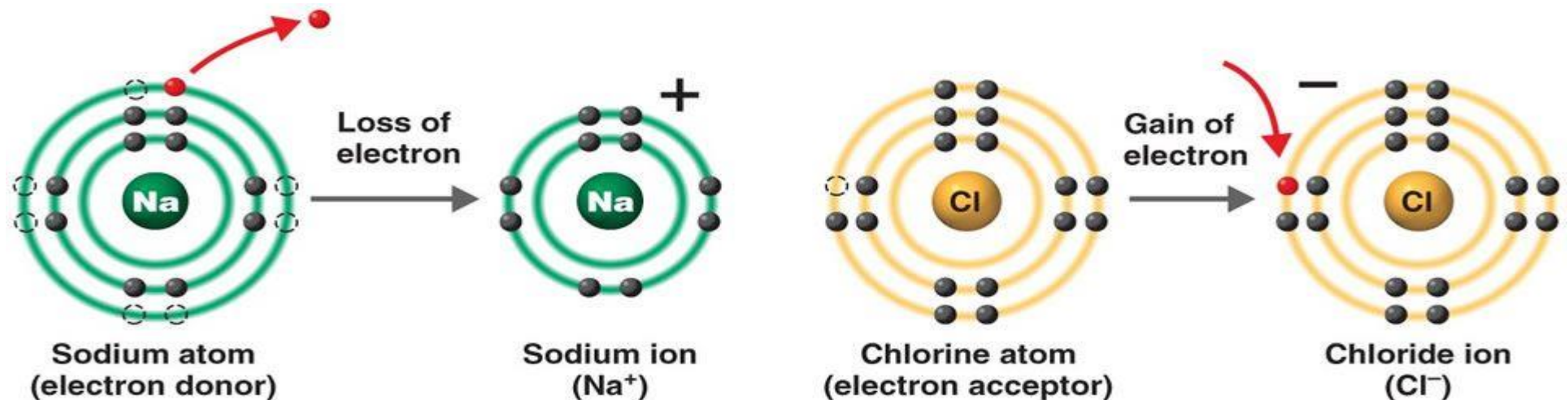
There are 5 major forces that maintain the structure of biomolecules:

- Only one is a strong force: **The covalent bond**
- The others are considered weak forces:
 1. The ionic bond
 2. The hydrogen bond
 3. Hydrophobic interaction (not chemical bond)
 4. Van Der Waals attraction (not chemical bond)

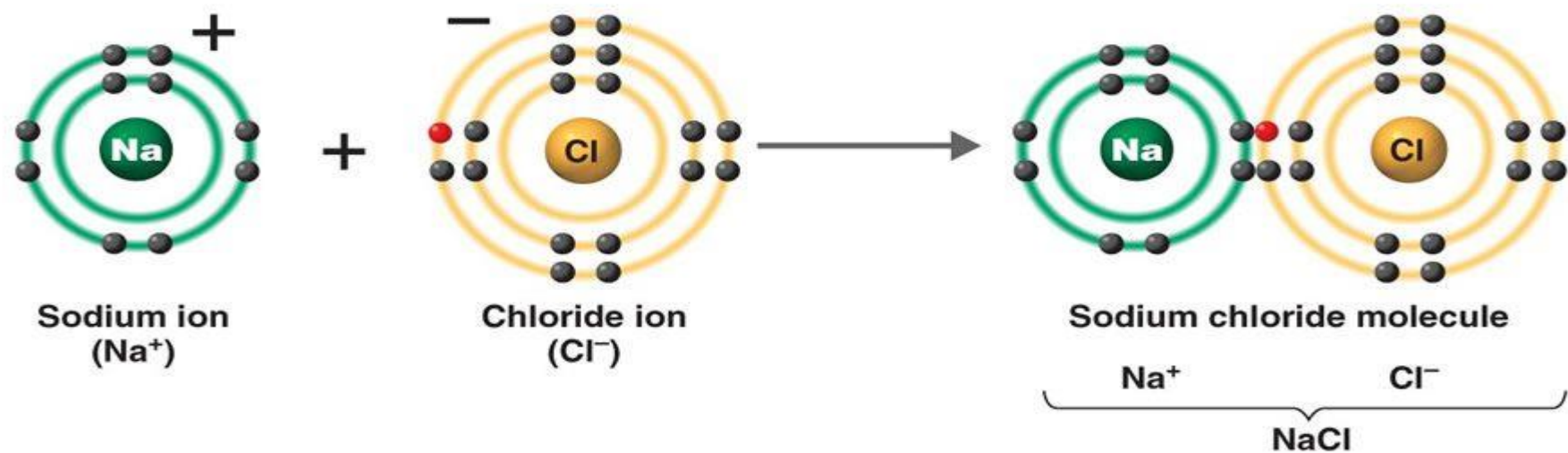
Compounds...

Atoms form compounds in two ways

1. Ionic bonds – consists of ions and forms through the electrical force between oppositely charged ions
 - An ion is an atom that has lost or gained electrons
 - Cation – an ion that loses electrons so becomes positively charged
 - Anion – an ion that gains electrons so becomes negatively charged
2. Covalent bonds – forms when atoms share one or more pairs of electrons
 - A molecule consists of two or more atoms held together by covalent bonds

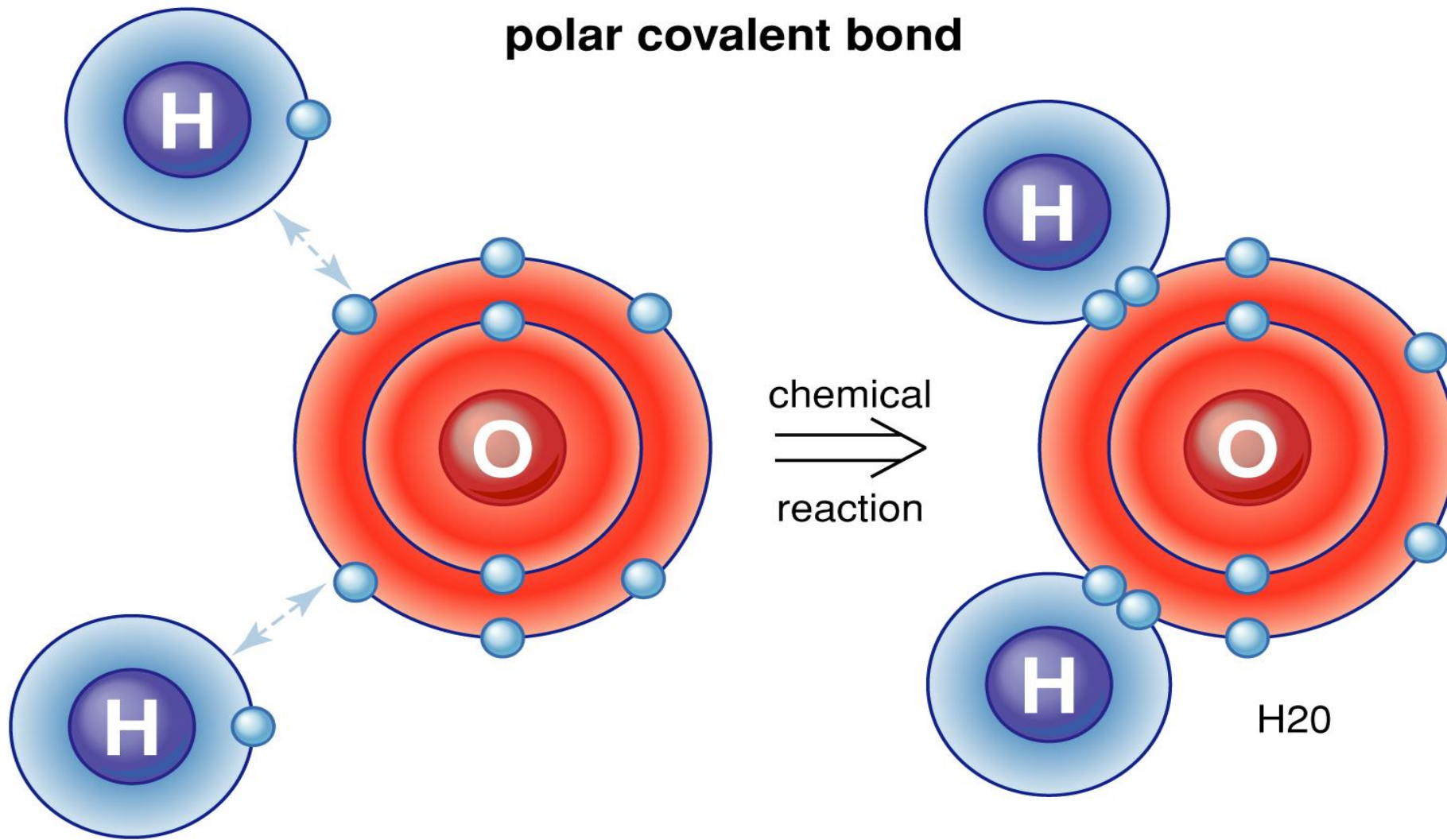


(a) A sodium atom (Na) loses one electron to an electron acceptor and forms a sodium ion (Na^+). A chlorine atom (Cl) accepts one electron from an electron donor to become a chloride ion (Cl^-).



(b) The sodium and chloride ions are attracted because of their opposite charges and are held together by an ionic bond to form a molecule of sodium chloride.

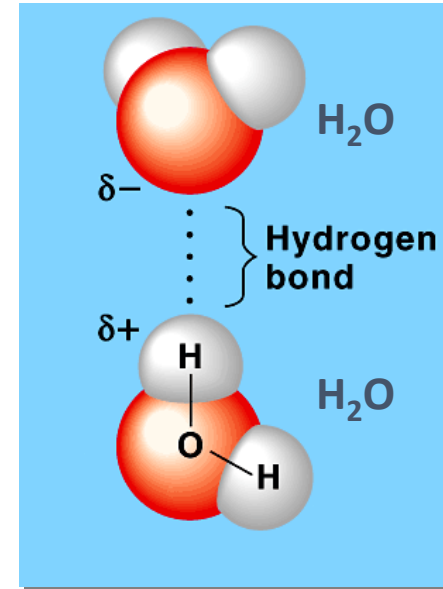
polar covalent bond



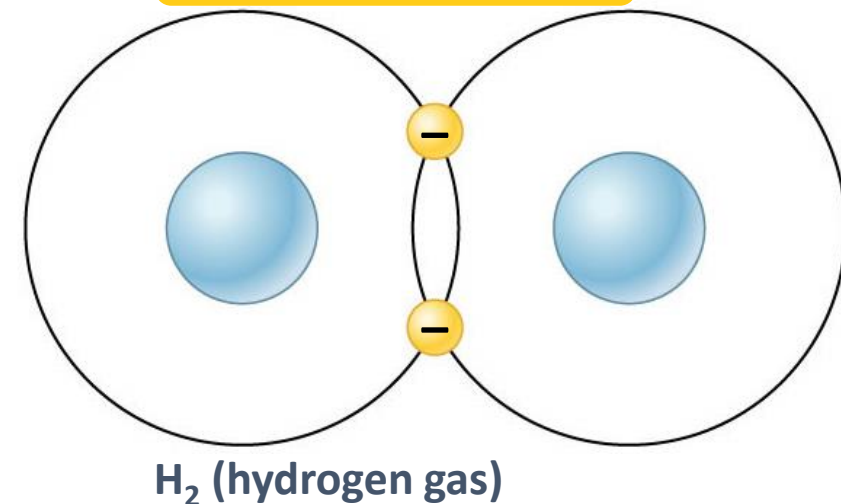
Bonds in Biology

- Weak bonds
 - hydrogen bonds
 - attraction between + and -
 - hydrophobic & hydrophilic interactions
 - interaction with H₂O
 - van derWaals forces
 - (ionic)
- Strong bonds
 - covalent bonds

Hydrogen bond

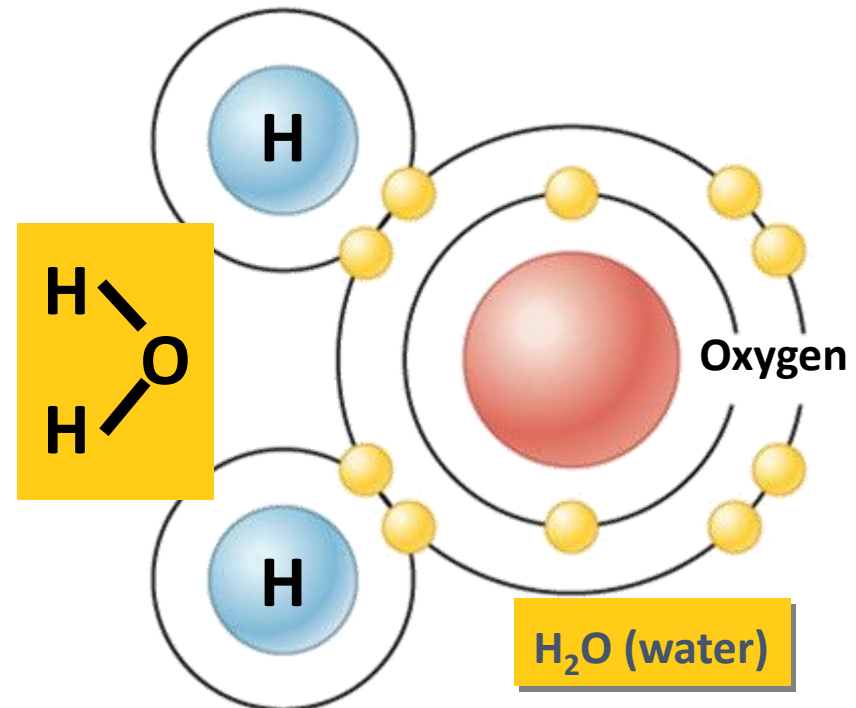
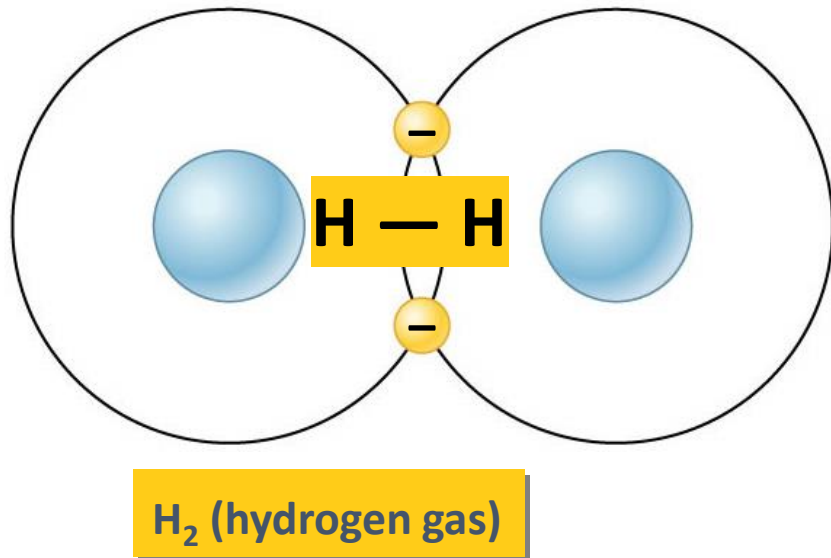


Covalent bond



Covalent bonds

- Why are covalent bonds strong bonds?
 - two atoms share a pair of electrons
 - both atoms holding onto the electrons
 - very stable
- Forms molecules



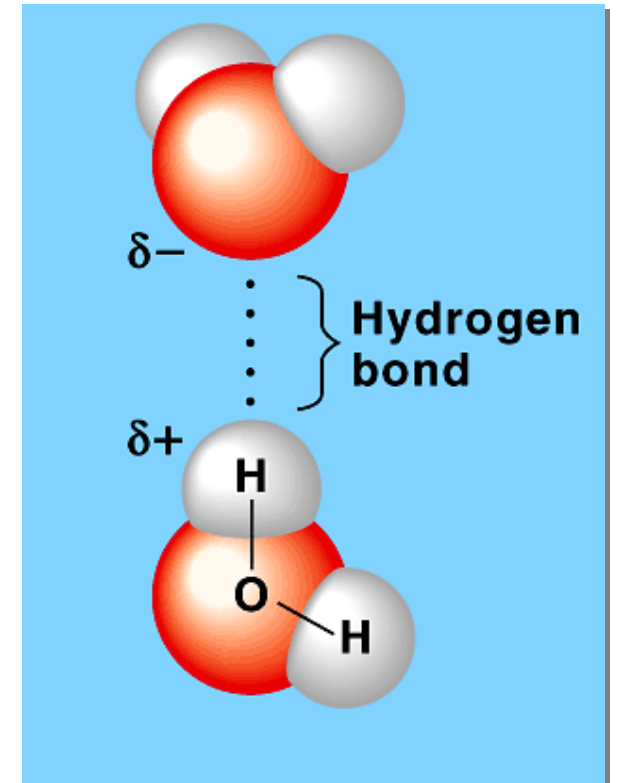
Chemistry of Life

Properties of Water



Water's Unique Properties...

- The structure of the water molecule gives water its unique properties.
- Each molecule of water consists of one atom of oxygen and two atoms of hydrogen, so it has the chemical formula H_2O .
- Water is a **polar** molecule, which means that it has a region with a slight negative charge (the oxygen atom) and a region with a slight positive charge (the hydrogen atoms)
- The oppositely charged regions of water molecules interact to form **hydrogen bonds**
 - attraction between positive H in one H_2O molecule to negative O in another H_2O
 - Weak bond



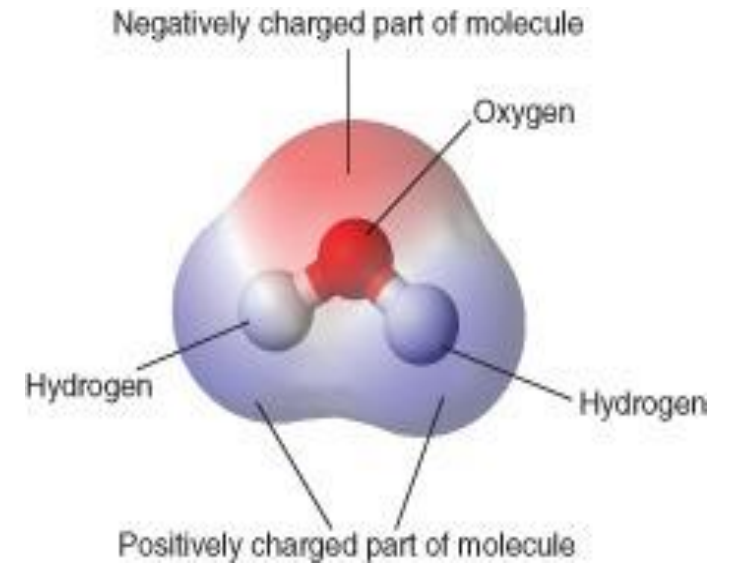
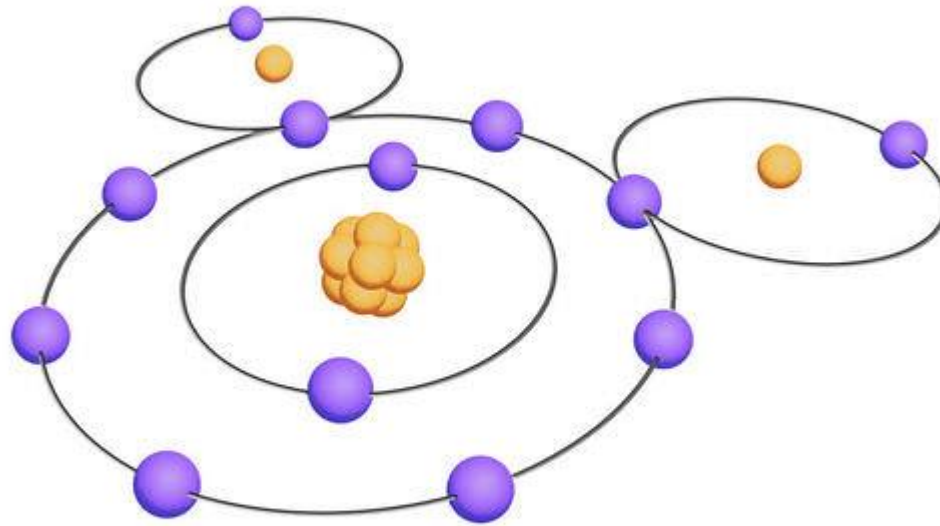


Figure: This model is an atomic diagram of water, showing the two hydrogen atoms and oxygen atom in the center. The protons (red) are in the center (nucleus) of each atom, and the electrons (light blue) circle each nucleus.

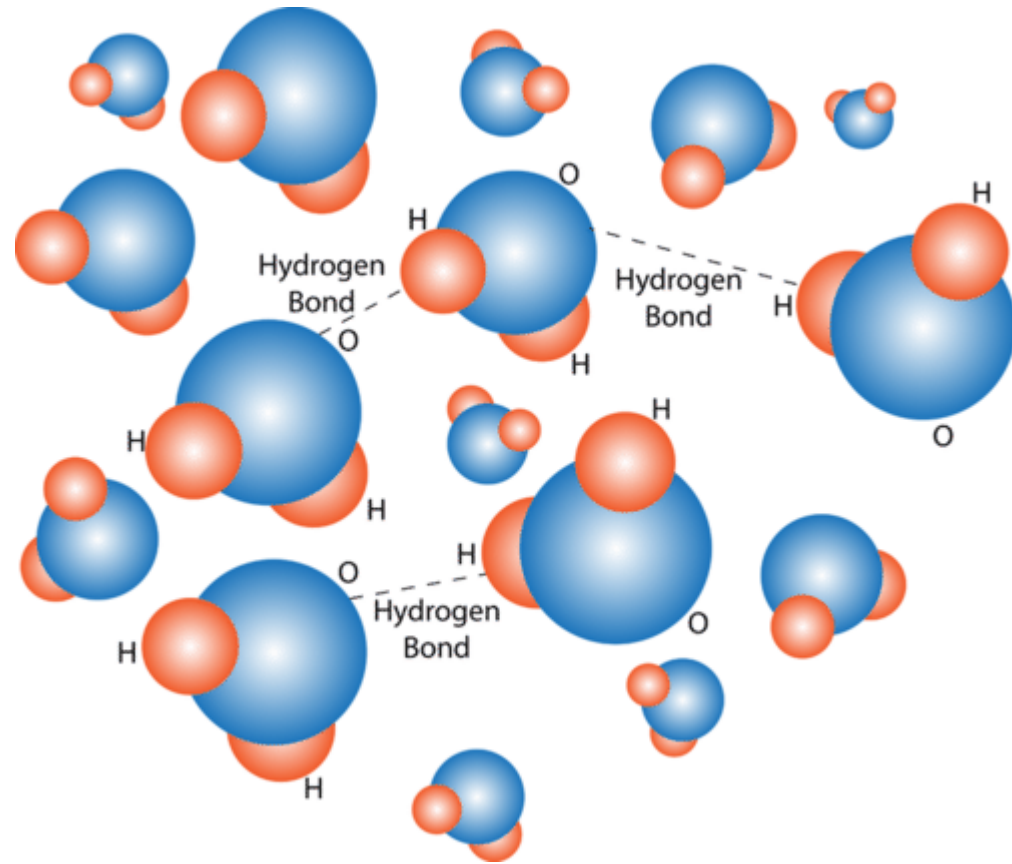
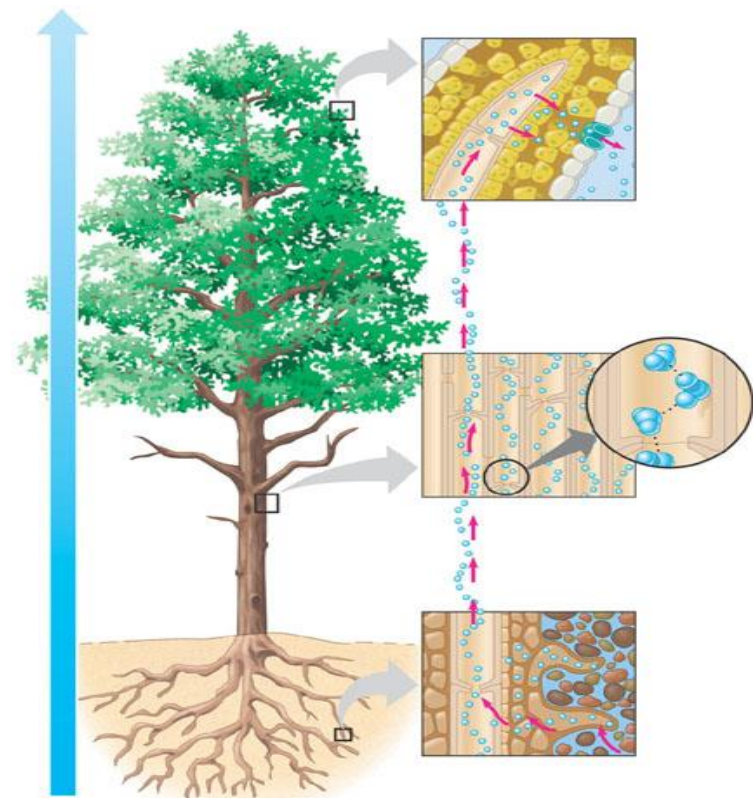


Figure: Hydrogen bonds form between positively and negatively charged parts of water molecules. The bonds hold the water molecules together. How do you think this might affect water's properties?

Important Properties of Water...

- Hydrogen bonds are responsible for several important properties of water
 1. **Cohesion** – the attraction among molecules of a substance – makes water “stick” together
 - Surface tension
 - For example, if you drop a tiny amount of water onto a very smooth surface, the water molecules will stick together and form a droplet, rather than spread out over the surface.
 2. **Adhesion** – the attraction among molecules of DIFFERENT substances – makes water “stick” to other materials
 - Capillary action; the ability of a liquid to flow against gravity in a narrow space.
 - water climbs up paper towel or cloth



Important Properties of Water...

- **3. High boiling point** – Hydrogen bonds also explain why water's **boiling point** (100°C) is higher than the **boiling** points of similar substances without hydrogen bonds. Because of water's relatively high boiling point, most water exists in a **liquid** state on Earth. Liquid water is needed by all living organisms. Therefore, the availability of liquid water enables life to survive over much of the planet.
- **4. High specific heat** – because it takes a lot of energy to raise or lower the temperature of water. As a result, water plays a very important role in temperature regulation. Since **cells** are made up of water, this property helps to maintain **homeostasis**.

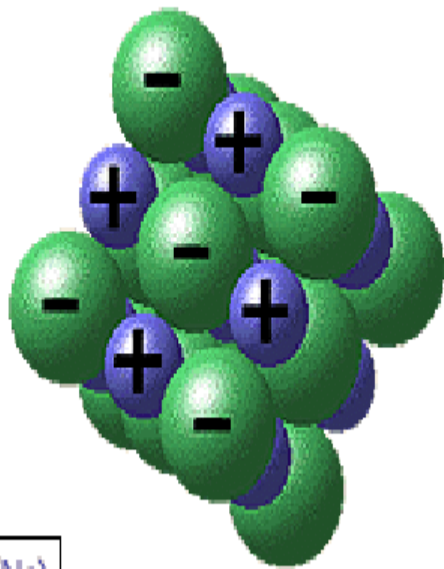
Important Properties of Water...

- 5. Expands when freezes** – when water freezes its volume becomes larger than in the liquid or gas state (just the opposite of most other compounds).
- In a large body of water, such as a lake or the ocean, the water with the greatest density always sinks to the bottom.
 - Water is most dense at about 4°C. As a result, the water at the bottom of a lake or the ocean usually has [temperature](#) of about 4°C.
 - In climates with cold winters, this layer of 4°C water insulates the bottom of a lake from [freezing](#) temperatures.
 - Lake organisms such as [fish](#) can survive the winter by staying in this cold, but unfrozen, water at the bottom of the lake.

A little more on water...

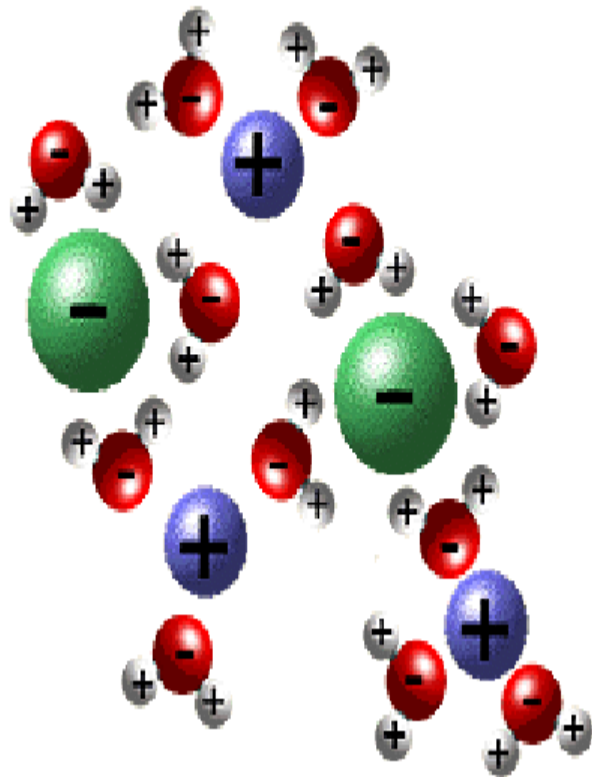
- **6. Solvent for polar molecules** – many compounds that are important for life dissolve in water.
- Water is the largest component of cells' interiors, and chemical reactions in the cell take place in water
- When one substance dissolves in another – a **solution** is made
 - Each solution is made up of two parts
 - Solute – what gets dissolved (usually in smallest amount)
 - Solvent – what does the dissolving (usually in the largest amt)

NaCl crystal structure



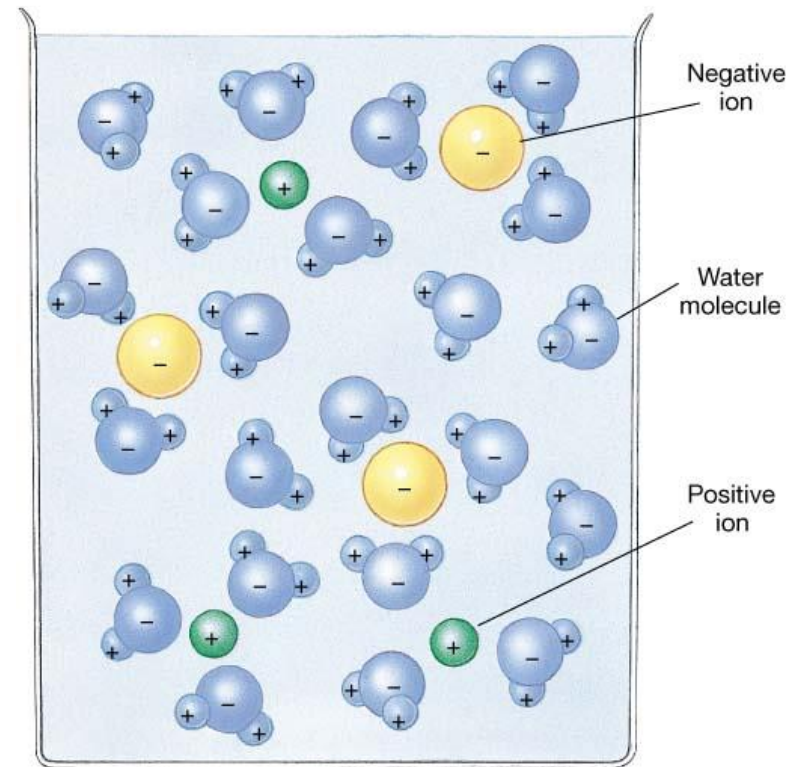
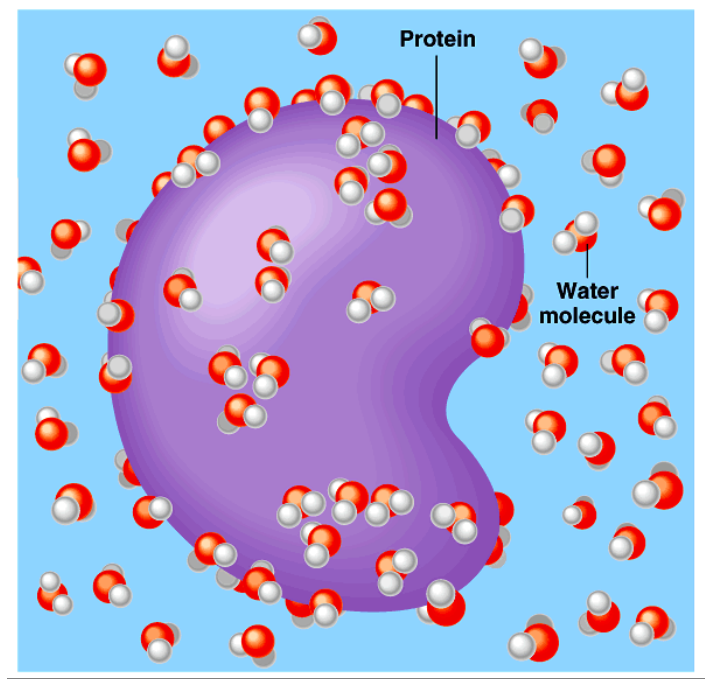
sodium (Na)
chlorine (Cl)

NaCl in water



What dissolves in water?

- Hydrophilic
 - substances have attraction to H₂O
 - polar or non-polar?

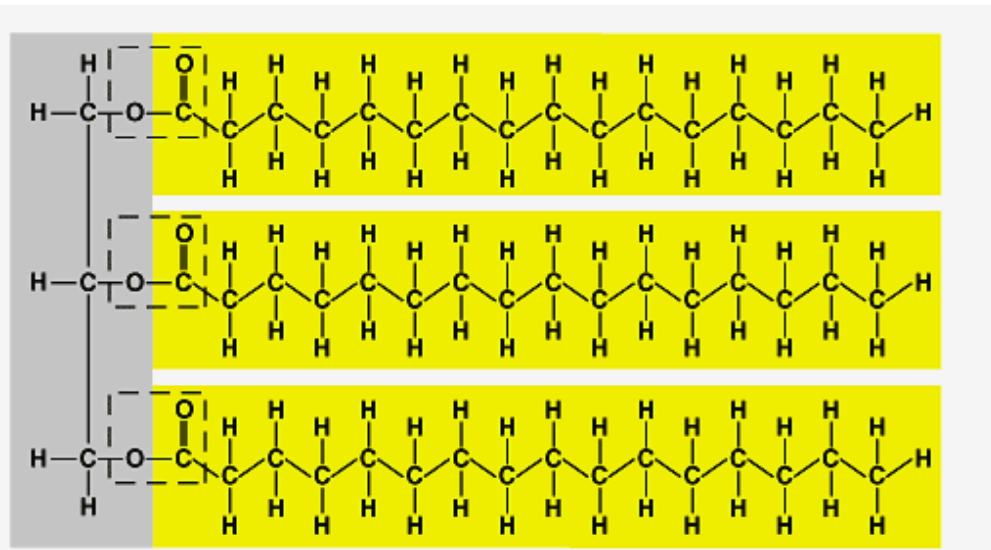


What doesn't dissolve in water?

- Hydrophobic

- substances that don't have an attraction to H₂O

- polar or non-polar?



fat (triglycerol)

Ionization of water & pH

- Water ionizes
 - H^+ splits off from H_2O , leaving OH^-
 - if $[\text{H}^+] = [\text{OH}^-]$, water is neutral
 - if $[\text{H}^+] > [\text{OH}^-]$, water is acidic
 - if $[\text{H}^+] < [\text{OH}^-]$, water is basic
- pH scale
 - how acid or basic solution is
 - $1 \rightarrow 7 \rightarrow 14$



Acids and bases...

- When some substances dissolve in water they break up into ions
- Acids and bases are such substances – they are very important to living organism
 - Acids – release H^+ ions when dissolved in water
 - Bases – accept H^+ ion when dissolved in water
- Organisms must maintain a stable pH and even a small change in pH can disrupt many biological processes (remember homeostasis?)

pH scale...

- The pH scale runs from 0 to 14
- 0 – 6 are considered acids (low pHs)
- 7 is neutral
- 8 – 14 are considered bases (high pHs)

Buffers & cellular regulation

- pH of cells must be kept ~ 7
 - pH affects shape of molecules
 - shape of molecules affect function
 - pH affects cellular function
- Control pH by buffers
 - reservoir of H^+
 - donate H^+ when $[H^+]$ falls
 - absorb H^+ when $[H^+]$ rises

