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 bons,
- 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

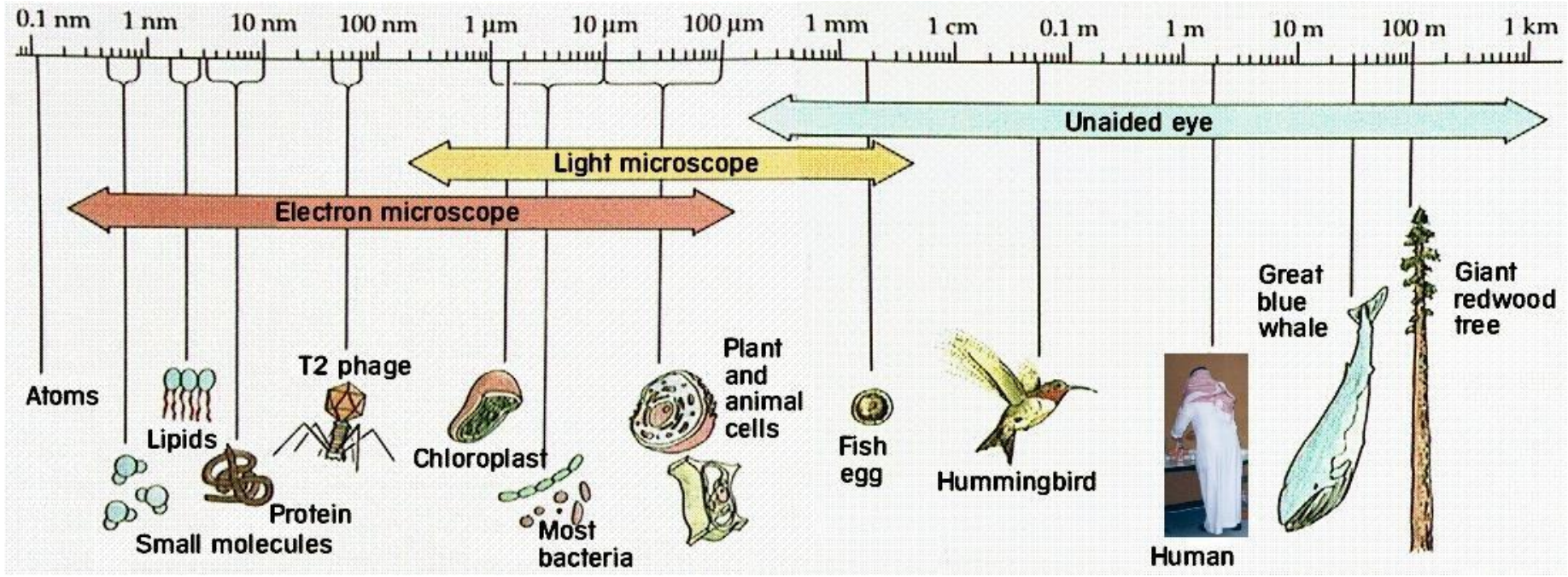
- Living matter consists of some chemical elements.
- Those elements bind together to form molecules.
- Most of compounds in Biological systems are organic compounds (have Carbon)
- Chemical compounds have reactive functional groups that participate in biological structure and biochemical reactions.
- 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

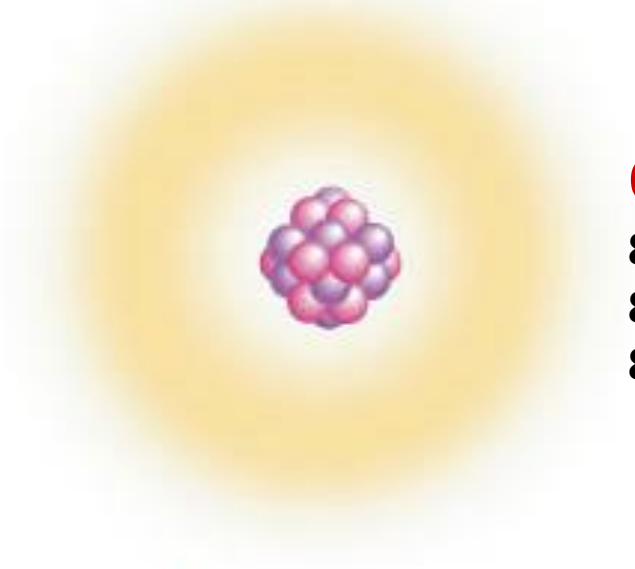
- Relative sizes (or ranges) for some biological things, and the resolving power of available tools!
  - Note that the scale is logarithmic.
  - Remember: 1 m = 10 dm = 100 cm = 1000mm = 10^6 µm =10^9 nm = 10^{10} A °



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

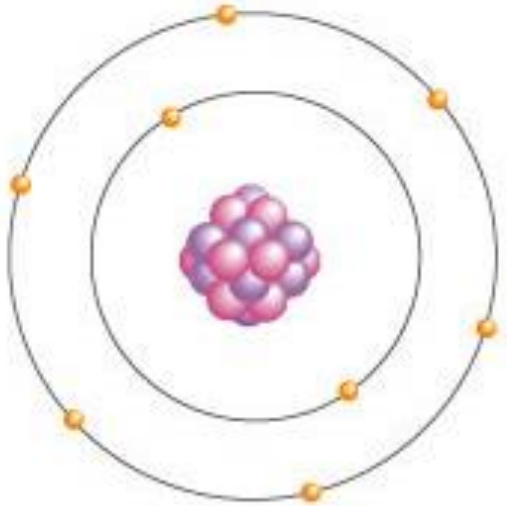
Hydrogen

1 proton
1 electron



Oxygen

8 protons
8 neutrons
8 electrons



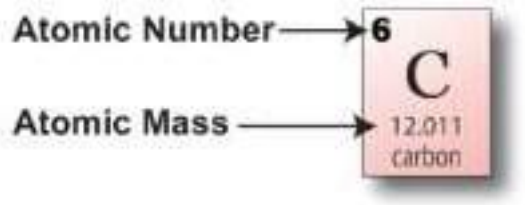
Proton + Neutron 0 Electron –

The matter versus element and molecule?

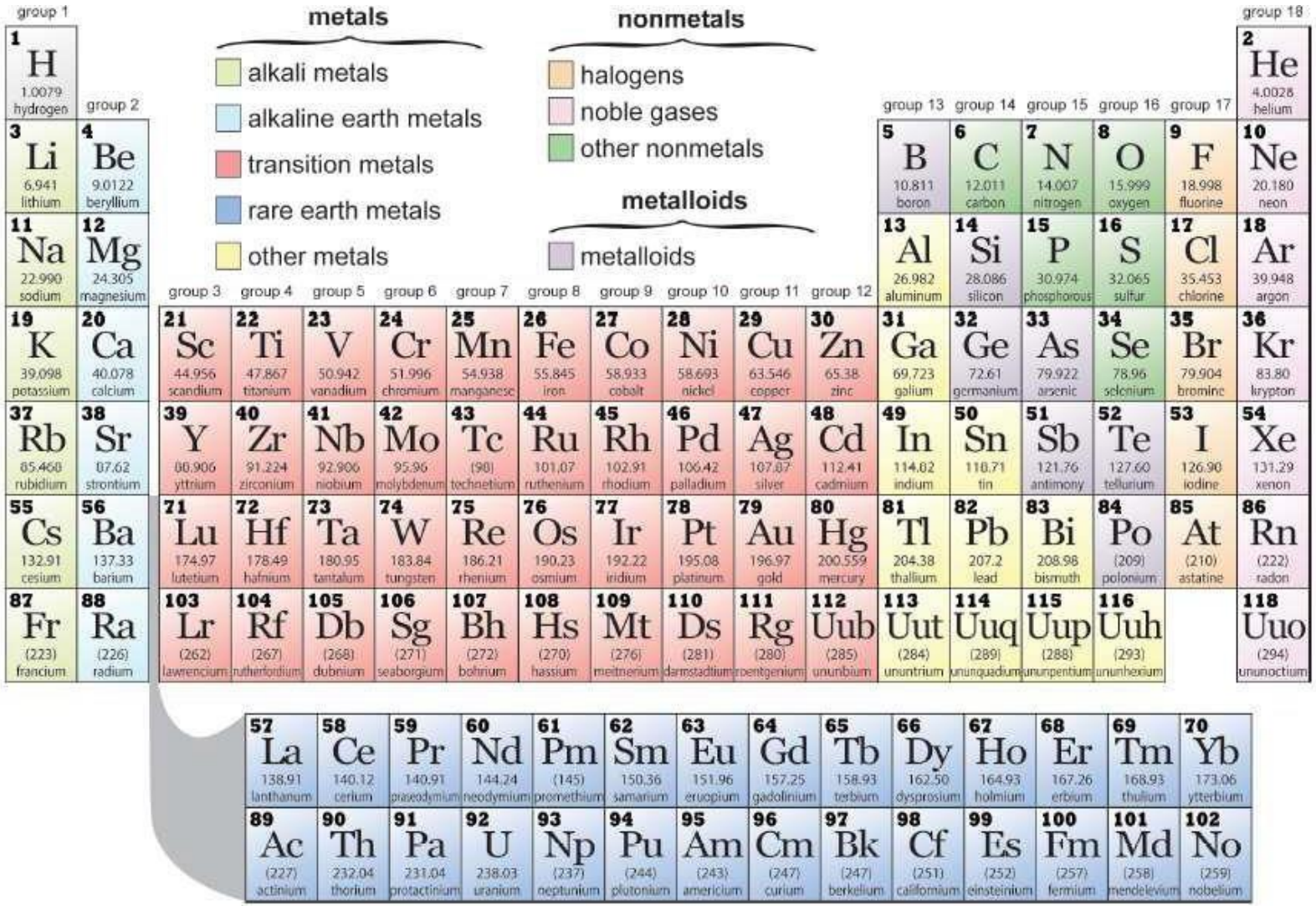
- The atomic number of each element represent the number of protons in its nucleus.

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.



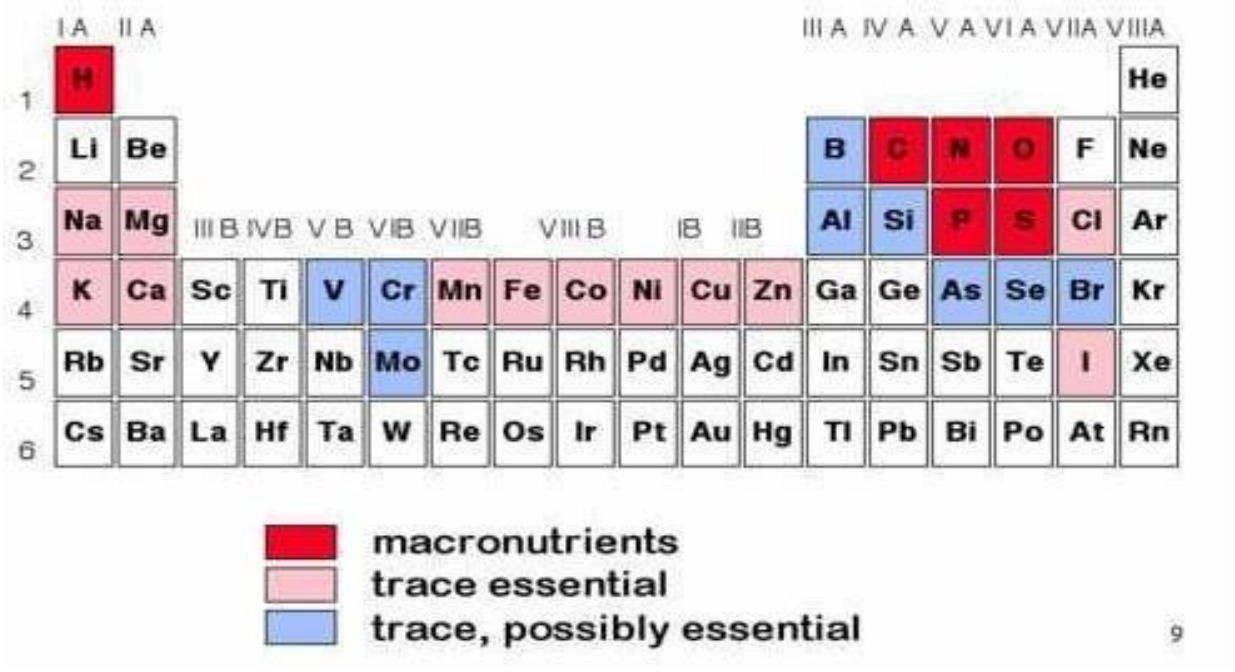
Periodic table of elements



Elements in living cells

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

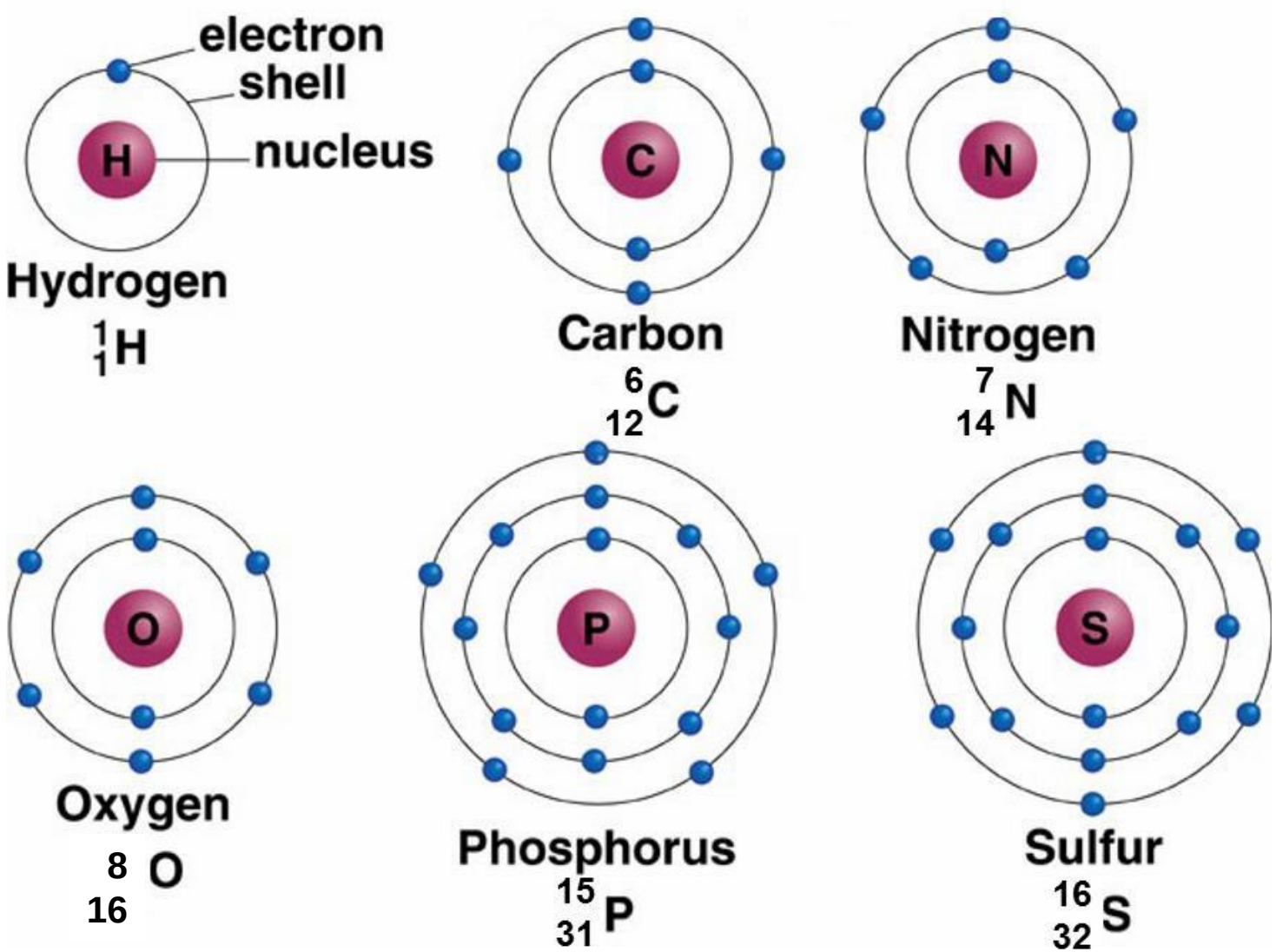
- **Macronutrients** are elements that are most abundant in the cell, **(C, H, N, O, P, S)**
- **Essential elements** are found in small amounts, but essential (Na, Mg, K, Ca, Mn, Fe, Co, Ni, Zn, Cu, Cl, I).
- **Trace Possibly Essential elements**: some are common, others are less common (V, Cr, Mo,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



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)


electron
shell
nucleus
H
Hydrogen
$^{1}_{1}H$
C
Carbon
$^{6}_{12}C$
N
Nitrogen
$^{7}_{14}N$
O
Oxygen
$^{8}_{16}O$
P
Phosphorus
$^{15}_{31}P$
S
Sulfur
$^{16}_{32}S$

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:

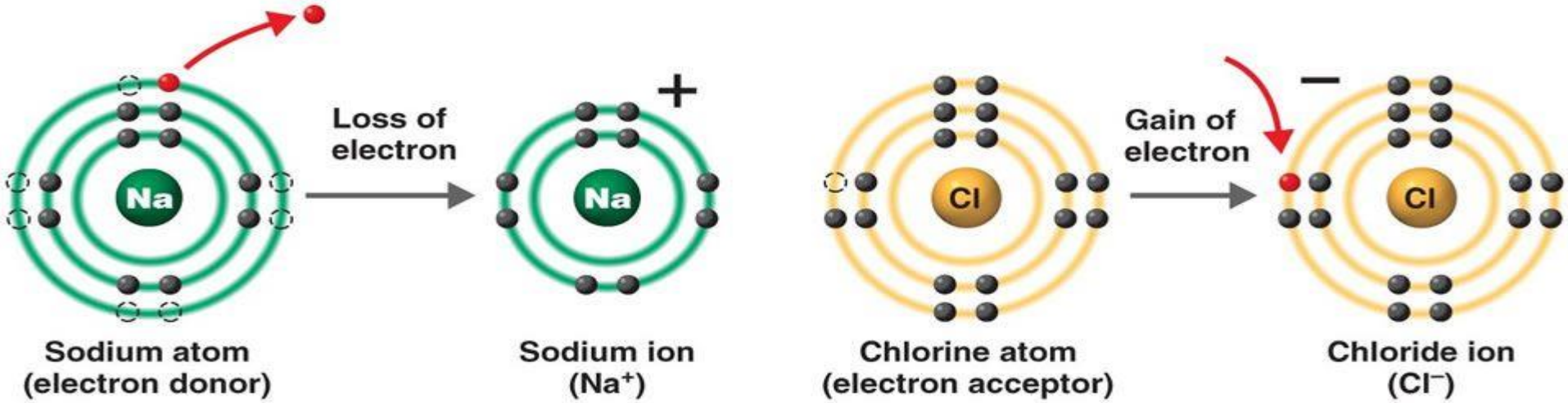
- Only one is a strong force: The covalent bond
- The others are considered weak forces:

1. The ionic bond
2. The hydrogen bond
3. Hydrophobic interaction (not chemical bond)
4. Van Der Waals attraction (not chemical bond)

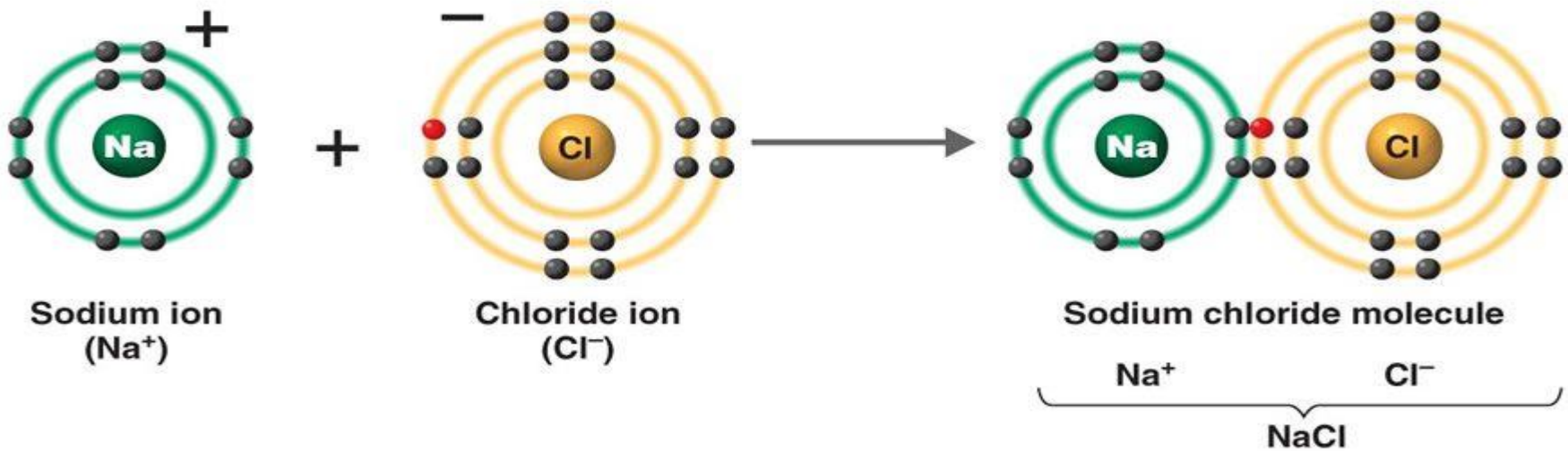
Compounds…

Atoms form compounds in two ways

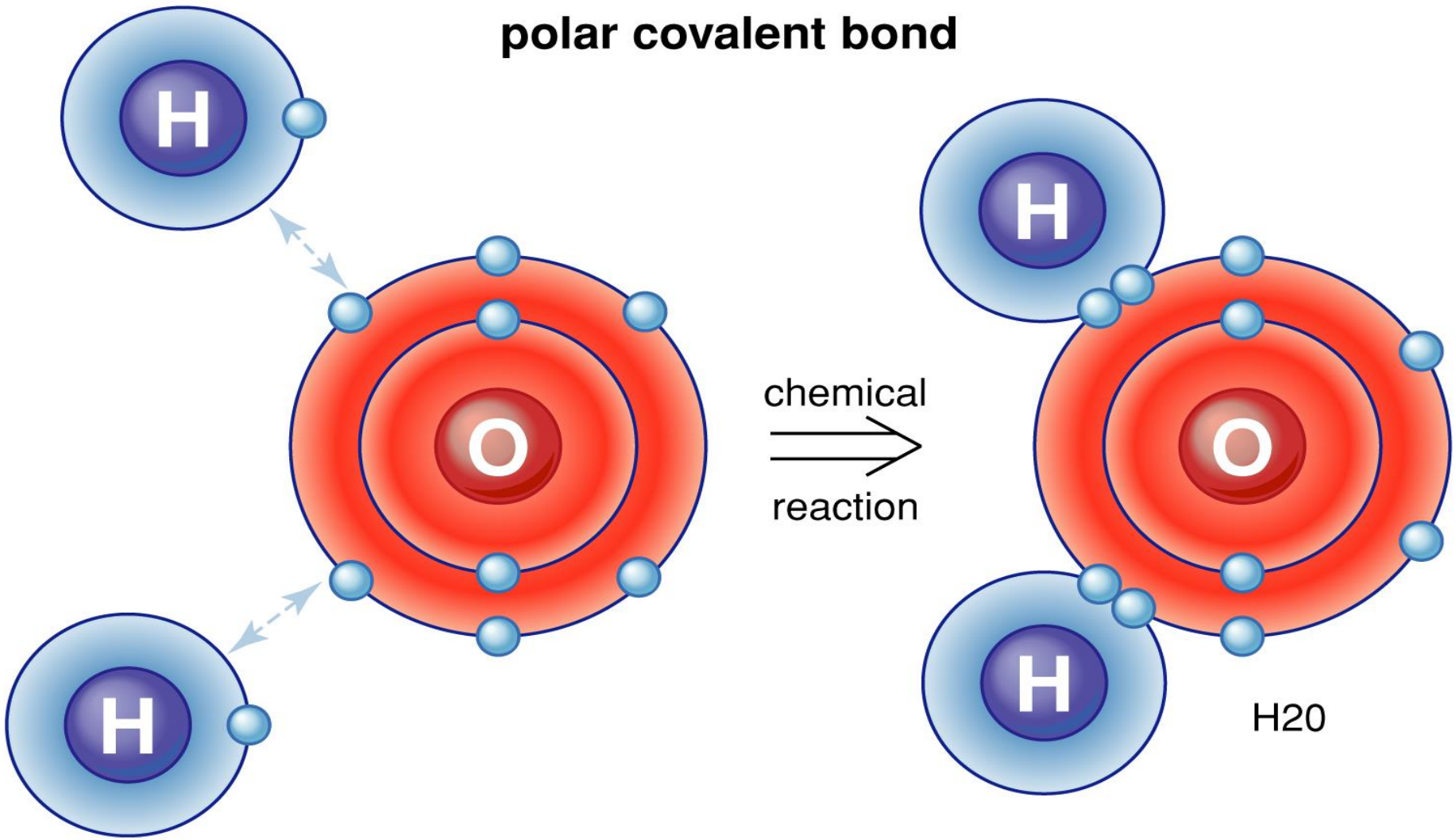
1. Ionic bonds – consists of ions and forms through the electrical force between oppositely charged ions
   - An ion is an atom that has lost or gained electrons
     - Cation – an ion that loses electrons so becomes positively charged
     - Anion – an ion that gains electrons so becomes negatively 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^-).



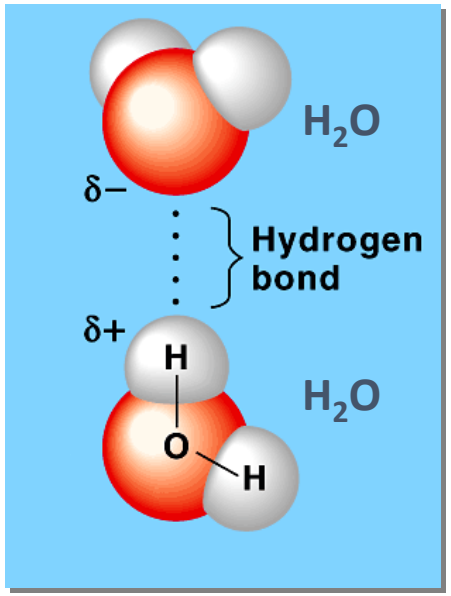
(b) The sodium and chloride ions are attracted because of their opposite charges and are held together by an ionic bond to form a molecule of sodium chloride.



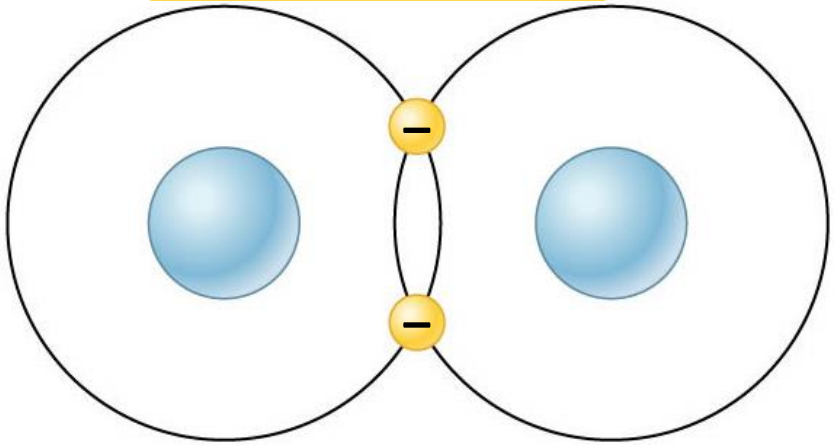
Bonds in Biology

- Weak bonds
  - hydrogen bonds
    - attraction between + and –
  - hydrophobic & hydrophilic interactions
    - interaction with H_2O
  - van derWaals forces
  - (ionic)
- Strong bonds
  - covalent bonds

Hydrogen bond



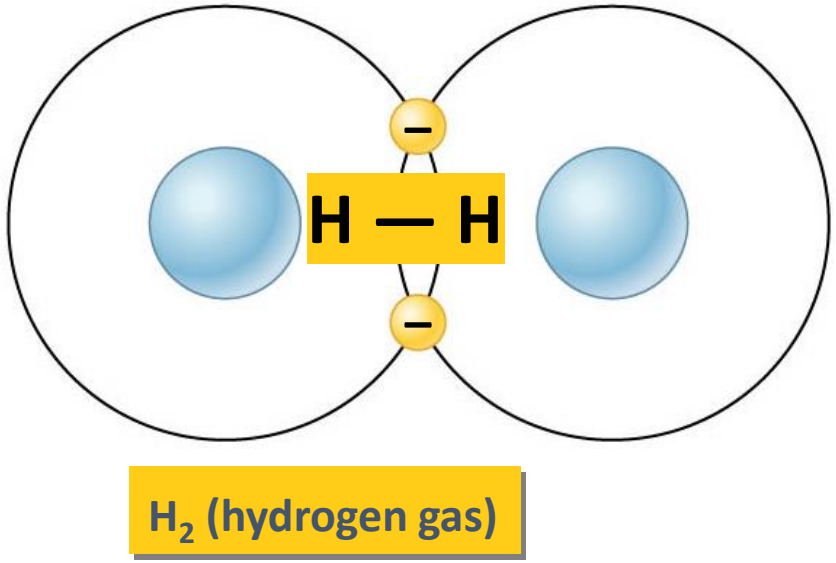
Covalent bond

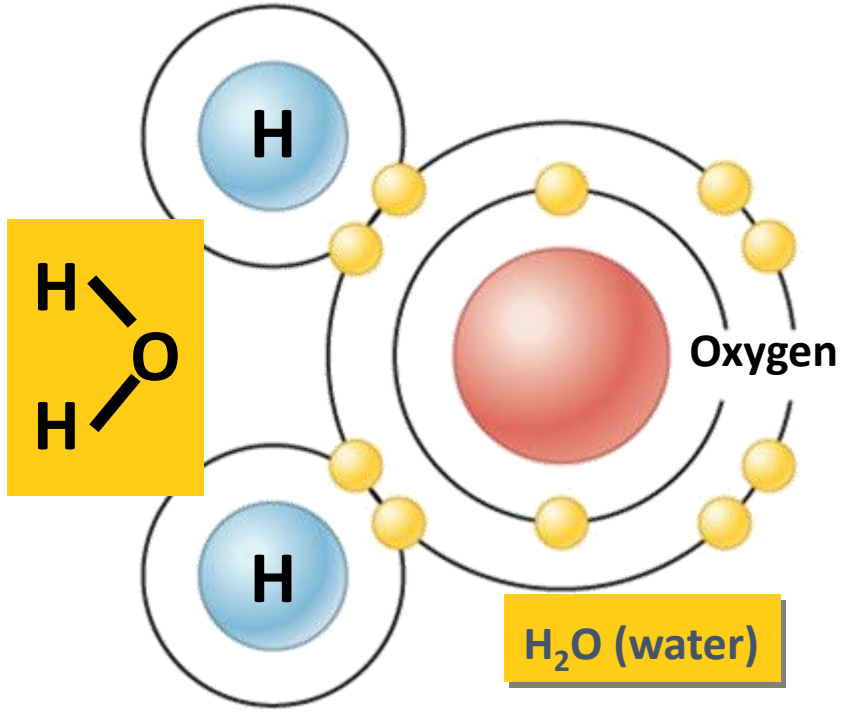


H_2 (hydrogen gas)

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



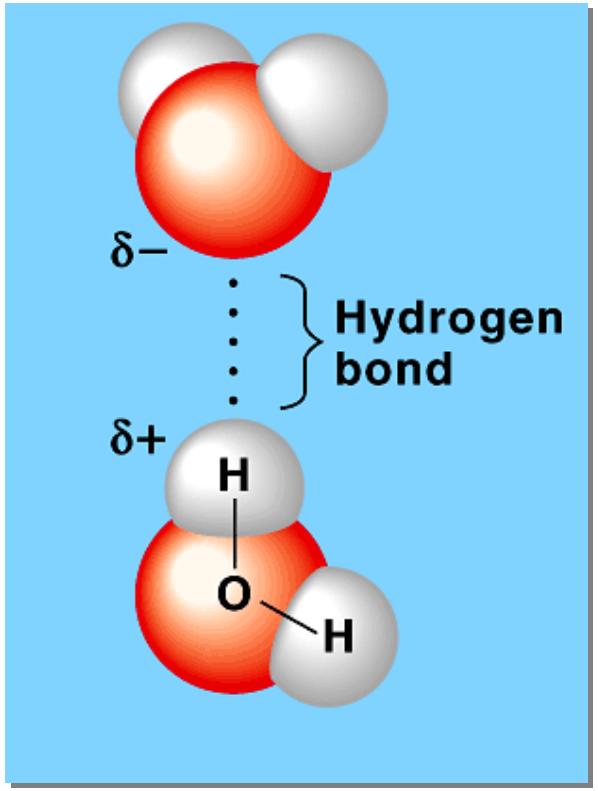


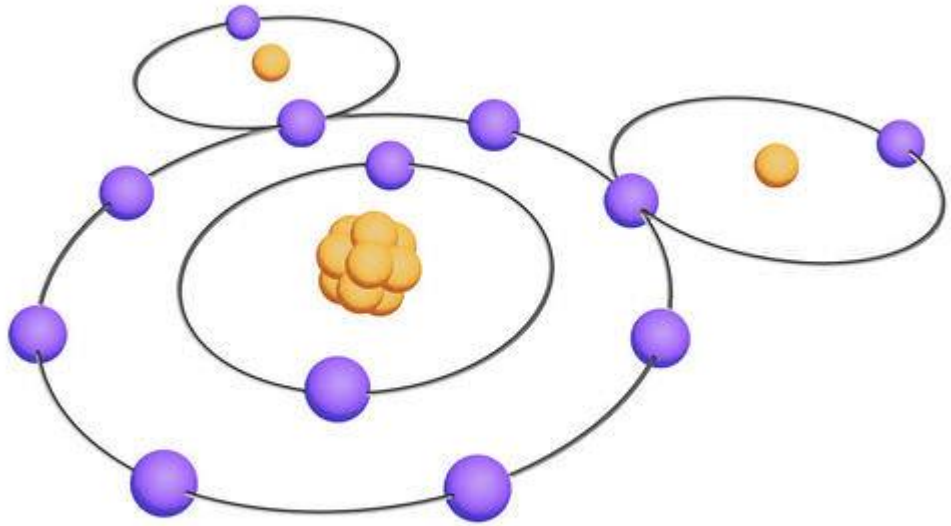
Chemistry of Life

Properties of Water

Water's Unique Properties…

- The strucutre 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





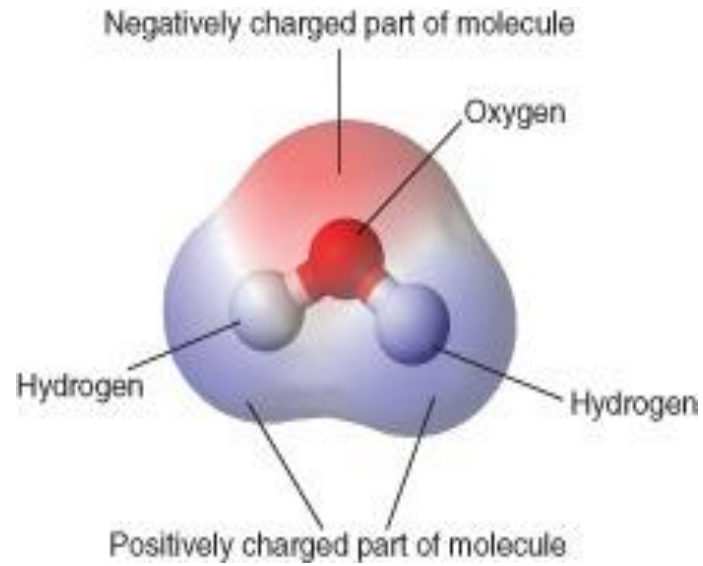


Figure: This model is an atomic diagram of water, showing the two hydrogen atoms and oxygen atom in the center. The protons (red) are in the center (nucleus) of each atom, and the electrons (light blue) circle each nucleus.

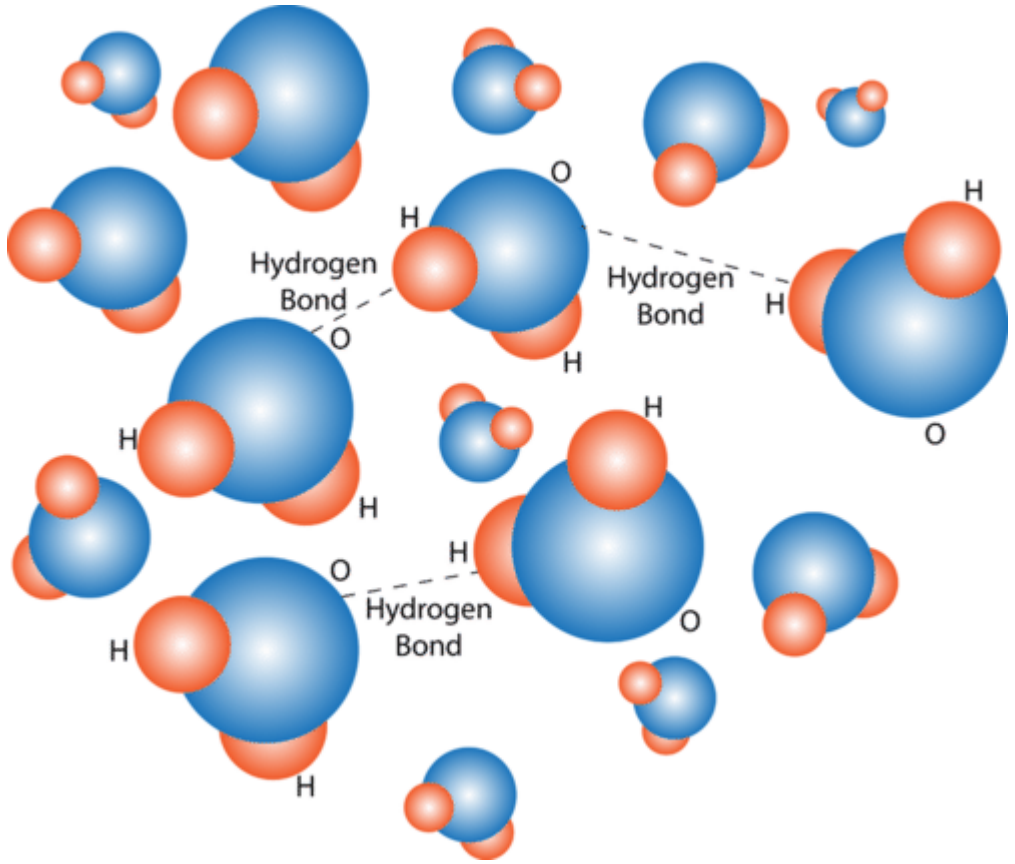
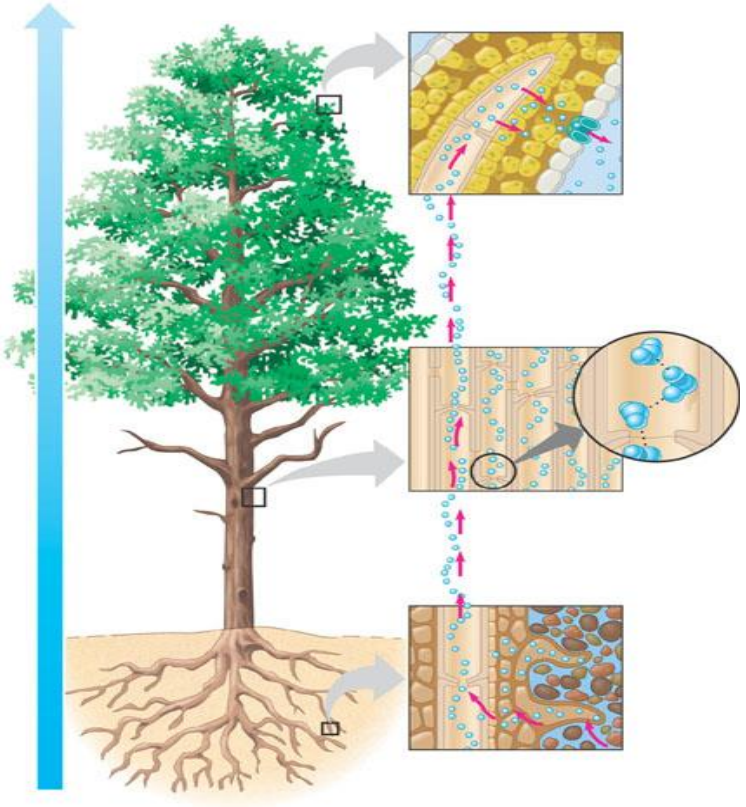


Figure: Hydrogen bonds form between positively and negatively charged parts of water molecules. The bonds hold the water molecules together. How do you think this might affect water's properties?

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…

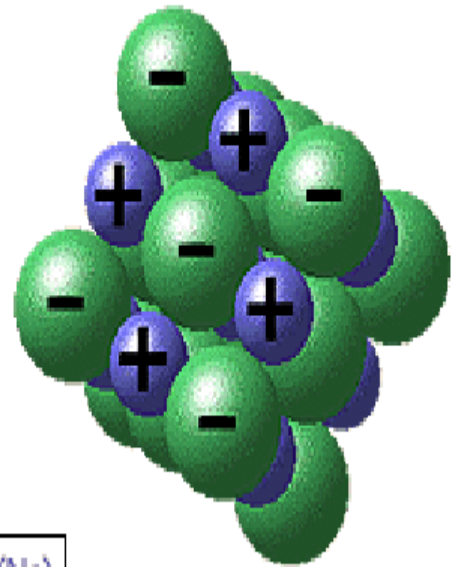
5. Expands when freezes – when water freezes its volume becomes larger than in the liquid or gas state (just the opposite of most other compounds).

- 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…

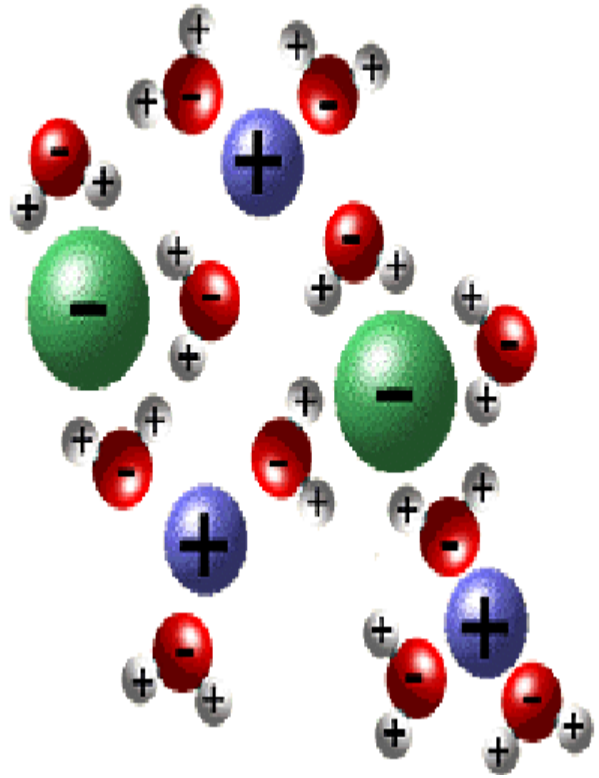
- **6. Solvent for polar molecules** – many compounds that are important for life dissolve in water.
- Water is the largest component of cells' interiors, and chemical reactions in the cell take place in water
- When one substance dissolves in another – a **solution** is made
  - Each solution is made 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



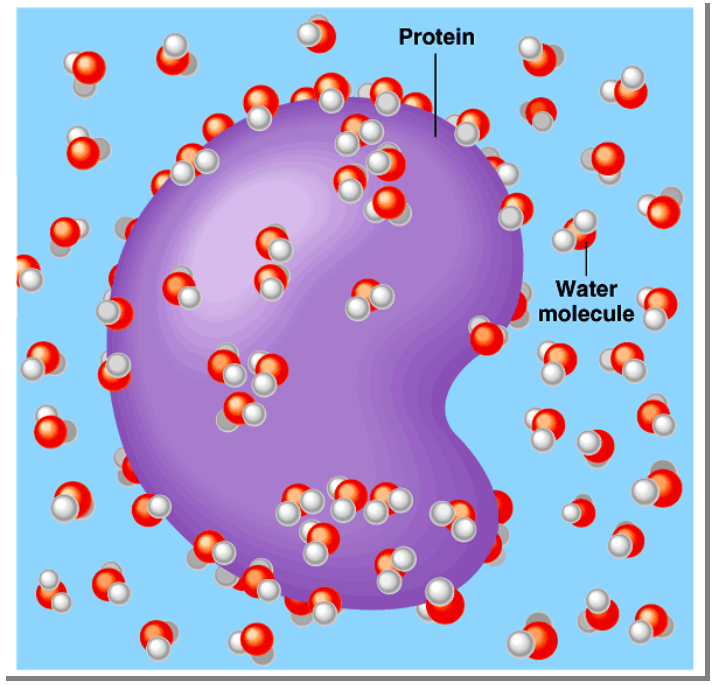
sodium (Na)
chlorine (Cl)

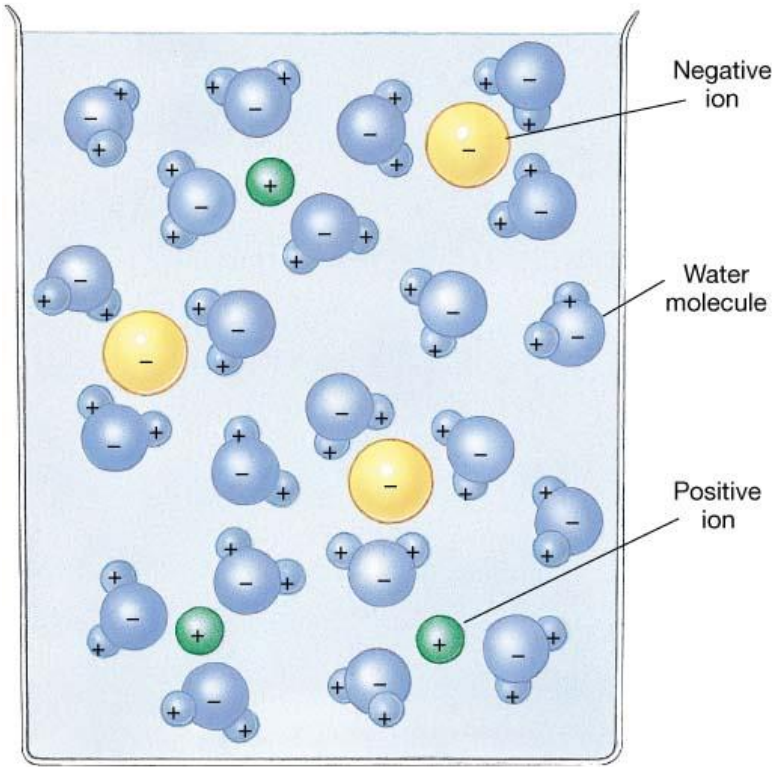
NaCl in water



What dissolves in water?

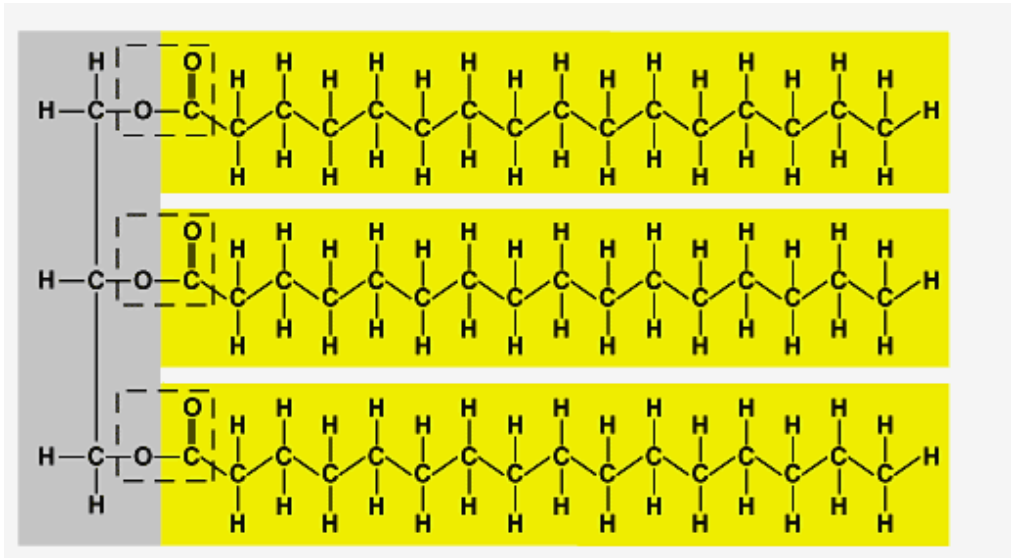
- Hydrophilic
  - substances have attraction to H_2O
  - polar or non-polar?





What doesn't dissolve in water?

- Hydrophobic
  - substances that don't have an attraction to H_2O
  - polar or non-polar?



fat (triglycerol)

Ionization of water & pH

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

$$H_2O \rightarrow H^+ + OH^-$$

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 staple 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
- O – 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