Ch. 7 Solutions

Solutes, Solvents, Solutions

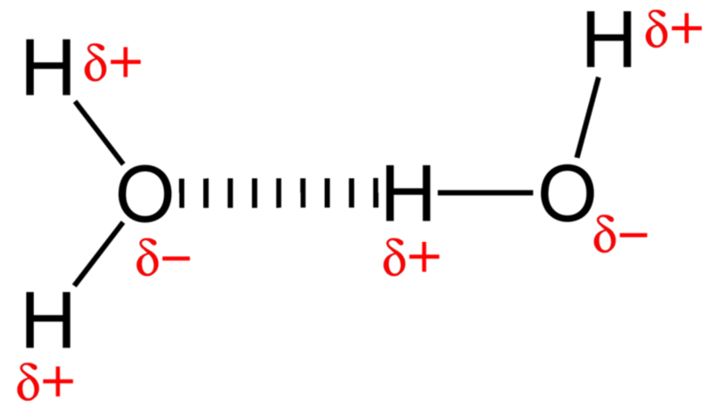
- A solution is a homogenous mixture in which one substance called the solute is uniformly dispersed in another substance called the solvent
  - Solute – substance dispersed
  - Solvent – dispersing medium
  - Solution – homogenous mixture of the two
- Ex) NaCl dissolved in water
  - Na+ and Cl- are the solutes
  - Water is the solvent
  - Na+ and Cl- dispersed in the water is the solution

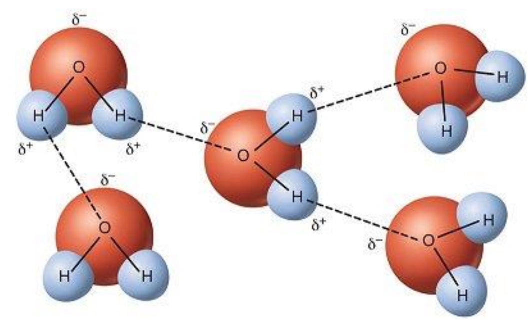
Electronegativity and Partial Charges

- Electronegativity of an element is the power of attraction which atoms of an element have for electrons in a covalent bond
- Atoms of certain elements, especially oxygen and nitrogen *(and flourine, though not as important in biomolecules)* have a strong affinity for shared electrons in a covalent bond
- Therefore atoms of these elements have a high electronegativity
- Electrons spend more time around atoms of these elements, creating a partial negative charge (δ-) around them and a partial positive charge (δ+) around the atoms they bond with, creating polar covalent bonds

Hydrogen Bonds

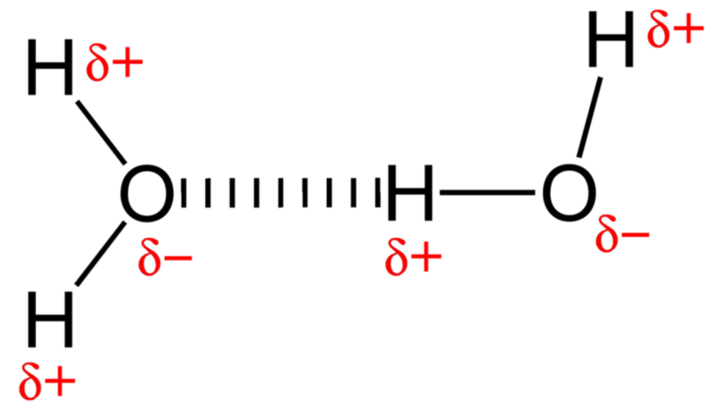
- Water (H_2O) is a polar covalently bonded molecule
  - The O atom has a δ- and the two H atoms have a δ+
  - The hydrogen atoms of one molecule of water have an attraction for the oxygen of another water molecule
  - Such attractions are called hydrogen bonds

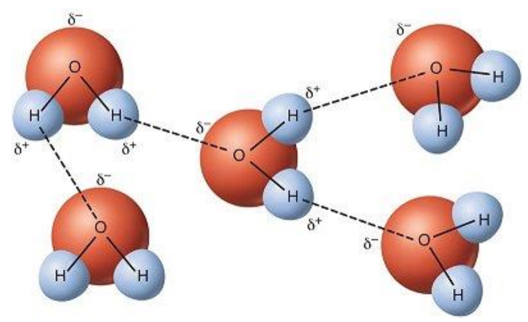




Definition - Hydrogen Bonds

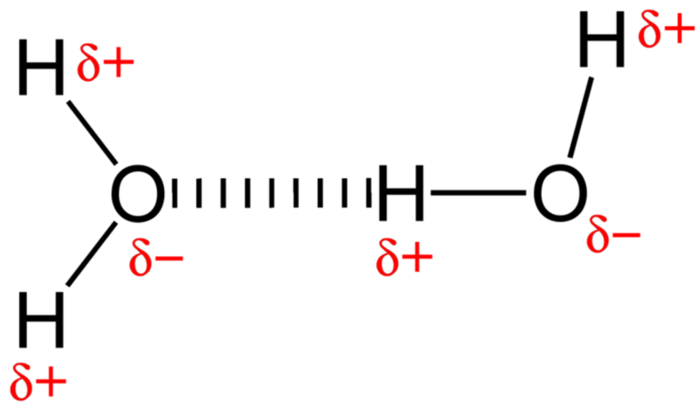
– A type of chemical bond in which a hydrogen atom which is covalently bonded to either O, N, or F forms a bond with another electronegative atom in the same or another molecule

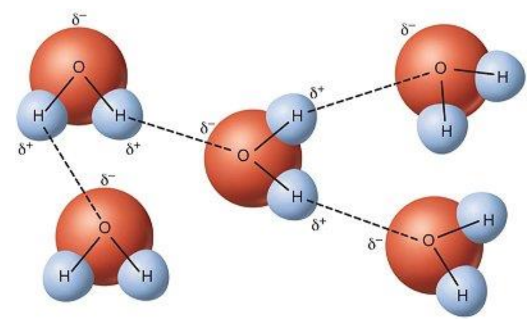




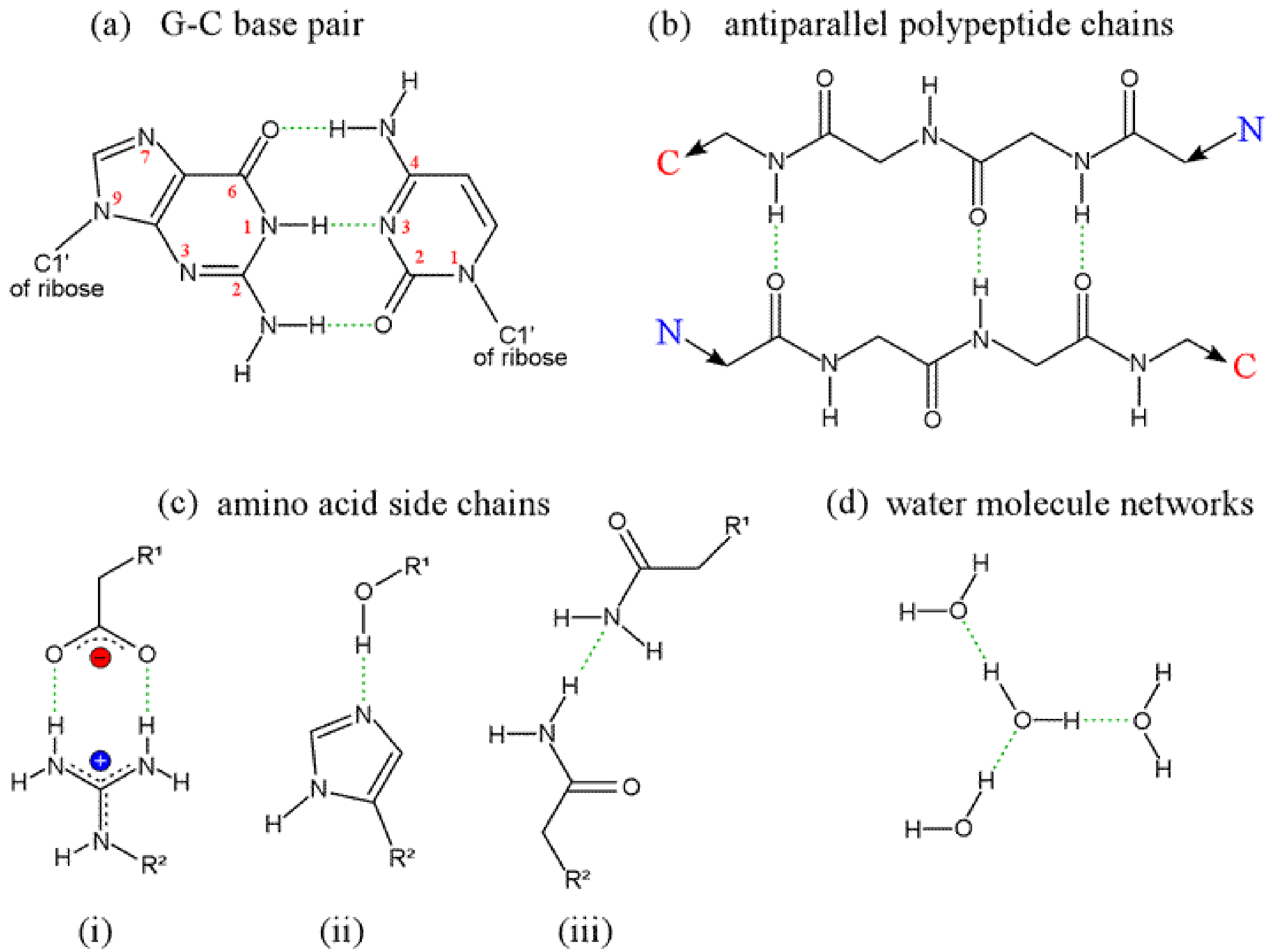
Hydrogen Bonds

– A hydrogen bond is the attraction between a δ+ on the hydrogen atom of a polar covalent bond and a δ- on an oxygen, nitrogen (or flourine) of another covalent bond
  - The polar covalent bond containing the oxygen or nitrogen atom can be in a different molecule from the hydrogen atom (as in water), or it can be in the same molecule as the hydrogen molecule (as in many proteins)
  - Hydrogen bonds are weaker than covalent bonds and are indicated by a dotted line



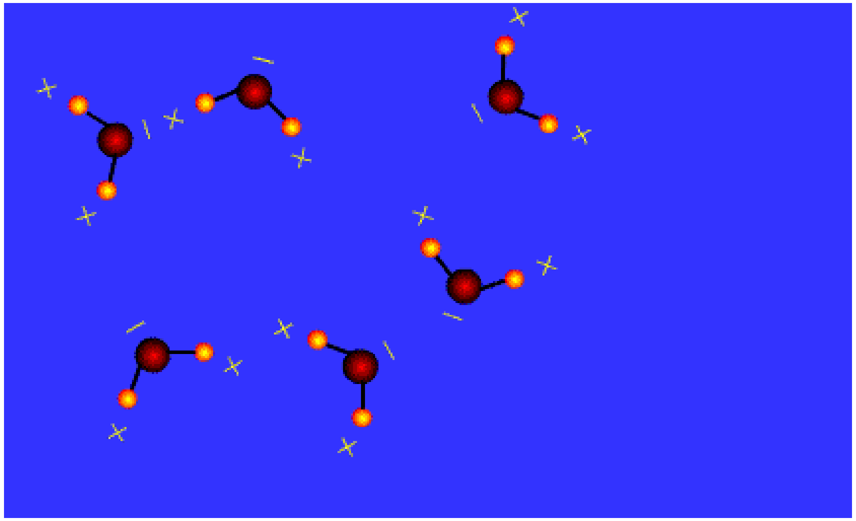


Examples of Hydrogen Bonds



Physical Properties of Water

- Hydrogen bonding occur between water molecules
- The δ+ on hydrogen or one water molecule attracts the δ- on oxygen of another water molecule
- Many of the features of hydrogen bonding make water very important in biology
- These include
  - Solubility
  - Reactivity
  - High Specific Heat Capacity
  - Lubrication



Solubility

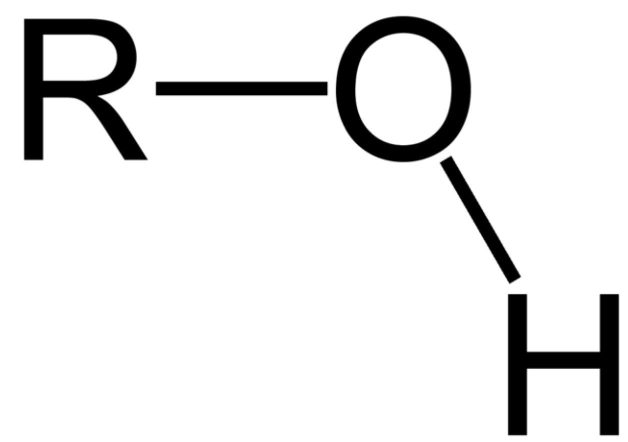
- Many organic and inorganic substances are soluble
- Soluble indicates that they will dissolve or break up in water
- Solubility involves hydrogen bonding
- Solubility is seen with molecules with polar covalent bonds and with molecules with ionic bonds

Solubility and Covalent Bonds

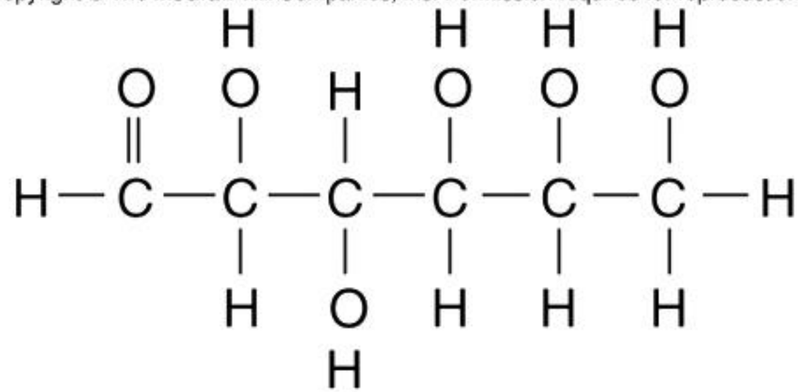
- Solubility of molecules with polar covalent bonds
  - Many organic molecules contain polar covalent bonds
  - The hydration spheres that form around these molecules carry them into the solution
  - Molecules that interact readily with water are said to be hydrophilic (water loving)
  - Molecules without any (or without many) polar covalent bonds are hydrophobic (water hating)

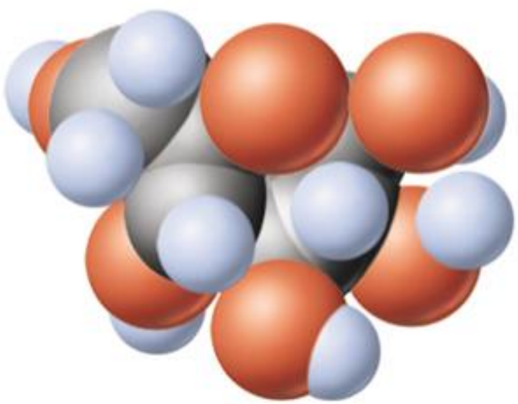
Biochemical Significance of Molecules that are Hydrophilic

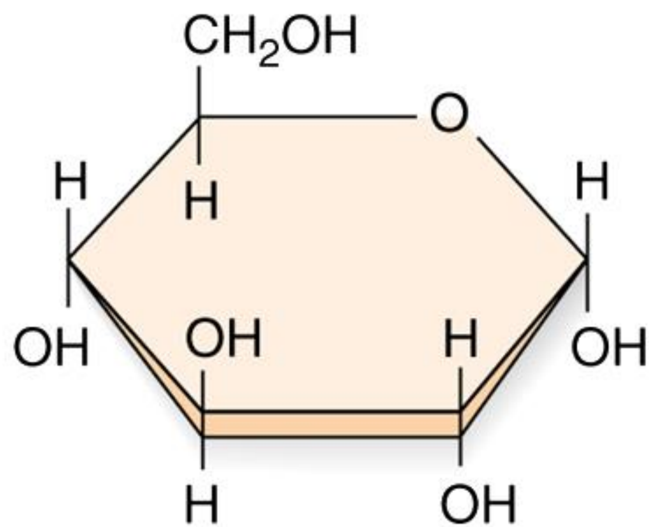
- Many biomolecules such as carbohydrates have a –OH (hydroxyl) group
  - A –OH group is an oxygen covalently bonded to a hydrogen
  - They are often indicated as illustrated to the right
  - R is another atom covalently bonded to oxygen, if R=H, this would be a water molecule
- Through these groups, a carbohydrate is able to hydrogen bond with water
- Thus sugar mixes well with water
- Such substances are said to be hydrophilic



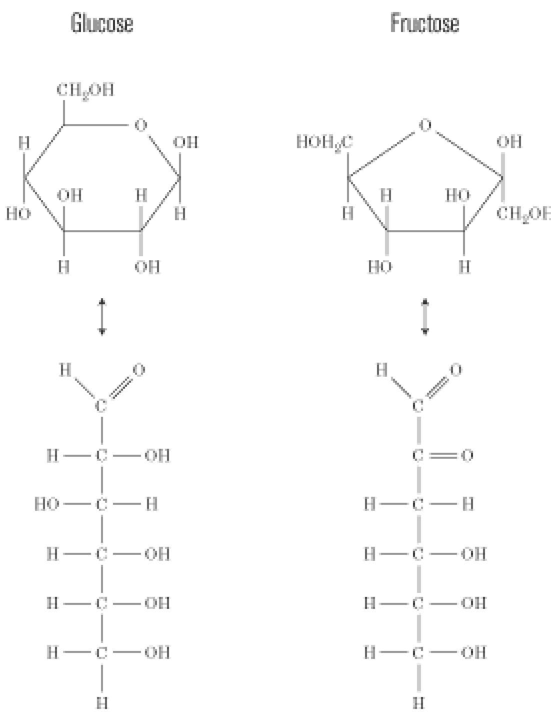
Glucose

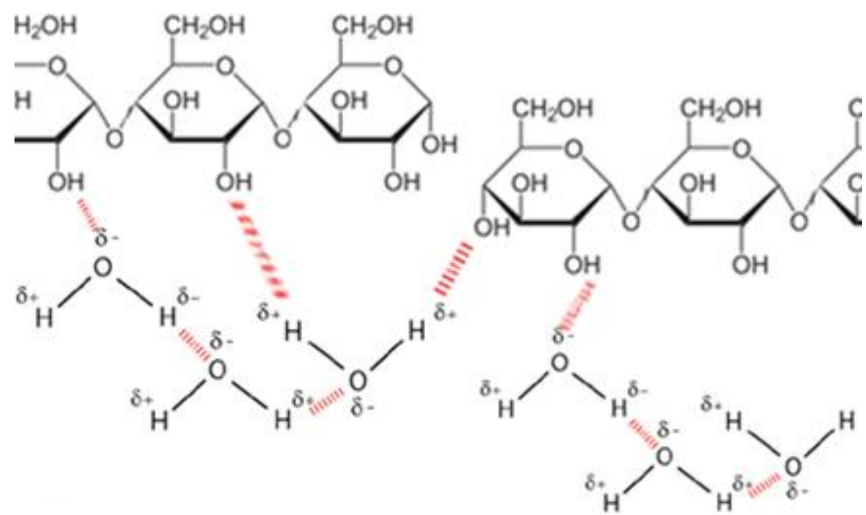






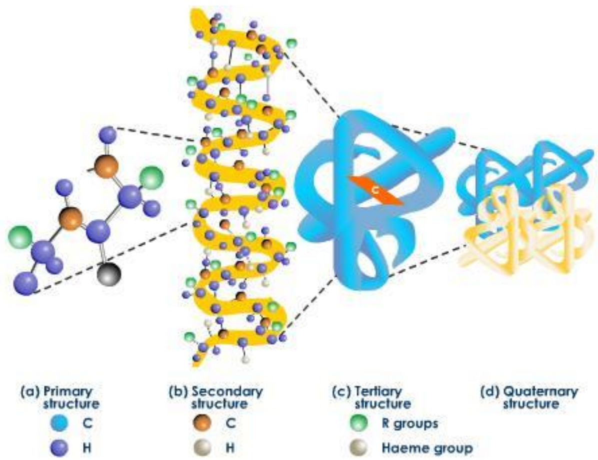
Structural Formulas illustrating Carbohydrates Solubility in Water

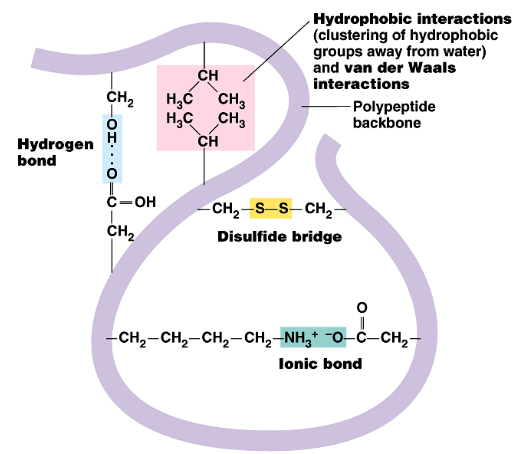




Protein Solubility in Water

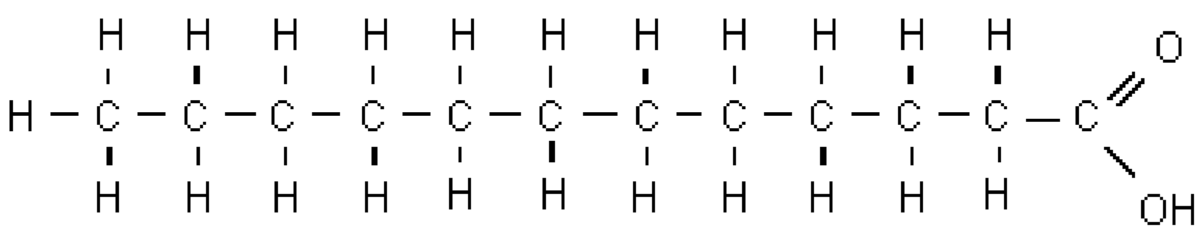
- Globular proteins, such as enzymes, peptide hormones and antibodies, are generally soluble in water because they fold in such a way that their hydrophilic groups are on the outside of the molecule





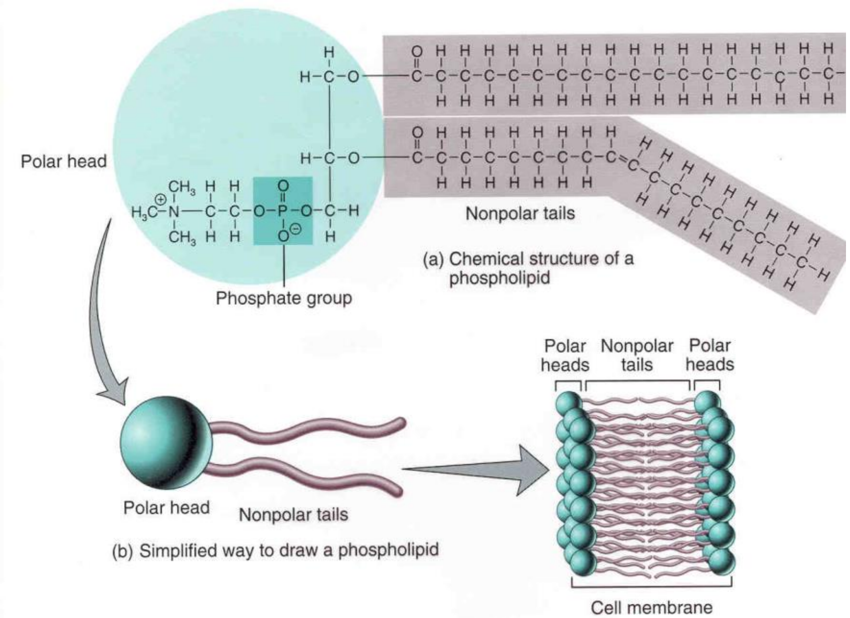
Hydrophobic

- Many molecules or parts of molecules are hydrophobic or ‘water hating’
- These include hydrocarbons, fatty acid chains and some parts of amino acids
- Hydration spheres do not form around these molecules and they do not dissolve in water
- Groups of such molecules tend to cluster together (such as oil in water)



Phospholipid Bilayer of Cell Membrane

- Phospholipids make up the bulk of a cell membrane
- Phospholipids are composed of a phosphate group (PO_4^{3-}) linking a diglyceride to a nonlipid group
  - A diglyceride is made up of two fatty acids with a glycerol backbone
  - Placing –lipid at the end of its name indicates that the molecule consists primarily of lipid
  - Lipids are hydrophobic, however the nonlipid end is hydrophilic
  - Phospholipids in cell membranes are organized in a double layer with the hydrophobic portions facing each other and way from both the extracellular and intracellular fluids, while the nonlipid group is in contact with the extracellular and intracellular fluids

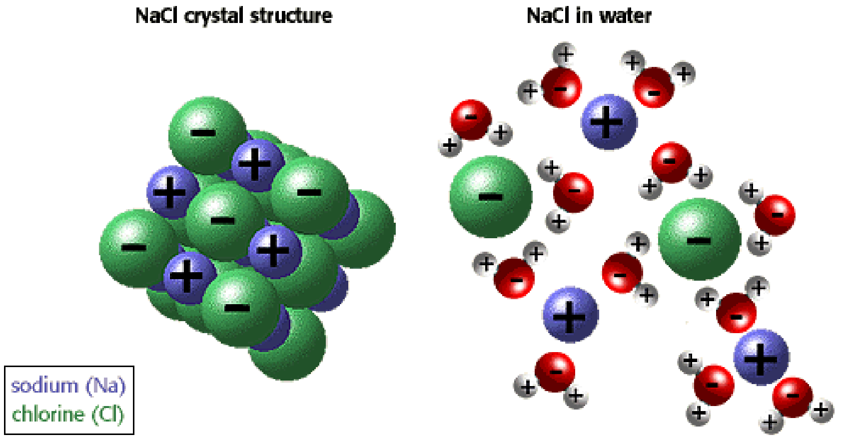


Solubility and Ionic Bonds

- Solubility of compounds with ionic bonds
  - Water is a bent molecule with the hydrogen atoms close together
  - This causes water molecules to have a negative and a positive pole
  - Many inorganic compounds are held together by ionic bonds (at least partially)
  - Ionic bonded compounds dissociate in water
  - This means that the ionic bonds are broken and the ions are surrounded by water molecules
  - The positive ions will be surrounded by the oxygens and the negative ions will be surrounded by the hydrogens

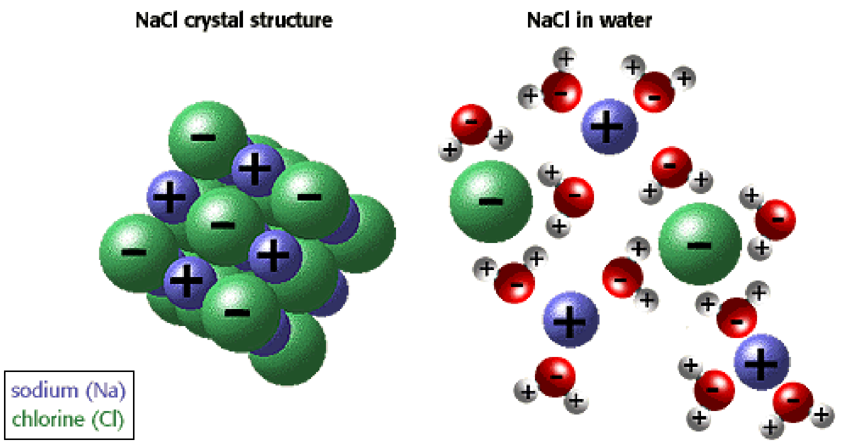
Ionic Compound Solubility in Water

- Ionic bonded substances such as NaCl are soluble in water because the water molecule are able to surround their ions



Electrolytes

- Ionic bonded compounds dissociate in water
- Cations are surrounded by the δ- oxygen atoms of water molecules and the anions are surrounded by the δ+ of the hydrogen atoms of water molecules
- A solution with dissociated ions can conduct an electric current
  - Cations move towards the negative terminal and anions move towards the positive terminal
  - Soluble inorganic compounds whose ions will conduct an electric current are called electrolytes
  - Electrolyte are crucial for many reasons such as creating a charge gradient across the plasma membrane
  - Common electrolytes and ions released in body fluids are listed on the following page



Important Electrolytes That Dissociate in Body Fluids

NaCl (sodium cloride)	→	$Na^+ + Cl^-$
KCl (potassium chloride)	→	$K^+ + Cl^-$
$CaCl_2$(calcium chloride)	→	$Ca^{2+} + 2Cl^-$
$NaHCO_3$ (sodium bicarbonate)	→	$Na^+ + HCO^{3-}$
$MgCl_2$ (magnesium cloride)	→	$Mg^{2+} + 2Cl^-$
Na_2HPO_4 (disodium phosphate)	→	$2Na+ + HPO_4^{2-}$
Na_2SO_4 (sodium sulfate)	→	$2Na^+ + SO_4^{2-}$

Electrolytes Role in the Body

- Chemically, electrolytes are substances that become ions in solution and acquire the capacity to conduct electricity
- Electrolytes are present in the human body, and the balance of the electrolytes in our bodies is essential for normal function of our cells and our organs
- Electrolytes affect the amount of water in your body, the acidity of your blood (pH), your muscle function, and other important processes
- You lose electrolytes when you sweat. You must replace them by drinking fluids that contain electrolytes. Water does not contain electrolytes.
- Common electrolytes that are measured by doctors with blood testing include sodium, potassium, chloride, and bicarbonate, calcium, phosphorous

Electrolytes and Nonelectrolytes

- Electrolytes
  - When solutes called electrolytes dissolve in water, they separate into ions forming solutions that are able to conduct an electrical charge
    - They can be further classified as
      - Strong electrolytes (100 percent dissociate in water)
        - $Mg(NO_3)_2$ $Mg^{2+}(aq) + 2NO_3^-(aq)$
      - Weak electrolytes dissolve mostly as molecules, but a percentage will dissociate as ion
        - HF $H^+(aq) + F^-(aq)$
- Nonelectrolytes
  - When nonelectrolytes dissolve in water, they dissolve as molecules, not ions. They do not conduct an electric charge
    - $C_{12}H_{22}O_{11}(s)$ $C_{12}H_{22}O_{11}(aq)$

Electrolytes in Body Fluids

- Ch. 7, Pg 254

Solubility

- The term solubility is used to describe the amount of a solute that can dissolve in a given amount of solvent
- Many factors contribute to solubility
  - Type of solute
  - Type of solvent
  - Temperature

Gout and Kidney Stones (A Problem of Saturation in Body Fluids)

- Ch. 7, pg 256

Electrolytes Role in the Body

- Electrolytes can be acids, bases, and salts.
- They can be measured by laboratory studies of the blood in different ways. Each electrolyte can be ordered as a separate test, such as:
  - Ionized calcium, serum calcium, serum chloride, serum magnesium, serum phosphorous, serum potassium, serum sodium
  - Note: Serum is the part of the blood that doesn’t contain cells
- Sodium, potassium, and chloride can also be ordered as part of an electrolyte panel, a basic metabolic panel or a comprehensive metabolic panel
- The electrolyte – urine test measures electrolytes in urine. It usually measures the levels of calcium, chloride, potassium, or sodium.

Electrolytes Role in the Body

- Electrolyte balance can be disturbed a number of ways such as:
  - Too little water intake or loss of water due to excessive diarrhea or vomiting (especially important for Na^+)
  - Kidney disease
  - Liver disease
  - Congestive heart failure

Electrolytes Role in the Body - Sodium

•Sodium is the major positive ion (cation) in fluid outside of cells.

•The chemical notation for sodium is Na+.

•Excess sodium (such as that obtained from dietary sources) is excreted in the urine.

•Sodium regulates the total amount of water in the body and the transmission of sodium into and out of individual cells also plays a crucial role in membrane potential and action potentials

•Therefore, too much or too little sodium can cause cells to malfunction, and extremes in the blood sodium levels (too much or too little) can be fatal.

•**Increased sodium (hypernatremia)** in the blood occurs whenever there is excess sodium in relation to water. There are numerous causes of hypernatremia; these may include kidney disease, too little water intake, and loss of water due to diarrhea and/or vomiting.

•**A decreased concentration of sodium** hyponatrium occurs whenever there is a relative increase in the amount of body water relative to sodium. This happens with some diseases of the liver and kidney, in patients with congestive heart failure, in burn victims, and in numerous other conditions.

•A Normal blood sodium level is 135 - 145 milliEquivalents/liter (mEq/L), or in international units, 135 - 145 millimoles/liter (mmol/L).

Electrolytes Role in the Body Potassium

- •Potassium is the major positive ion (cation) found inside of cells.
- •The chemical notation for potassium is K+.
- •The proper level of potassium is essential for normal cell function.
- •Among the many functions of potassium in the body are regulation of the heartbeat and the function of the muscles.
- •A seriously abnormal increase in potassium (hyperkalemia) or decrease in potassium (hypokalemia) can profoundly affect the nervous system and increases the chance of irregular heartbeats (arrhythmias), which, when extreme, can be fatal.
- •**Increased potassium is known as hyperkalemia.** Potassium is normally excreted by the kidneys, so disorders that decrease the function of the kidneys can result in hyperkalemia. Certain medications may also predispose an individual to hyperkalemia.
- •**Hypokalemia, or decreased potassium**, can arise due to kidney diseases; excessive loss due to heavy sweating, vomiting, or diarrhea, eating disorders, certain medications, or other causes.
- •The normal blood potassium level is 3.5 - 5.0 milliEquivalents/liter (mEq/L), or in international units, 3.5 - 5.0 millimoles/liter (mmol/L).

Electrolytes Role in the Body Chloride

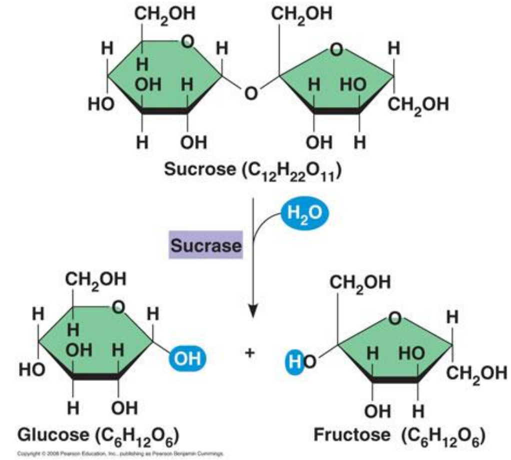
- Chloride is the major anion (negatively charged ion) found in the fluid outside of cells and in the blood.
- The chemical notation for chloride is Cl^-
- Chloride also plays a role in helping the body maintain a normal balance of fluids.
- The balance of chloride ion (Cl^-) is closely regulated by the body. Significant increases or decreases in chloride can have deleterious or even fatal consequences:
- **Increased chloride (hyperchloremia):** Elevations in chloride may be seen in diarrhea, certain kidney diseases, and sometimes in overactivity of the parathyroid glands.
- **Decreased chloride (hypochloremia):** Chloride is normally lost in the urine, sweat, and stomach secretions. Excessive loss can occur from heavy sweating, vomiting, and adrenal gland and kidney disease.
- The normal serum range for chloride is 98 - 108 mmol/L.

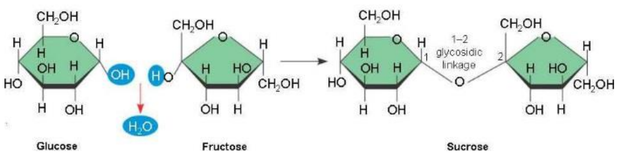
Electrolytes Role in the Body Bicarbonate

- The bicarbonate ion acts as a buffer to maintain the normal levels of acidity (pH) in blood and other fluids in the body. Bicarbonate levels are measured to monitor the acidity of the blood and body fluids. The acidity is affected by foods or medications that we ingest and the function of the kidneys and lungs.
- The bicarbonate test is usually performed along with tests for other blood electrolytes.
- Disruptions in the normal bicarbonate level may be due to diseases that interfere with respiratory function, kidney diseases, metabolic conditions, or other causes.
- The chemical notation for bicarbonate on most lab reports is HCO_3^- or represented as the concentration of carbon dioxide (CO_2). The normal serum range for bicarbonate is 22-30 mmol/L.

Reactivity

- In our bodies, chemical reactions occur in water, and water molecules are also participants in some reactions
  - Hydrolysis and dehydration synthesis are two important examples
    - Hydrolysis is a type of catabolic reaction in which a complex molecule is broken down and the components of water (H+ and OH-) are added to the fragments
    - Dehydration synthesis is a type of anabolic reaction that involves the formation of a complex molecule by the removal of water





High Heat Capacity

- Heat Capacity is the ability to absorb and retain heat
- Because water molecules are attracted to one another due to hydrogen bonding, temperatures have to be very high before individual molecules have enough energy to break apart and become vapors
- Therefore water resists changes and moderates temperatures (both externally and internally)
- Because water accounts for 2/3rds of body weight, water helps stabilize body temperature
- Water in the blood plasma is able to pick up large amounts of heat and release this as it travels close to the surface
- When water at the body surface does vaporize in the form of perspiration, it carries it carries away a significant amount of heat

Homogenous Mixtures: Solutions, Colloids, Suspension

- Homogenous mixtures come in three forms
  - Solutions, colloids and suspensions
  - Suspensions include particles that are greater than 7500nm, these particles are too large to stay evenly dispersed and if left alone, sedimentation will form
    - This is the case for blood
    - Whole blood is a suspension of blood cells in plasma
    - If blood is removed from the body and clotting is prevented, blood cells will settle to the bottom of a container
    - This settling rate "sedimentation rate, sed rate, or eurythrocyte sedimentation rate (ESR)" can be measured for clinical reasons
  - Solutions include solutes that are < 2nm
    - If the solutes are dissolved in an aqueous solution of water it is written as $X_{(aq)}$
  - Colloids are in between and include particles that are 2-500nm
    - Colloids are an essential component of the ECM of connective tissue
  - *Molecule size is not necessary to remember, but colloids have interesting properties biologically*

Colloids and Suspensions

- Colloids
  - A solution containing dispersed proteins and/or other large molecules
    - Colloids differ from solutes primarily in the size of the molecules

Colloids and Suspensions

- Colloids in biological systems
  - Many large and complex organic molecules such as proteins or protein complexes (proteoglycans in the ECM) are held in a solution because of intermolecular forces
  - These can form thick viscous colloid dispersions with interesting properties

Colloids and Suspensions

- Colloids in biological systems
  - Remember the ingredients of connective tissue
    - Specialized cells
    - ECM
      - » Fibers
      - » Ground substance (colloids composed of proteoglycans and)
  - Colloids can go back and forth from a gel to a sol state
  - Colloids respond to the following
    - Heat
    - Cold
    - pH
    - Movement
  - Colloids will go towards their gel state under the following situations
    - Cold, immobilization, inflammation, infection, acidic pH
  - Colloids will go towards their sol state under the following conditions
    - Heat, less acidic pH, mobilization

Colloids and Solutions in the Body

- Ch. 7, pg 270

Osmotic Pressure

In Osmosis, water molecules move across a selectively permeable membrane from a region of low concentration of solutes to a region of high concentration of solutes

Osmotic pressure is the force created across a semipermeable membrane in the body

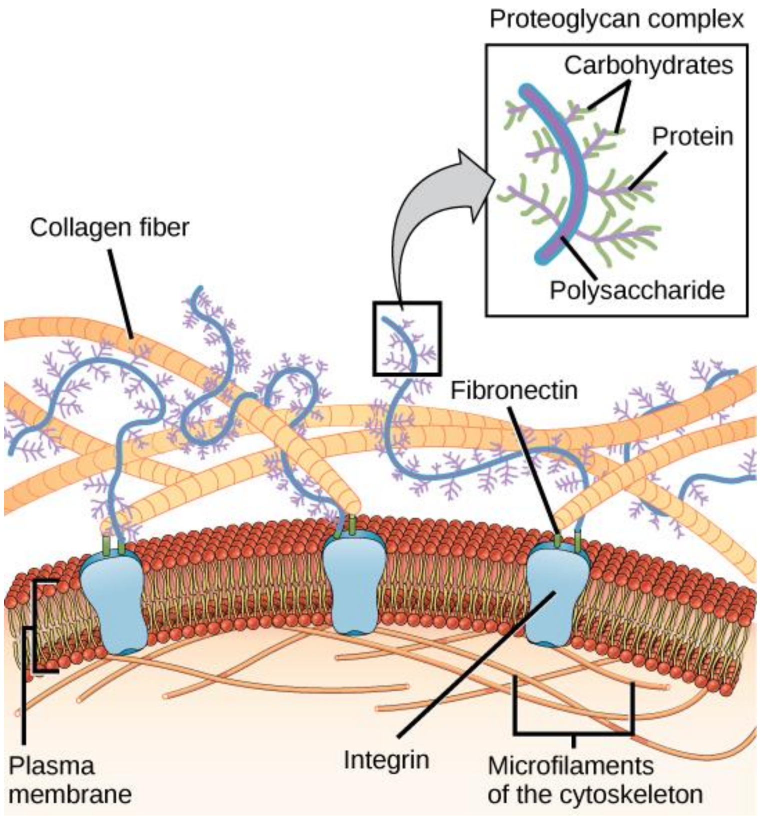
This is seen in across the capillaries and influences the movement of plasma and interstitial fluid

Cell Structure

- Cells consist of
  - Plasma membrane
  - Cytoplasm
    - Cytosol
    - Organelles
    - Nucleus

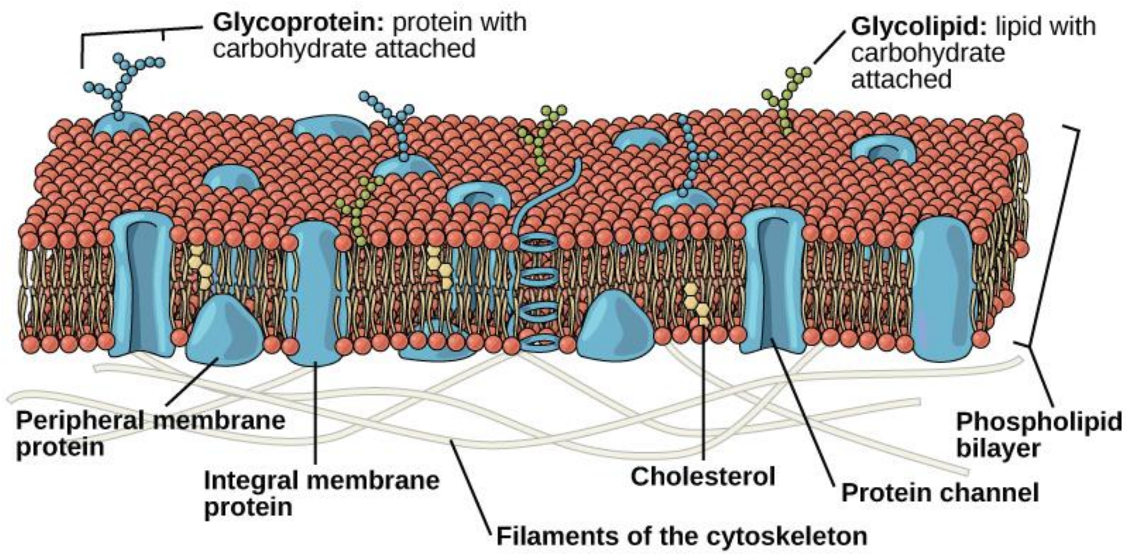
Plasma Membrane

- The plasma membrane consists of the following:
    - Phospholipid bilayer
    - Proteins
    - Carbohydrates
    - Steroids
- We will primarily discuss the structure and role of the phospholipid bilayer and the proteins



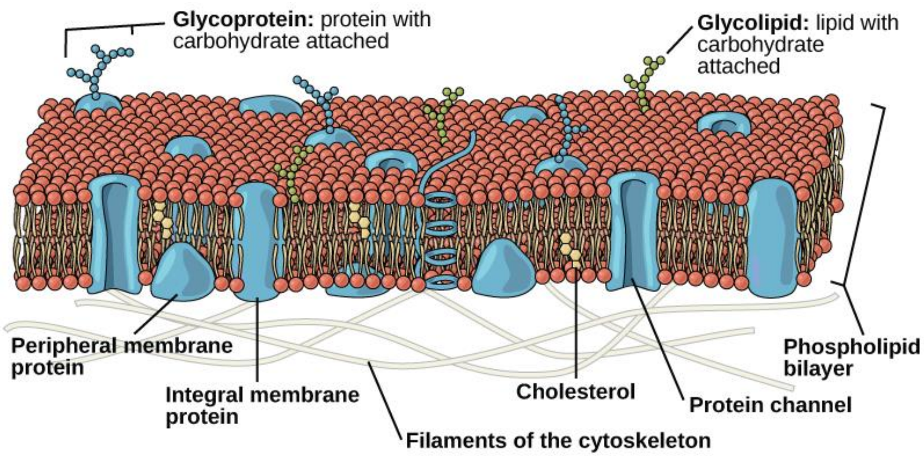
Phospholipids Bilayer

- Forms most of surface area of the the cell membrane (though only 42 percent of weight)
- Contains a diglyceride (two fatty acids bonded to a glycerol backbone) and a phosphate group
- Have hydrophilic end (phosphate portion) and hydrophobic end (lipid portion)
- Large molecules and water soluble solutes cannot pass through the lipid bilayer so it serves as the primary barrier



Proteins of the Plasma Membrane

- Proteins serve many roles on the plasma membrane. They can be one or more of the following:
  - Anchoring proteins - Attach cell membrane to other structures and stabilize its position
  - Recognition proteins - Recognized by the immune system as either self or not self
  - Receptor proteins - Sensitive to extracellular molecules such as neurotransmitters or hormones
  - Carrier proteins - Binds solutes and transports them across the membrane
  - Channels - Permits movement of ions across plasma membrane
  - Ions and water soluble material do not dissolve in lipids and can not cross the lipid bilayer, they use these channels to cross

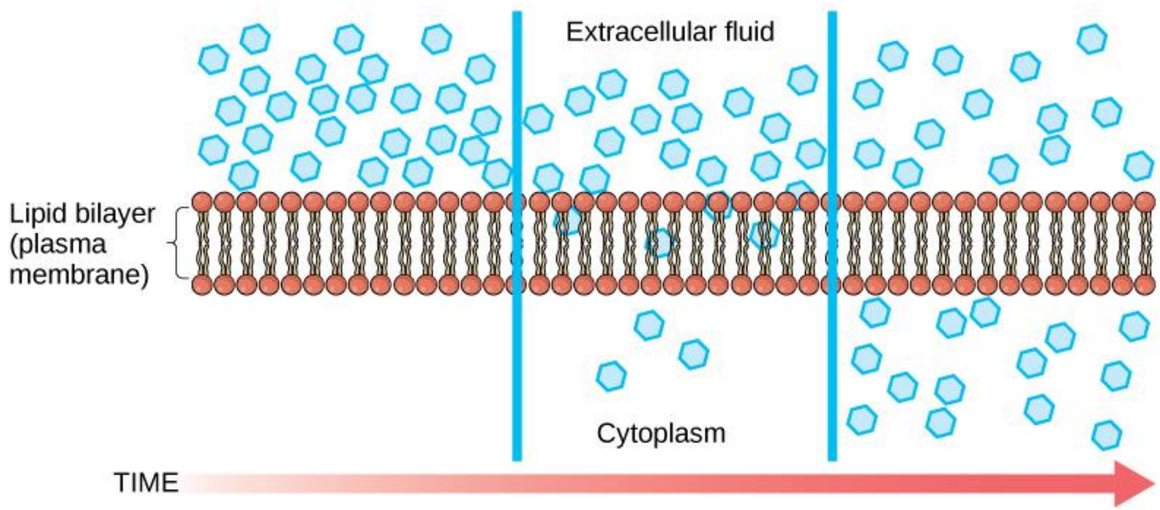


Plasma Membrane Function

- The plasma membrane performs the following functions:
  - Acts as a physical barrier between the inside and outside of the cell
  - Regulates exchange between the inside and outside of the cell
  - Sensitivity – responds to chemical, pH and mechanical changes in the extracellular environment
  - Provides structural support

Movement of Substances Across the Plasma Membrane

- The plasma membrane is selectively permeable
- Certain substances can move freely across, others can not
- The movement of these substances is regulated by the proteins structures on the membrane
- The movement is either passive (no ATP required) or active (requires ATP)



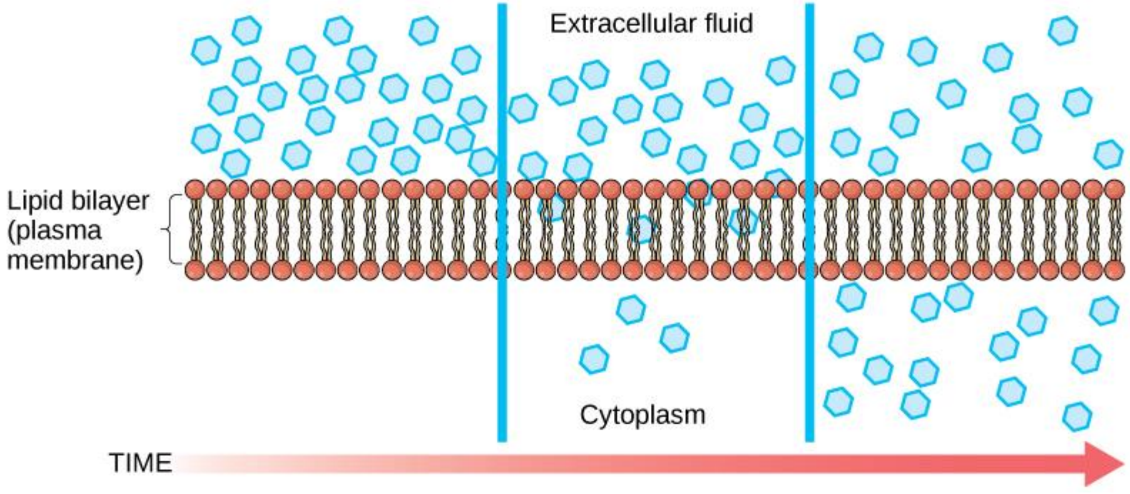
Passive Transport Mechanisms

- Passive Transport requires no energy
- The energy is inherent in the concentration gradient.
- Passive transport involve several types of diffusion which means that the substances move from high concentration to low concentration

- These types of diffusion are:
  - Simple diffusion
  - Osmosis
  - Channel-mediated diffusion
  - Facilitated diffusion

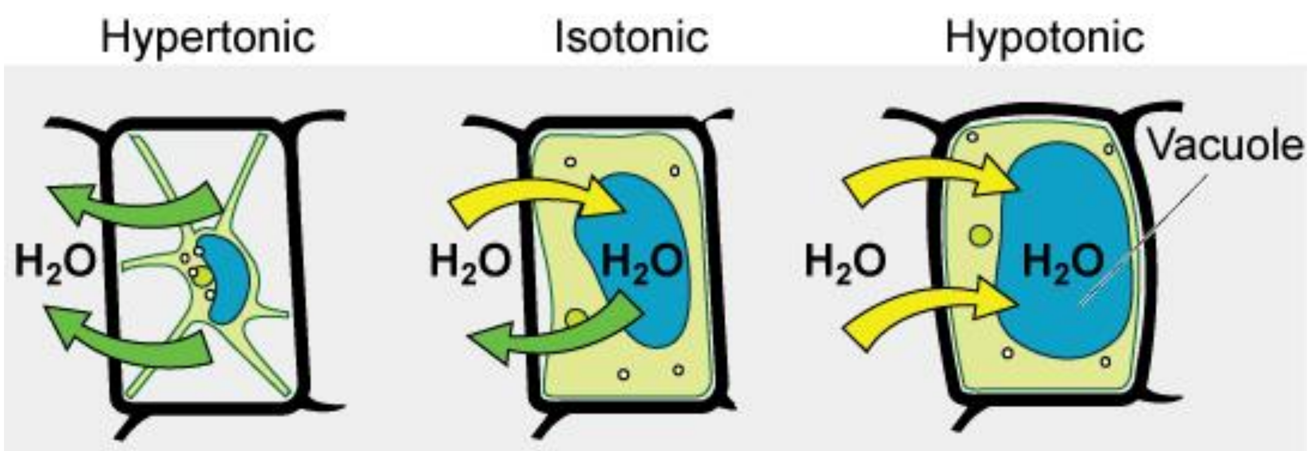
Simple Diffusion

- Substances move from an area of higher concentration to an area of lower concentration
- Therefore substances move down there concentration gradient
- Some substances can diffuse through the lipid portion of the cell membrane (alcohol, fatty acids, steroids, dissolved gases, lipid soluble drugs)
  - Example) Carbon Dioxide, plasma membrane is freely permeable to CO_2
  - Concentrations build up within the cell, CO_2 diffuses down its concentration gradient to the interstitial fluid



Simple Diffusion and Osmosis

- The movement of water across a selectively permeable membrane (permeable to water and not to the solutes)
- Water moves in the direction of the higher concentration of solutes
- Movement occurs between two solutions which have either the same, more, or less solutes
  - Isotonic – the two solutions have the same concentration of solutes, no net movement occurs
  - Hypertonic – this solution has a higher concentration of solutes
  - Hypotonic – this solution has a lower concentration of solutes



Review Question on Properties of Water

- What type of bonds are found between individual atoms in a water molecule?
  - Polar covalent bonds
- Which atom of a water molecule has a high electronegativity?
  - Oxygen
- What partial charges are found in the atoms that make up water?
  - δ- on oxygen, and δ+ on the hydrogen atoms
- What kind of intermolecular bonds hold water molecules together? Explain how these work?
  - Hydrogen bonds
  - The δ+ on the hydrogen bonds with the δ- on the oxygen of another water molecule
- We discussed four properties of water that were due to hydrogen bonding
  - Solubility
  - Reactivity
  - High heat capacity
  - Lubrication