Course: Cell Physiology-PHYS-115

CHEMISTRY REVIEW

Chemical Reactivity, Bonds, Reactions, Enzymes, Water

Learning Objectives:

- ❖ Define the term “atom”. List the subatomic particles, and describe their relative masses, charges, and positions in the atom.
- ❖ Define atomic number, atomic mass number, and isotope,
- ❖ Define molecule, and distinguish between a compound and a mixture.
- ❖ Explain the role of electrons in chemical bonding and in relation to the octet rule.
- ❖ Differentiate among ionic, covalent, and hydrogen bonds.
- ❖ Compare and contrast polar and nonpolar compounds.
- ❖ Define the three major types of chemical reactions: synthesis, decomposition, and exchange. Comment on the nature of oxidation-reduction reactions and their importance.
- ❖ Describe the enzymatic reaction and explain “the lock & key hypothesis”.
- ❖ Describe the basic three types of mixtures.
- ❖ Describe the role of water in life.
- ❖ Define “diffusion” and “osmosis” and describe their biological effects.

Introduction:

- Cell biology provides the meeting place between chemistry and anatomy.

- Only by understanding the basic concepts of chemistry, we can appreciate the close relationship that exists between structure & function within cells and tissues.

Chemical Reactivity:

- **Chemical reactions** occur when ***atoms*** combine with, or dissociate from, other atoms.

- A **chemical bond** forms when atoms unite chemically, with an ***energy relationship.***

- ***Atoms:*** The word *atom comes from the Greek word meaning "**indivisible**"* However, we now know that atoms are clusters of even smaller particles called ***protons, neutrons,*** and ***electrons.***

Chemical Reactivity:

- An atom's ***subatomic particles*** differ in ***mass, electrical charge***, and ***position in the atom.***

- An atom has a central **nucleus** *containing protons and neutrons* tightly bound together. The nucleus, in turn, is surrounded by *orbiting electrons*.

- *Protons bear a positive electrical charge*, and *neutrons are neutral*, so the nucleus is positively charged. The tiny *electrons bear a negative charge* equal in strength to the positive charge of the proton.

- All atoms are electrically neutral because the number of protons in an atom is precisely balanced by its number of electrons. e.g., *hydrogen has one proton and one electron, and iron has 26 protons and 26 electrons*. ***For any atom, the number of protons and electrons is always equal.***

Chemical Reactivity:

- ***The atomic number of any atom is equal to the number of protons*** in its nucleus and is written as a subscript to the left of its atomic symbol. Hydrogen, with one proton, has an atomic number of 1 ($_1\mathbf{H}$). Helium, with two protons, has an atomic number of 2 ($_2\mathbf{He}$), and so on.

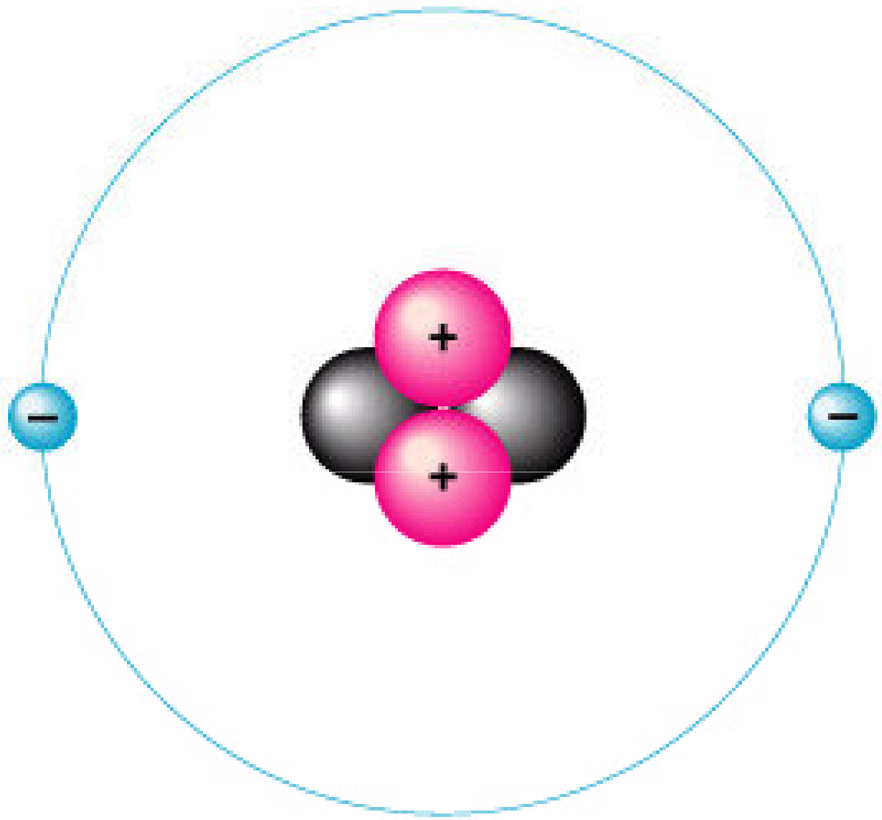
- The number of protons is always equal to the number of electrons in an atom, ***so the atomic number indirectly tells us the number of electrons in the atom as well.***

Chemical Reactivity:

- ***The mass number of an atom is the sum of the masses of its protons and neutrons***. *The mass of the electrons is so small that it is ignored. Hydrogen has only one proton in its nucleus, so its atomic and mass numbers are the same: Helium, with two protons and two neutrons, has a mass number of 4.*

- ***Isotopes have the same number of protons (and electrons), but differ in the number of neutrons they contain***. E.g. the most abundant isotope of hydrogen has a mass number of 1, ($_1H$), and some other hydrogen atoms have a mass of 2 or 3 ***amu*** (atomic mass units), which means that they have one proton and, respectively, one or two neutrons.

Chemical Reactivity:



Helium Atom

Chemical Reactivity:

- Electrons occupy relatively fixed regions of space around the nucleus of the atom. These regions are called ***energy levels or energy shells*** and they are numbered ***1 to 7*** (*from the nucleus outward*), but ***the number of shells varies according to the number of electrons that atom has***.

- *Each electron shell can hold a specific number of electrons*. ***Shell 1****, the shell immediately surrounding the nucleus, accommodates* ***only 2 electrons***. ***Shell 2*** *holds a* ***maximum of 8****, and* ***shell 3 has room for 18***. ***The shells tend to be filled with electrons consecutively.*** For example, shell 1 fills completely before any electrons appear in shell 2.

- *The electrons in the atom's outermost energy level are involved in chemical bonding*. Inner electrons usually do not take part in bonding because they are more tightly *held by the atomic nucleus.*

- ***Chemical behavior of an atom depends on the number of electrons in the outer shell.***

Chemical Reactivity:

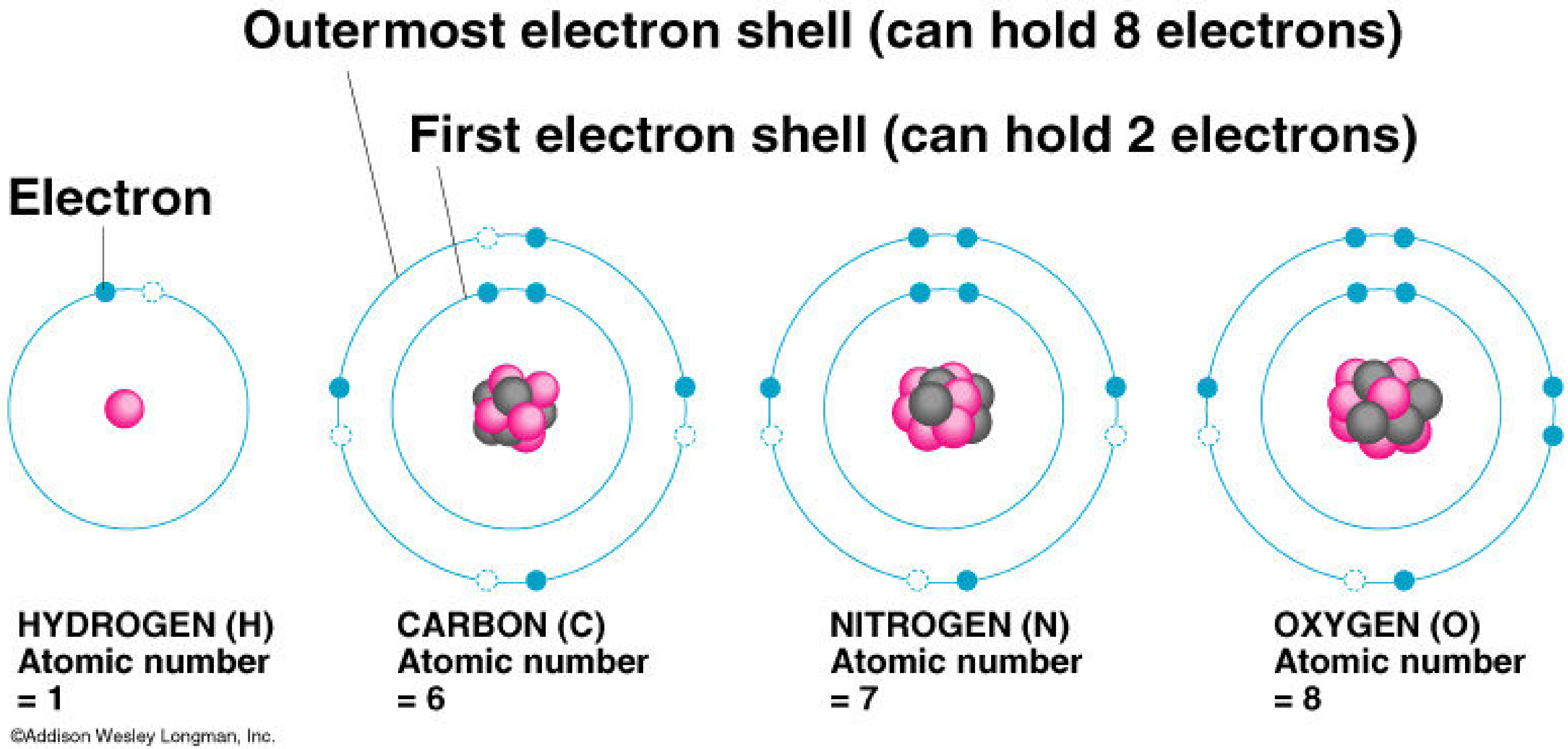
- ❖ When the outermost energy level of an atom is filled to capacity or contains ***eight electrons***, the atom is stable. Such atoms are ***chemically inert,*** *that is,* ***unreactive (inertia)***.

- ❖ On the other hand, atoms in which the outermost energy level contains fewer than eight electrons tend to ***gain, lose, or share electrons*** with other atoms to bring the number up to 8 and achieve stability.

- ❖ The number of electrons that can participate in bonding is still limited to a total of eight. The term **valence shell** specifically indicates an *atom's outermost energy level or that portion of it containing the electrons that are chemically reactive.*

- ❖ The key to chemical reactivity is the **octet rule**, or **rule of eights; Atoms interact so s as to create the situation of having 8 electrons in the outer shell.** ***Atoms tend to interact in such a way that they have 8 electrons in their valence shell.***

- ❖ **Exceptions to the rule of 8** is that ***shell 1 is full when it has two electrons.***



Octet Rule = atoms tend to gain, lose or share electrons so as to have 8 electrons

- ✓**H would like to Gain 1 electron** ***(shell-1 exception)***
- ✓**C would like to Gain 4 electrons**
- ✓**N would like to Gain 3 electrons**
- ✓**O would like to Gain 2 electrons**

Chemical Bonds

Chemical Bonds:

- Most atoms do not exist in the free state, but instead are chemically combined with other atoms. Such *a combination of two or more atoms held together by chemical bonds is called a **molecule.***

- ***Compounds*** are formed when electrons are given, taken, or shared between atoms in order for participating atoms to end up with complete outer shells.

- ***Mixtures*** are substances composed of two or more components ***physically intermixed*** *(no chemical bonding occurs between the components of a mixture). Most matter in nature exists in the form of* mixtures, but there are only three basic types: ***solutions, colloids,*** and ***suspensions.***

Chemical Bonds:

- Mixtures can separated by ***physical means***; straining, filtering, evaporation..etc, while compound can be only separated by ***chemical means*** (**breaking bonds**). Some *mixtures are* ***homogeneous,*** *whereas others are* ***heterogeneous***. While ***all compounds are homogeneous.***

- When atoms combine with other atoms, they are held together by **chemical bonds;** an energy relationship between the electrons of the reacting atoms, and it is made or broken in less than a trillionth of a second.

- Three major types of chemical bonds—***ionic, covalent, and hydrogen bonds***—*result from attractive forces between atoms.*

Chemical Bonds – IONIC BONDS:

- Ionic bonds form when ***electrons are fully transferred from one atom to another.***

- When this happens, the precise *balance of +ve and -ve charges is lost* so that charged particles called ***ions*** are formed.

- *Ions are chemically stable (8 electrons in the outer shell), but electrically unstable*. The atom that gains one or more electrons is the ***electron acceptor***. It acquires a net -ve charge and is called an ***anion.*** The atom that loses electrons is the ***electron donor***. *It* acquires a net +ve charge and is called a ***cation*** (formed from metals “minerals).

Chemical Bonds – IONIC BONDS:

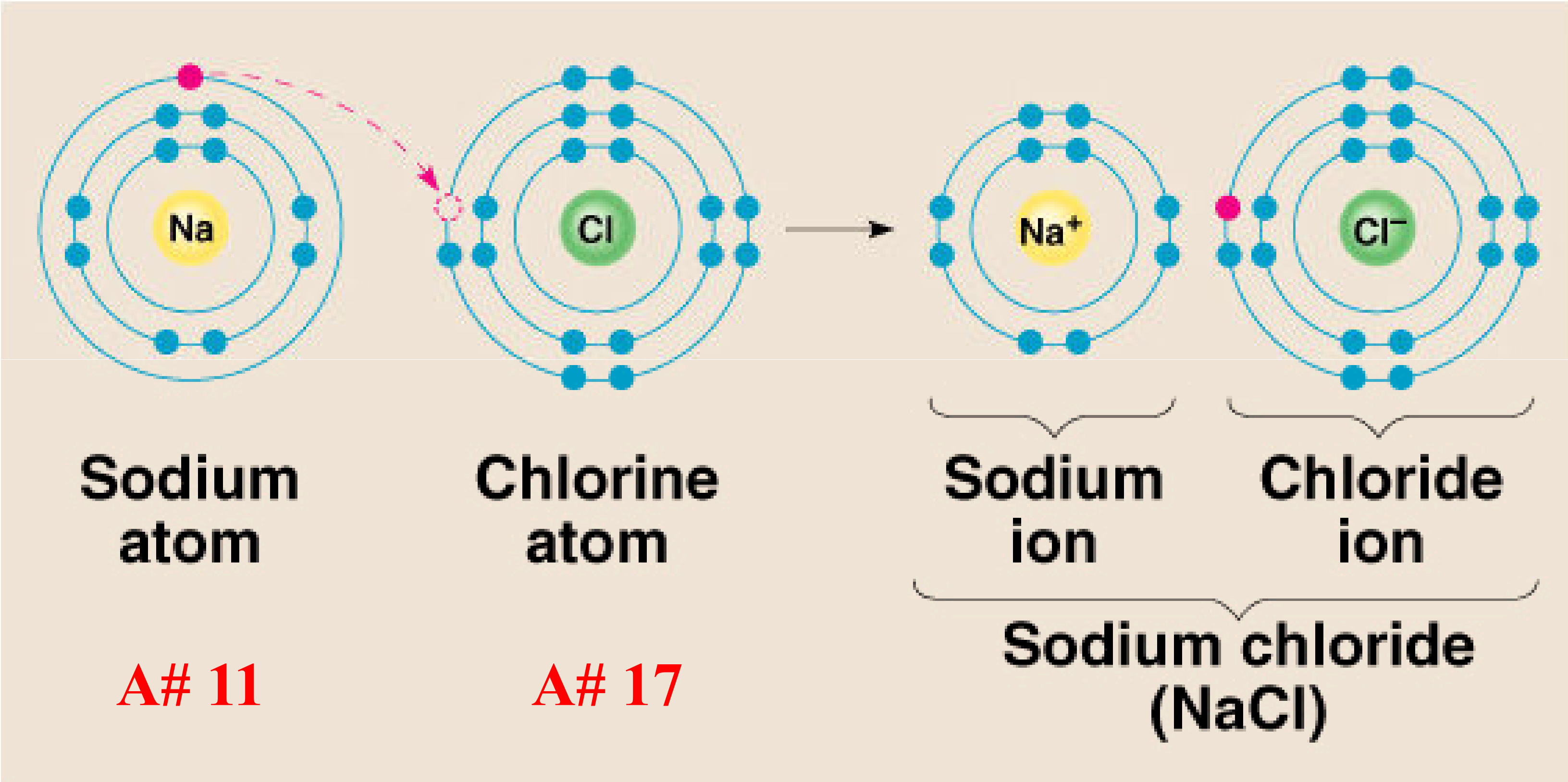
- Both ***anions*** and ***cations*** are formed whenever electron transfer between atoms occurs. Because opposite charges attract, these ions tend to stay close together, resulting in an **ionic bond**.

- Single atoms form anions in the body e.g. chloride or iodide. Many anions in the body form from groups of atoms collectively forming negatively charged radicals (e.g. $SO_4^{=}$, PO_4^{---}) each behaves as a single ion.

- Many ions in the body are large organic molecules (e.g. proteins) with –ve charge.

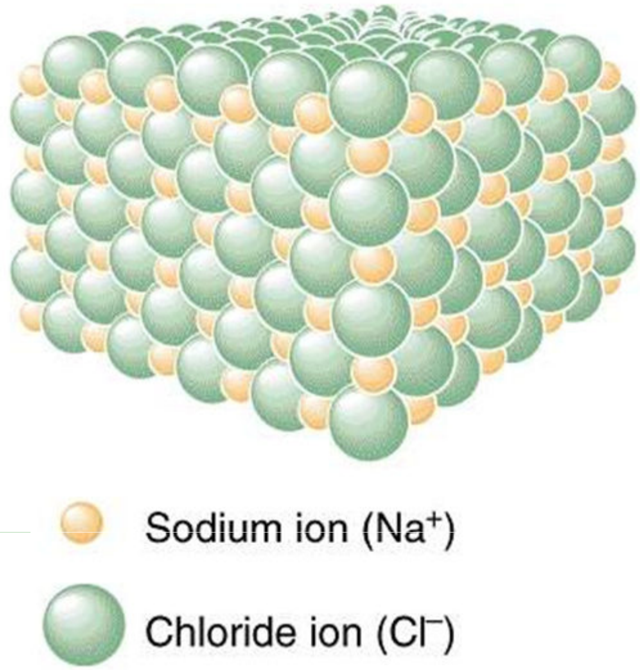
Chemical Bonds – IONIC BONDS:

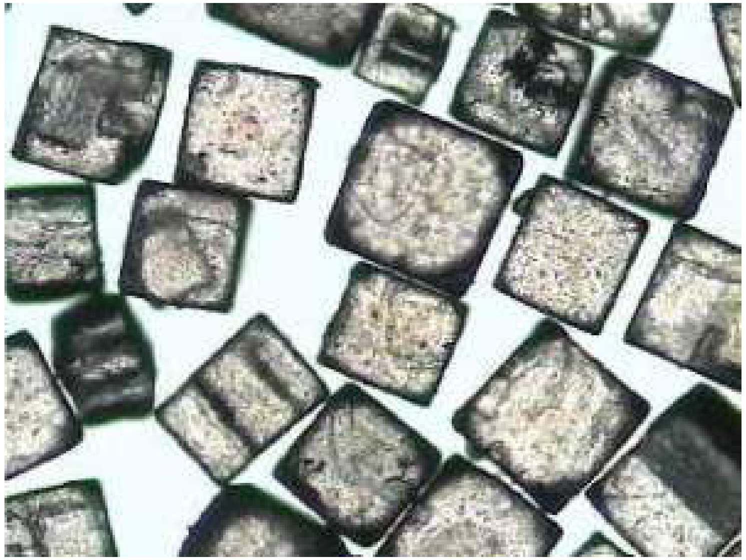
❖ One example of ionic bonding is the formation of table salt, or ***sodium chloride*** (**NaCl**), by interaction of sodium and chlorine atoms.



Ionic bond – electron from Na is transferred to Cl, this causes a charge imbalance in each atom. The Na becomes (Na+) and the Cl becomes (Cl-), charged particles or ions.

Chemical Bonds – IONIC BONDS:





$NaCl$

Chemical Bonds – COVALENT BONDS:

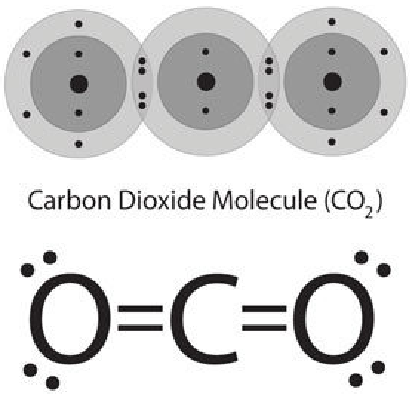
- Covalent bonds form when electrons are shared between atoms. e.g. O_2, CO_2, H_2O

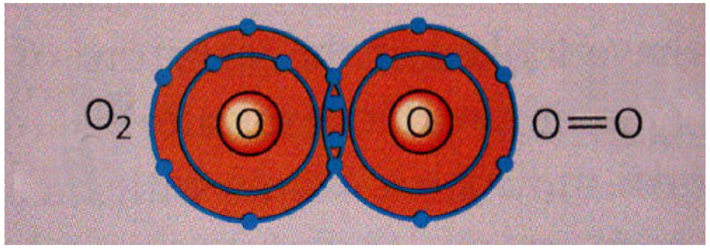
- Covalent bonds can be:

  - **Non-polar covalent bonds**: **when electrons are shared *equally*** (both reactants have equal electro-negativity). e.g.:O_2, S_2, CO_2

CO_2

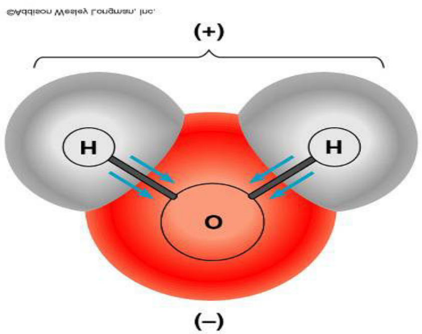
C (6) , O (8)





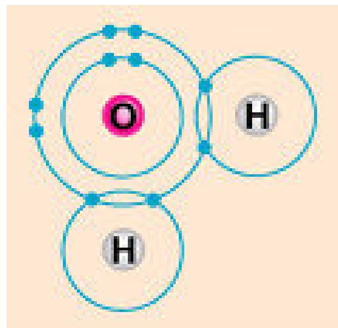
O2

  - **Polar covalent bonds:** **When electrons are shared unequally** (one reactant is more electronegative than the other). e.g. H_2O



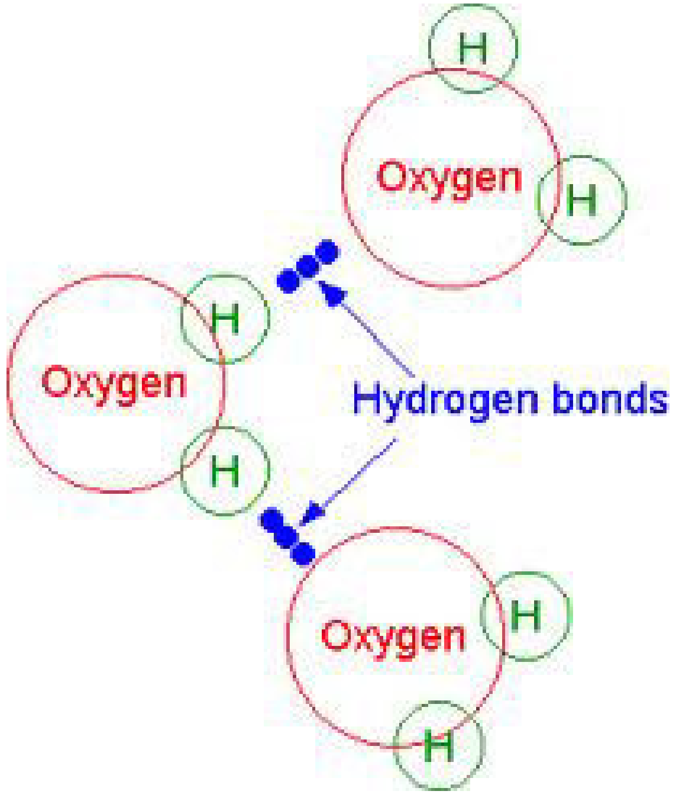
In water "O" is more electronegative than "H", so electrons spend more time closer to "O" There is a partial –ve charge on the "O" and a partial +ve charge on the "H".

Water is a polar molecule



Chemical Bonds – HYDROGEN BONDS:

- *Unlike the stronger ionic and covalent bonds, hydrogen bonds are more like attractions than true bonds*. Hydrogen bonds form when a hydrogen atom, already covalently linked to one electronegative atom (usually nitrogen or oxygen), is attracted by another electron- hungry atom, so that a "bridge" forms between them ***(Polar covalent molecules are held together***).



- Hydrogen bonding is common between dipoles such as water. Partial +ve charged atoms are attracted to partial –ve charged atoms. e.g. ***in water, the hydrogen of one molecule is attracted to the oxygen of another.***

- Hydrogen bonding is responsible for the tendency of water molecules to cling together and form films, referred to as ***surface tension*** causing water to beads up into spheres when it sits on a hard surface also to be liquid at room temperature.

Chemical Bonds – HYDROGEN BONDS contd.:

- Water is a major solvent, supporting life as we know it, because of H bonds.

- Water expends much energy alternating between different hydrogen bonds so:
  - ***it has high heat capacity, enabling us to maintain constant body temperature.***
  - ***it needs a lot of heat to evaporate it, making sweat a useful cooling mechanism.***

- Hydrogen bonding is important in determining molecular structure in cells:
  - ***Secondary structure of protein is caused by hydrogen bonding.***
  - ***Double strands of DNA are held together by hydrogen bonds between purines and pyrimidines.***
  - ***Copying of DNA info to RNA, is only possible because of hydrogen bonds.***

Chemical Bonds – WEAKER FORCES BETWEEN ATOMS & MOLECULES:

- These all determine tertiary and quatemary structures of proteins, allowing them to have a spatial configuration which determines their functions in the biochemistry of the cell.

- **Van der Waal's forces**: transient electrostatic forces due to distance between atoms. e.g. ***the ability of geckos, which can hang on a glass surface using only one toe***, to climb on sheer surfaces has been attributed to the Van der Waal's forces between these surfaces and the spatula (plural spatulae), or microscopic projections, which cover the hair-like setae found on their footpads.

- **Hydrophobic interactions**: form when there are many hydrophobic groups together in a watery medium. The hydrophobic groups are all attracted to each other to form a hydrophobic region, because that shield them from water. This is important in driving ***protein folding, formation of phospholipid bilayer of cell membrane.***

Types of Chemical Reactions:

- There are many types of reactions, including the following four reaction which are used by cells:

1- Synthesis Reaction: A + B = AB

Dehydration synthesis, or condensation reactions involve removal of water :

- An enzyme removes **H** from one reactant and **OH** from the other, to form water. The instability of the two reactants after loosing H & OH, causes them to join together. Three types of dehydration synthesis (studied in detail later):

  - **Pure dehydration synthesis**: e.g. two sugar molecules interact $\longrightarrow$ ***disaccharide.***

  - **Neutralization reactions**: acids react with bases, e.g. amino acids $\longrightarrow$ ***peptide bonds.***

  - **Ester formation reactions**: acids react with alcohols, e.g. three fatty acid molecules react with glycerol (a sugar alcohol) to form triglyceride.

Types of Chemical Reactions:

2- Decomposition Reaction: AB =A + B

The one we study are mainly Hydrolysis, the opposite of dehydration synthesis. A digestive enzyme makes the atoms of water available, while pulling components apart. One of the components takes up **H** and the other takes up **OH**, making stable products. Examples are the ***breakdown of carbohydrates, proteins, and triglycerides.***

3- Exchange reaction: AB + CD = AC + BD or AB +C = A + BC

Groups are moved from one compound to another, or traded for a different group. A ***phosphate group is removed from one compound and added to another compound.*** e.g. ATP (adenosine triphosphate) + glucose = ADP + glucose-6-phosphate. This is one way in which a small amounts of energy are moved around the cell.

4- Oxidation & Reduction Reactions:

Oxidation= adding oxygen or removing hydrogen. ***Reduction= removing oxygen or adding hydrogen***. *These must occur simultaneously, and do not need oxygen itself.* One molecule gives up its H, which causes it to become oxidized. Another molecule (oxidizing agent) accepts the H, causing it to become reduced.

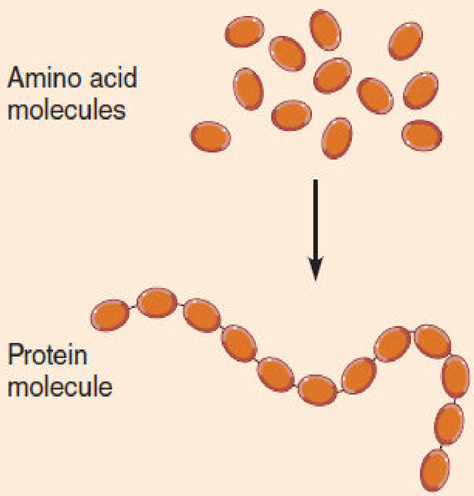
Types of Chemical Reactions:

(a) Synthesis reactions

Smaller particles are bonded together to form larger, more complex molecules.

Example

Amino acids are joined together to form a protein molecule.

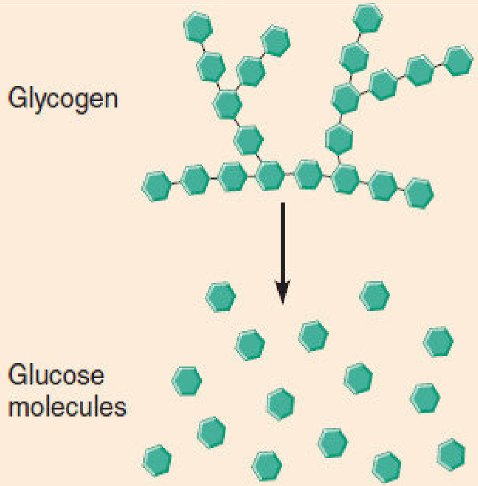


(b) Decomposition reactions

Bonds are broken in larger molecules, resulting in smaller, less complex molecules.

Example

Glycogen is broken down to release glucose units.

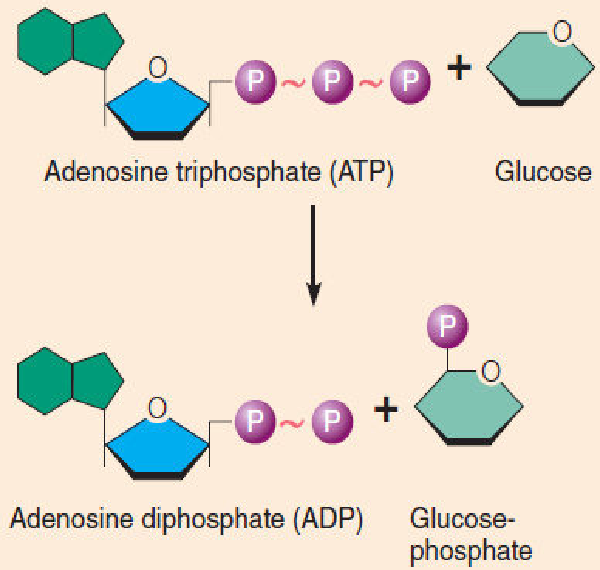


(c) Exchange reactions

Bonds are both made and broken (also called displacement reactions).

Example

ATP transfers its terminal phosphate group to glucose to form glucose-phosphate.



Types of Chemical Reactions-ENZYMES:

- ❖ In the cell, most reactions would occur imperceptibly slowly, were it not for enzymes. This allows the cell to have biochemical control.

- ❖ We owe everything we ever do, to our enzymes. ***Enzymes are almost always proteins***, and they are well understood.

- ❖ **Enzyme + Substrate (S) = unchanged enzyme + Product (s).**

- ❖ **Lock and Key hypothesis:** The enzyme has an affinity for the substrate (s), the substrate(s) possibly fitting into the physical shape of the enzyme like a lock and key.

- ❖ The interaction between enzyme and substrate causes the enzyme to change it configuration. The resulting stresses on the substrate(s) causes them to be changed to the product (s), which are then released from the enzyme, leaving the enzyme ready to act upon (an)other substrate molecule(s).

Chemical Components in the Cell - *Water, The Universal Solvent:*

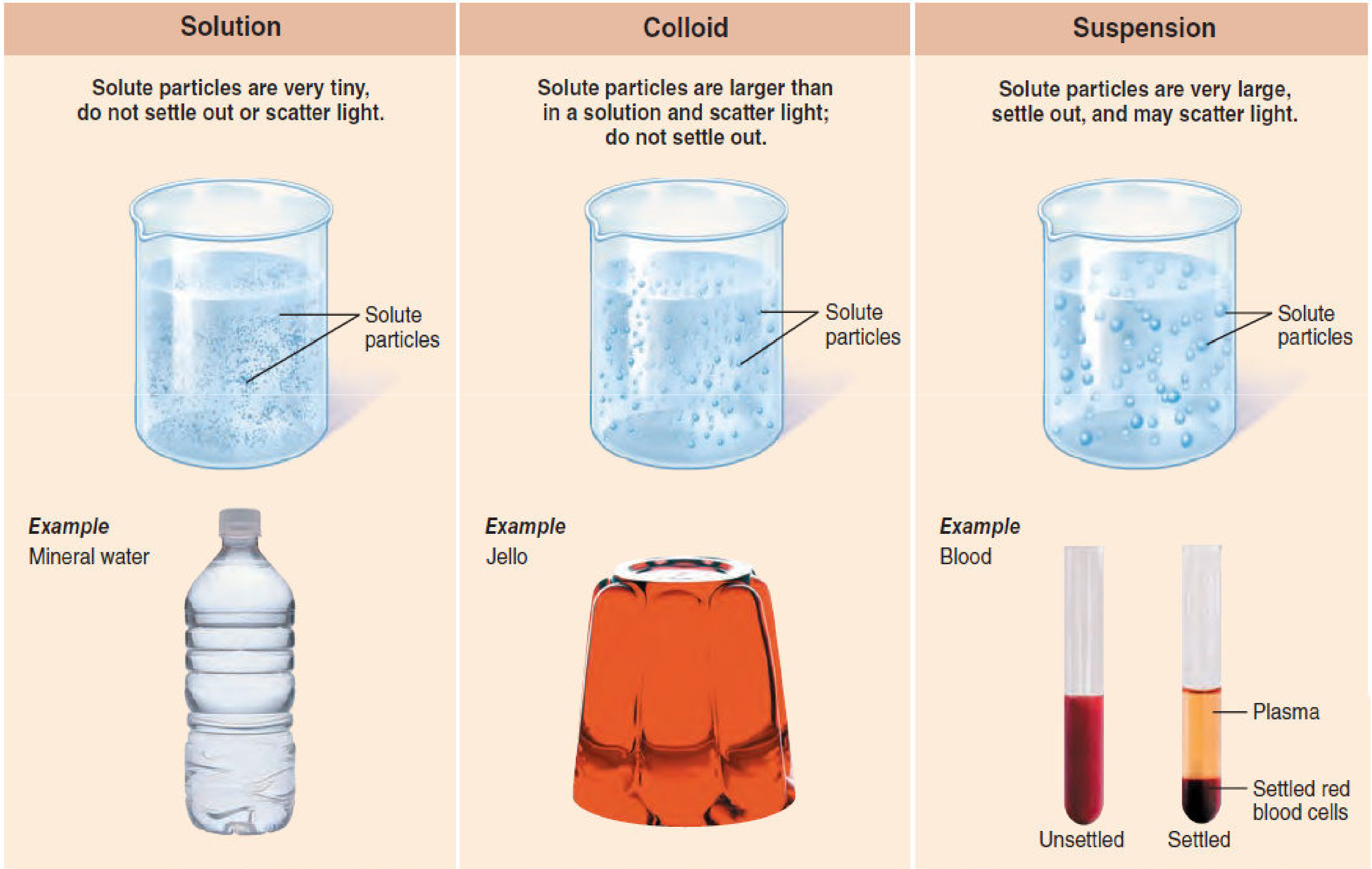
- **Solvents:** are liquids (or gas) in which substances (solutes) are dissolved or suspended.

- **Solutions** are formed when solutes particles are very **small**, forming a **clear** fluid, e.g. mineral water.

- **Suspensions** are formed when solute particles are **large**, & the mixture is **not clear.** Suspensions are temporary, because the particles settle out, blood and sand in water.

- **Colloids** are formed from particles of **intermediate** size, e.g. ***proteins in water:***
  - Some colloids are **opaque**, e.g. milk, but particles do not settle out.
  - Other colloids are **translucent,** e.g. plasma, but they may scatter light rays.
  - Colloid can **change from liquid to gel** form, and may alternate between the two.

Water, The Universal Solvent:



The three basic types of mixtures

Water and Life:

- We can live 30-60 days without food, but we die after only 2-3 days without water. Water is needed for biochemical processes.

- **The body needs to be 60-70% water**,; *enzymes only function in water*, and *reactants need to be in water in order to collide.*

- Water is needed for *bioelectrical processes*; water is a great conductor of electricity:
  - Every cell is like a little self-charging battery, using ion movements to charge itself.
  - Every cell needs this for life, and nerve & muscle cells conduct electrical impulses.

Water and Life:

- Water is the *medium for the transport & exchange* of: nutrient, respiratory gases, hormones & neurotransmitters, and waste products.

- Water is the *main component of body lubricants*: Between cells (interstitial fluid), between organs in body cavities (serous fluid), within organ cavities (mucous) in digestive & reproductive tracts, between bones, in joints (synovial fluid).

- Water *acts as a cushion*: Surround the brain (cerebrospinal fluid), surround the fetus (amniotic fluid).

Diffusion and Osmosis:

- **Diffusion:** a molecule moves ***from*** an area of ***greater concentration to*** an area of ***lesser concentration***, down a concentration gradient. ***It evens out the concentration gradient.*** Diffusion rate is proportion to the concentration gradient.

- **Osmosis:** ***water molecules*** pass ***from*** a solution of a ***lesser consternation of solute***, ***to*** a solution of ***greater concentration of solute***, via a semi-permeable membrane. ***This evens out the concentration gradient in a situation where the solute is unable to move.***

Diffusion and Osmosis:

- ❖ Biological effects of osmosis:
  - ➢ Place a cell in pure water; water enters cell from outside, cell swells and bursts.
  - ➢ Place a cell in a strong saline solution; water leaves the cell, so the cell shrinks ("crenation") and gets dehydrated.
- ❖ **Osmolarity** depends on the number of particles in solution. e.g. 0.9% NaCl (two ions), and 5% glucose (one particle), both isosmotic with cytoplasm.