**Chemistry** [1]

page 39: there are naturally 92 occurring elements, each differing from others in the number of protons and electrons in its atoms. Living organism is made of a small selection, four of them: carbon (C), hydrogen (H), nitrogen(N), and oxygen(O), which make up 96.5% of an organism’s weight. Less common elements of living organisms are the sodium (Na), Magnesium (Mg), Phosphorus (P), Sulfur (S); Chlorine (Cl), Potassium (K), and Calcium (Ca).

A chart with a number of dots

AI-generated content may be incorrect.

Isotops: same atoms with the same number of protons and electrons but different amount of protons.

A table of periodic table

AI-generated content may be incorrect.

page 48: Water is the 70% of the cell weight

page 40: Atoms with more than four shells are very rare in biological molecules. Shells are the orbits where electrons lies around the nucleus. The first shell (closest to the nucleus) can hold a maximum of two electrons, the 2nd->8 electrons, 3rd->8 electrons, 4th and 5th->18 electrons each.

Atoms with all shell occupied are stable and chemically unreactive, examples are the inner gases helium (1 shell and 2 electrons), neon (2 shells and 2+8 electrons), and argon (3 shells and 2+8+8 electrons).

Highly reactive are the hydrogen (1 shell and 1 electron) and the others with unfilled shells. Valence is the number of electrons an atom must acquire or lose, either by sharing (covalent bond) or transfer (ionic bond).

A diagram of a cell

AI-generated content may be incorrect.

Non-covalent bonds (Panel 2-7, page 70): they are less than 1/20 the strength of a strong covalent bond, they are bonds of electric nature. They define the specificity between molecules, as the number of non-covalent bonds and the shape of molecules allows for binding to other specific ones.

* Ionic bonds: are bonds of electric attraction nature, they occur when an atom transfers electrons to another one, example is the salt (NaCl). In this process, the atom that lost its electron became positively charged, and the one acquiring the electron became the negative one; both atoms became ions (positive and negative). The difference in charge makes the chemical bond between. In ionic bonds, cations are the positive ions (atoms that shared one of its electrons), anions are the negative ions (atoms that received another electron).
* Hydrogen bonds: Is the combination of O-H-O or N-H-O, occurs when an hydrogen atom is sandwiched between other two atoms.
* van der Waals attraction: Arises whenever two atoms come within a very short distance of each other. It is a result of fluctuating electric charges.
* Hydrophobic interaction: Created by the three dimensional structure of water, which forces hydrophobic groups together in order to minimize their disruptive effect on the hydrogen bonded networks of water molecules. This produces the expulsion of hydrophobic molecules from water. This causes phospholipid molecules together in cell membranes, and gives most protein molecules a compact, globular shape.
* ​Hydrolysis is a chemical reaction in which a molecule reacts with water, leading to the cleavage of a bond and the formation of two or more products. In this process, a water molecule (H₂O) splits into a hydrogen ion (H⁺) and a hydroxide ion (OH⁻), which then interact with the fragments of the original molecule, effectively breaking it apart. ​

**General Mechanism**:

For a compound represented as AB, the hydrolysis reaction can be depicted as:​

AB+H2O→A-H+B-OH

Here, the bond between A and B is broken, with A bonding to the hydroxyl group (OH⁻) and B bonding to the hydrogen ion (H⁺) from the water molecule.

## Covalent bonds

A diagram of a cell

AI-generated content may be incorrect.

A molecule is a cluster of atoms held together by covalent bonds, example is the hydrogen (H2). In covalent bonds electrons are shared instead of transferred. The shared electrons complete the outer shell of both atoms. In covalent bonds, the nucleus of both atoms are separated together by an equivalent distance called the bond length, where the repulsive and attractive forces between the two nucleus are in balance.

The bond (ionic or covalent) is also measured by its strength. Bond strength is measured by the amount of energy that must be supplied to break that bond, usually expressed in units of kilocalories per mol (kcal/mole). A kilocalorie is the amount of energy needed to raise the temperature of one liter of water by one degree centigrade. Thus if 1kcal must be supplied to break 6x0^23 bonds of a specific type, then the strenght of that bond is 1kcal/mole. 1kilojoule is equal to 0.239 kilocalories.

Covalent bond atoms: H (1 covalent bond), O (2 bonds), N (3 bonds), S, P, C (4 bonds) (more than a covalent bond). These can accommodate a maximum 8 electrons in the outher shell and make covalent bonds with many other atoms as needed to complete 8 electrons.

Typically, covalent bonds are stronger in a factor of 100 to collisions with other molecules. The making and breaking of covalent bonds are controlled by enzymes (catalyst), these are violent events.

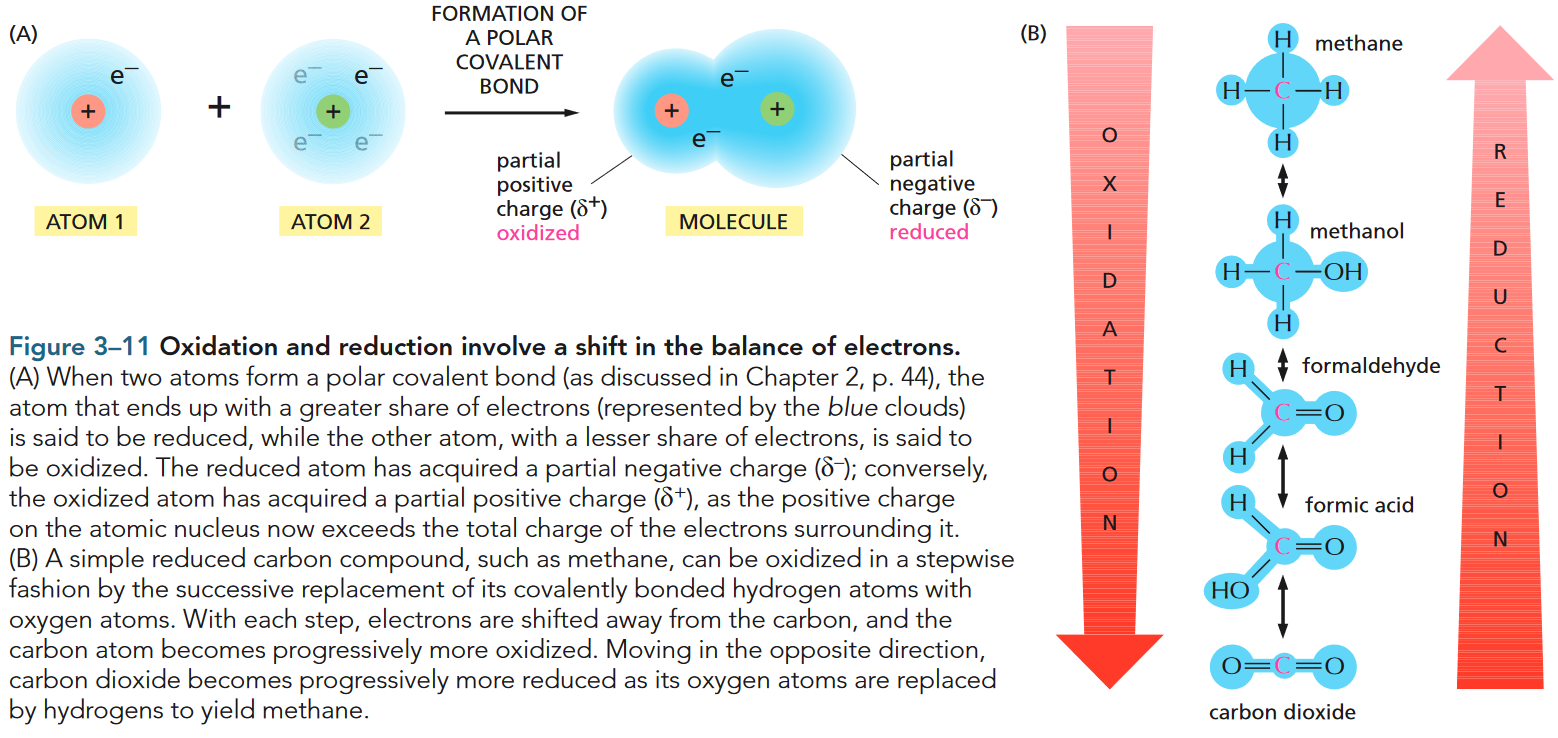
Noncovalent bonds are weaker and associate and dissociate quicker.

Polarity of covalent bonds: In a molecule of different atoms, the electrons are attracted differently. For instance, O, N, Sulfure, Chlorine, attract electrons strongly, while H attracts electrons weakly. Molecules of the same atom, like benzene (made of carbon), are neutral as they attract electrons with the same strength.

The polarity of covalent bonds allows also more molecule formation as a weak non-covalent ionic bond. This is a formation of electric nature like ionic bonds, but weaker.

3D-Geometry of covalent bonds: when two atoms share 2 electrons (1 covalent bond), the atoms may rotate with respect to each other. When two atoms share 4 electrons (2 covalent bonds) both are fixed in space. Besides, single bonds have a definite orientation in space, which is a consequence of the orientation of the orbits of the shared electrons. This define the 3D-geometry of molecules.

### Oxydation and Reduction



* Oxidation: Refers to the removal of electrons from an atom, thereby the atom become more positive. In the cell it occurs with the addition of oxygen and in more than one step through enzymatic reactions. Examples are
  + When a Carbon atom becomes covalently bonded to an atom with a strong affinity for electrons (O, S, Chlorine), the carbon gives up more than its equal share of electrons and forms a polar covalent bond. The nucleus of the C atom becomes positive than the negative charge of the electron and is said to be oxidazed.
  + When a sugar molecule is oxidized to CO2 and H2O, the O2 molecule involved in forming H2O gains electrons and thus are said to be reduced.
  + Dehydrogeneration reactions: When a molecule in a cell release an electron, it often also release a proton (H+), i.e., AH → A+e+H+
  + Oxidation occurs when the number of C-H bonds decreases.
  + Cells uses enzymes to catalyze the oxidation of organinc molecules in small steps. This allows harvesting useful energy.
* Reduction: The addition of electrons to the atom. Example
  + A Carbon atom in the C-H linkage has more than its share of electrons, the Carbon atom becomes negative and is said to be reduced.
  + Hydrogeneration reactions: A+e-+H+ -> AH. It occurs when a molecule in a cell pick up an electron, it often pickup a proton (H+), which are freely available in water.
  + Due to hydrogeneration, reduction occurs when the number of C-H bond increases.

In a chemical reaction the number of electrons is conserved. One atom is oxidized and the other is reduced. Oxidation and Reduction occur simultaneously.

### Condensation and Hydrolysis

Condensation occurs when a reaction releases a molecule of water. Condensation reactions all are energetically unfavorable.

Condensation:

A-H+HO-B →A-B + H2O

Hydrolysis reaction occurs when water is added to the reaction and is energetically favorable, .see Fig. 3-32 below.

Hydrolysis:

A-B + H2O → A-H+HO-B

## Type of molecules

Page 50: Hydrophilic molecules are the ones disolved in water, this is the case of NaCl, as the the Na+ component is attracted by the O- ion of water molecules, and the Cl- componet by the H+ ion of the water molecule.

Hydrophobic molecules are not disolved in water because the are sorrounded by H ions that are not attracted by water molecules.

Acids: are substances that release a H+ (hydrogen ion) in disociation. The acidity of a solution is defined by the concentration of H+ ions. It is measures with the pH scale as pH=-log10(H+ concentration moles/liter). Water is pH=7, there are 10^-7 moles/liter.

Bases: Substances that reduces the number of hydrogen ions in solutions. Example is ammonia, that combines with H+ ions. In water, these substances absorv one H+ of the molecule water and increase the number of OH- ions.

Page 54: Isomers: set of molecules with the same chemical formula but different orientation of their atoms in the covalent bonds.

## **Molecules in Cells**

A close-up of a chart

AI-generated content may be incorrect.

A diagram of different cells

AI-generated content may be incorrect.

Cell mass is mostly comprissed by small and macro molecules.

1. A diagram of different types of molecules

   AI-generated content may be incorrect.Small organic molecules are carbon compounds with molecular weight in the range 100 to 1000 and containing around 30 carbon atoms. They are usually found free in the cytoplasm. Small molecules are around one-tenth of the total mass of organic matter. They are less abundant than macromolecules. Cells contains four major families of small organic molecules
   1. Sugars: They are energy sources for cells and subunits of polysaccharides (CH2O)n. They are also linked to proteins and lipids. Examples are the simples sugars Monosaccharides. There are isomers in two forms D-form and L-form. The change of form are recognized by enzymes and other proteins and have important biological effects.
   2. Fatty acids: They are components of cell membranes as the most important function in cells. They are also concentrated food reserve in cells, they can be broken down to produce about 100 times as much usable energy as glucose. They are stored in the cytoplasm as droplets. The common properties is that they are insoluble in water and soluble in fat and organic solvents such as benzene.
   3. Aminoacids: They are the main component of proteins and are only 20 among all living cells (bacteria, plants, animals). They are only found in L-form as optical isomer. The collective properties of the amino acid side chains underline all the diverse and sophisticated functions of proteins. They are grouped according to whether their side chains are
      1. acidic (2)
      2. basic (3)
      3. uncharged polar (5): can carry a charge
      4. and non-polar (10)
   4. Nucleotides: They are the subunits of nucleic acids. They are named for the base it contains. It is molecule that comprises a Base (nitrogen-containing ring), a sugar (five-carbon), and one or more phosphate groups. The base sugar is named as base for historical reason; under acidic conditions they can each bind an H+(proton) and thereby increase the concentration of OH- aniions in aqueous solutions. Bases can be of two types
      1. Ribose: These are knows as ribonucleotides (RNA). This sugar has a hydroxyl group (-OH) attached to its second carbon atom. This structure is integral to ribonucleic acid (RNA), where ribose forms the sugar-phosphate backbone. The presence of the hydroxyl group in ribose makes RNA more reactive and less stable compared to DNA, which is more stable due to the absence of this group in deoxyribose.
      2. Deoxyribose: In contrast, deoxyribose lacks the hydroxyl group at the second carbon, having only a hydrogen atom instead. This absence of one oxygen atom is reflected in its name—'deoxy' indicating the loss of oxygen—and is characteristic of deoxyribonucleic acid (DNA).

Bases are five different into two groups:

* Pyrimidines compounds: Called like this because they derive from th same six-membered pyrimidine ring. Cytosine (C), Thymine (T), Uracil (U).
* Purine compounds: Guanine (G) and Adenine (A)

Functions:

1. Carry chemical energy in the phosphate group. This is accomplished with the ATP molecules (page 64)
2. They combine to form coenzymes.
3. They are used as specific signaling molecules in the cell such as the cyclic AMP (cAMP).
4. They carry the biological information to the construction of nucleic acids which are of two types:
   1. RNA: ribonucleic acids that contains the bases G, C, and U.
   2. DNA: deoxyribonucleic acids that contains the bases A, G, C, and T. T plays the role of U in RNA.
5. Macromolecules

* Uses as monomer subunits (small organic molecules), they are proteins, nucleic acids and large polysacchrides.
* They are the most abundant of carbon-containing molecules on living cells and confer the most distinctive properties of living cells.
* They are formed by the covalent link of monomers into a long chain that together implements a properties not predicted from the single subunits.
* Their biosynthesis is through a condensation reaction, unfavorable reaction where a molecule of water is released.
* Their biosynthesis requires additional energy.
* Their shape (conformation) is set into one stable conformation by the weaker noncovalent bonds between the different parts of the molecule in a sufficient number.
  1. **Polysaccharides: contain thousands of monosccharide units, Panel 2-3 page 57. Cells used simple polysaccharides, composed only by glucose units (glycogen mainly) as long term stores of energy. Polysaccharides mixed with proteins are found in cell membranes**
  2. **Fattis/Lipids/Membranes**
  3. **Proteins: Polymers of aminoacids joined head-to-tail in a long chain than is folded into a 3D structure unique to each type of protein.**
     1. **Peptide bond: The covalent linkage between two adjacent amino acids.**
     2. **Polypeptide: Chain of aminoacids.**
     3. **N-terminus: All polypeptide has an amino (NH2) group at one end.**
     4. **C-terminus: All polypeptide has a carboxyl group (COOH) on the other end.**

The chemical reaction for each polymer is different but there are common properties:

* Each monomer is added in a condensation reaction, i.e., a water molecule is released when two monomers are joined.
* All the reactions are catalyzed by enzymes, which also assures that monomer of the appropriate type are incorporated.
* The polymer chain is not assembled at random from these subunits, instead they are added in a particular order, or sequence.

1. Enzymes: Especialized protein to catalyze chemical reactions. They specialize in particular chemical reactions. They are implemented in series, so that the product of one particular reaction becomes the starting material, or substrate, for the next.

## A diagram of different shapes and colors AI-generated content may be incorrect.Metabolism in the cell

The metabolism is a mechanism that creates order in the cell. Metabolism is composed by two sets of reactions:

1. Catabolic pathway: Is used to generate energy and a set of smaller molecules, it break down foodstuffs into smaller molecules. This process implement the oxidation (reduction of C-H bonds)
   1. Oxidation: Extraction of energy from food molecules by a process of controlled burning.
   2. Respiration: Process in the cell to produce energy from sugars with the combination:

SUGARS +O2 -> H2O+ CO2

* 1. A diagram of energy and reaction

     AI-generated content may be incorrect.Activation Energy: The most energetically favourable conditions for C atom is CO2, and for H is H2O. The molecules needs an extra energy to break its C-H bonds to release CO2 and H2O for a more stable state (energetically favourable). Inside the cell this activation energy is naturally given by the heat but greatly aided by enzymes (class of proteins).
  2. Enzymes: Bind tightly to one or two molecules called substrates and holds then in a way that greatly reduces the activation energy of a particular chemical reaction.
     + They reduce the activation energy and becomes a catalyst.
     + They speed up reactions in the order of 10^14 when compared to normal temperatures.
     + Enzymes are highly selective, they catalyse only one specific reaction among substrate pairs.
     + Enzymes associate with substrate molecules at a rate of 500,000 association per second, when the substrate molecules is at a high concentration (0.5 mM). If the substrate molecule has just a few covalent bonds with the enzyme, it disassociate quickly due to the random thermal motion. This prevents incorrect and unwanted association from forming between mismatched molecules.

1. Anabolic or biosynthesis: Uses the energy harnessed by the catabolism to drive the synthesis of many other molecules that form the cell. Driving reactions in the direction of order (∆G>0)

These two pathways occurs as

1. Couple reactions
2. Activated carrier molecules and Biosynthesis.

## Coupled reactions

Coupled reactions refer to convert substrate X into Z through and intermediate substrate Y. The intermediate substrate Y is non-favourable with X but favourable with Z, see Fig. 3-21 below.

Enzyme couples two kind of reactions

1. Energetically favourable reactions, the ones where Delta G<0, that release energy and produce heat.
   1. Energetically favorable reaction: Are those that decrease free energy (G) and increase disorder (according to the second principle of thermodynamics Delta G<0). Delta G reflects the degree to which a reaction creates a more disordered and more probable state of the universe. This occurs with the dissolving of salt in water.
2. Energetic unfavourable reactions, the ones with Delat G>0, which produce biological order. That is, these reaction build the high ordered and energy-rich molecules from small and simple ones. This is the case of two amino acids are joined together to form a peptide bond.

The energetic unfavourable reaction can only occur when coupled to a favourable one, and the total Delta G of the couple reaction is negative at the end. See a couple reaction in Fig. 3-21.

In a reaction A⇌B, if there are more A molecules than B, it is more probable that the transition from A to B happens than the contrary. This tendency makes Delta G more negative with A→B than B→A.

Free energy change (Delta G), in kilocalories per mol ,is concentration-dependent and concentration-independent part as follows

, at

Where is the standard free-energy change, and depends on the intrinsic characters of the reacting molecules. The second part depends on their concentration and makes more negative is the product becomes less than the reactant.

The chemical equilibrium is reached when the concentration effect balances the push given to the reaction by so there is not net change of free energy to drive the reaction in either directions, i.e., . In this case

, at

That is the amount of products and reactants is defined by the standard free-energy change.

A screenshot of a computer screen

AI-generated content may be incorrect.Enzymes lower the activation energy in the two directions of the reaction, and the equilibrium point with to remain the same.

## Activated Carrier Molecules

Activated molecules store the energy released on catabolic pathways, i.e., alont energy favourable reactions. This energy is released with the oxidation of food molecules, i.e., diminishing the number of C-H bonds and increasing the number of electrons in the Carbon atom.

The carrier molecules are the bridge between catabolism and anabolism.

For historical reasons they are referred to as coenzymes and are the ATP, NADH, and NADPH molecules.

The carrier molecules diffuses rapidly throughout the cell and thereby carry their bond energy (energy rich covalent bonds) from sites of energy generation to the sites here energy is used for biosynthesis and other cell activities.

A coupled reaction is used in the catabolism to capture a large part of energy released in a favourable reaction and drive an energy unfavourable reaction that produces an energy carrier molecule.

### ATP carrier

The most widely used carrier is the molecule ADP (adenosine 5’-diphosphate). ADP is a nucleotide molecule (see Panel 2-6 pp. 66). The number 5’ refers to the fifth Carbon atom for the sugar, see figure below.

A diagram of a hexagon with letters and numbers

AI-generated content may be incorrect.

ATP is formed in a cycle: ADP is transformed to ATP by adding an inorganic phosphate group to the ADP molecule. See figure 3-31 below. ATP is an energetic favourable hydroloysis molecule is coupled to another reaction to synthetize new molecules. Many of them involve the transfer of the terminal phosphate in ATP to another molecule.

A screenshot of a computer

AI-generated content may be incorrect.

For instance, the Hydrolysis from ATP, occurs with the influence of two water molecules. The lower water molecule in the figure below, detach the H atom from the upper water molecule. Then the Posphate attrac the O-H bond, and the second H joins to the ADP molecule.

A diagram of a chemical reaction

AI-generated content may be incorrect.

A diagram of a product of hydrolysis

AI-generated content may be incorrect.ATP makes unfavourable condensation reactions favourable. For instance, the condensation reaction

A-H + B-OH → AB +H2O

Is an unfavorable reaction. However, with the ATP molecule this reaction can occur, but the H2O molecule is used as hydrolysis to transform the ATP to ADP.

in joining A and B molecules it occurs in two steps

* + - 1. The B-OH molecule is transformed by the ATP molecule into a higher energetic state as

B-OH + ATP → B-O-PO3 + ADP

* + - 1. The B-O-PO3 molecule is favorable in joining an NH3 molecule in the second step

A-H + B-O-PO3 → A-B +Pi

* + - 1. The net result is

B-OH + ATP + A-H → A-B + ADP + Pi

### NADPH and NADH carriers

The NADPH carrier is formed from the NADP+ molecule. The NADPH is an NADP+ molecule plus a hydride ion (H atom + electron) as follows

H-C-OH + NADP+ → NADPH+C-O+H+

That is, from the two H atoms, one electron from one of the H joins the second H atom, becoming a hydride ion (H+electron) that joins the NADP molecule. The C-O molecule is oxidized (miss an electron), the NADP+ is reduced (gain an alectron).

Later, the NADPH is donor of this Hydrine into another molecule, as the ATP is a donor of the phosphate, whith a high negative free energy change.

The NADH molecules differs from the NADPH, that it is deficient in the phosphate group. The phosphate group makes no distinction in the electron transfer as it is far from the region where the Hydride ion is, but it makes a distinction to bind as substrate to other enzymes, they have different destinations.

NADPH operates with enzymes in anabolic reactions (synthesis), while NADH operates in catabolic reactions (decomposition).to generate ATP molecules. Inside the cell the ratio of NAD+ to NADH is kept high, while the ratio NADP+ to NADPH is kept low.

Other energy carrier molecules are given in Table 3-2.

A table with text on it

AI-generated content may be incorrect.

References

[1] B. Alberts, D. Bray, and K. Hopkin, *Alberts, B: Essential Cell Biology: With online resources*, 4th rev ed. edition. New York, NY: Norton & Company, 2014.