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**Principles of Biochemistry**

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**BIOCHEMISTRY 2**

Bioenergetics and Biochemical Reaction Types (Chapter 13)

Glycolysis, Gluconeogenesis, and the Pentose Phosphate Pathway (Chapter 14)

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* Living organisms are composed of lifeless molecules.
* **Biosphere** is all the living matter on or in
* the earth
* the seas
* the atmosphere.
* **Autotroph** is an organism
* it can synthesize its own complex molecules from very simple C and N sources, such as CO2 and NH3.
* **Heterotroph** is an organism that
* it requires complex nutrient molecules, such as glucose, as a source of energy and C.
* Carbon, oxygen and water are cycled between the heterotrophic and autotrophic worlds, with solar energy as the driving force for this massive process (**Fig. 1)**.



* All living organisms require a source of nitrogen
* it is necessary for the synthesis of amino acids, nucleotides, and other compounds **(Fig. 2)**.



* **Catabolism** is the degradative phase of metabolism
* organic molecules are converted into smaller and simpler end products **(Fig. 3)**.
* Catabolic pathways release energy some of which
* is conserved in the formation of ATP
* is reduced electron carriers
* the rest is lost as heat.
* In **anabolism**, also called biosynthesis
* small and simple precursors are built up into larger and more complex molecules (requires the input of energy).



* **Metabolism =** catabolism + anabolism
* **Metabolism** is a highly coordinated cellular activity.

**Chapter 13** **Bioenergetics and Biochemical Reaction Types**

* Living cells and organisms must perform work to stay alive, to grow and to reproduce.
* Living cells are chemical engines.
* Cells and organisms depend on a constant supply of energy.
* Energy is central theme in biochemistry.
* Cells have evolved highly efficient mechanisms for coupling the energy obtained from sunlight or fuels to the many energy-consuming processes.

**13.1 Bioenergetics and Thermodynamics**

* Bioenergetics is the quantitative study of the energy transductions - changes of one form of energy into another - that occur in living cells.

**Biological Energy Transformations Obey the Laws of Thermodynamics**

* The first law is the principle of the conservation of energy
* *for any physical or chemical change, the total amount of energy in the universe remains constant*
* *energy may change form or it may be transported from one region to another, but it cannot be created or destroyed*.
* The second law of thermodynamics says that the universe always tends toward increasing disorder
* *in all natural processes, the entropy of the universe increases*.
* Living cells and organisms are open systems
* they are exchanging both material and energy with their surroundings.
* **Gibbs free energy, (G),** expresses the amount of an energy capable of doing work during a reaction at constant temperature and pressure.
* When a reaction proceeds with the release of free energy, the free-energy change
* G has a negative value and the reaction is said to be exergonic.
* In endergonic reactions, the system gains free energy and G is positive.
* **Enthalpy**, **H**, is the heat content of the reaction system.
* it reflects the number and kinds of chemical bonds in the reactants and products.
* When a chemical reaction releases heat, it is said to be exothermic
* H has a negative value.
* Reaction systems that take up heat from their surroundings are endothermic
* H has a positive value.
* **Entropy**, **S**, is a quantitative expression for the randomness or disorder in a system.
* When the products of a reaction are less complex and more disordered than the reactants, the reaction is said to proceed with a gain in entropy.
* In biological systems (constant temperature and pressure),

**G = H - TS**

* G of spontaneously reacting system is always negative.

**Standard Free-Energy Change Is Directly Related to the Equilibrium Constant**

* The concentrations of reactants and products at equilibrium define the equilibrium constant, Keq.

aA + bB cC + dD Keq = [C]c [D]d / [A]a [B]b

* Under standard conditions (298 K = 25 oC, 1 atm), the force driving the system toward equilibrium is defined as the standard free-energy change, Go.
* There is a simple relationship between Keq and Go :

**Go = - RTlnKeq**

* The standard free-energy change is directly related to the equilibrium constant **(Table 13- 2 and 3)**.





* **(Table 13-4)** gives the standard free-energy changes for some representative chemical reactions.



**Standard Free-Energy Changes Are Additive**

* The Go values of sequential chemical reactions are additive.
* This principle of bioenergetics explains
* how a thermodynamically unfavorable (endergonic) reaction can be driven in the forward direction by coupling it to a highly exergonic reaction through a common intermediate.
* For example, (Pi : inorganic phosphate, HPO42-)

Glucose + Pi glucose 6-phosphate + H2O Go = 13.8 kJ/mol

ATP + H2O ADP + Pi Go = - 30.5 kJ/mol

ATP + glucose ADP + glucose 6-phosphate Go = - 16.7 kJ/mol

* The two reactions can be coupled in the form of a third reaction.
* The overall reaction is exergonic.
* This common-intermediate strategy is employed by all living cells in the synthesis of metabolic intermediates and cellular components.

**13. 2 Chemical Logic and Common Biochemical Reactions**

* Most of the reactions in living cells fall into one of five general categories:

1) reactions that make or break carbon–carbon bonds

2) internal rearrangements, isomerizations, and eliminations

3) free-radical reactions

4) group transfer reactions

5) oxidation-reduction reactions

1. Oxidation-Reduction Reactions
* Carbon atoms can exist in five oxidation states (**Fig. 13.9)**.
* CO2 is the most oxidized form.



* In many biological oxidations, a compound loses two electrons and two hydrogen ions (i.e. two hydrogen atoms).
* These reactions are commonly called **dehydrogenations**.
* The enzymes are called **dehydrogenases** (**Fig. 13.10).**



* In some biological oxidations,
* a carbon atom becomes covalently bonded to an oxygen atom and the enzymes are called **oxidases**.
* If the oxygen atom is derived directly from molecular oxygen (O2), the enzymes are called **oxygenases**.
* The catabolic (energy-yielding) pathways are oxidative reaction sequences.
* They result in the transfer of electrons from fuel molecules, through a series of electron carries, to oxygen.
* The high affinity of O2 for electrons makes the overall electron-transfer process highly exergonic.
* It provides the energy (ATP).
	+ ATP is the central goal of catabolism.

**13.3 Phosphoryl Group Transfers and ATP**

* ATP is the major carrier of chemical energy in all cells (**Fig. 13-11)**.
* The terminal phosphoryl group having phosphoanhydride bond is removed.
* Standard free energy of hydrolysis of ATP is the relatively large and negative (exergonic)
* This reaction is coupled to many endergonic reactions in the cell such as
	+ the synthesis of metabolic intermediates
	+ the synthesis of macromolecules from smaller precursors
	+ the transport of substances across membranes against concentration gradients
	+ mechanical motion.

 



* Other biologically important phosphorylated compounds and thioesters also have large free energies of hydrolysis (**Table 13- 6)** **(Fig. 13-13** and **16).**







 

**13.4 Biological Oxidation-Reduction Reactions**

* The transfer of phosphoryl groups is a central feature of metabolism.
* Another kind of transfer is electron transfer in oxidation-reduction reactions.
* Some reactant is oxidized (loses electrons) as another is reduced (gains electrons).
* The flow of electrons provides energy for organisms.
* In nonphotosynthetic organisms, the sources of electrons are reduced compounds (foods).
* In photosynthetic organisms, the initial electron donor is a chemical species excited by the absorption of light.
* The path of electron flow in metabolism is complex.
* Electrons move from various metabolic intermediates to specialized electron carriers in enzyme-catalyzed reactions.
* Cells contain a variety of molecular energy transducers, which convert the energy of electron flow into useful work.

**The Flow of Electrons Can Do Biological Work**

* In living cells, reduced compound such as glucose is used as the source of electrons.
* Glucose is enzymatically oxidized.
* The released electrons flow spontaneously through a series of electron-carrier intermediates to another chemical species, such as O2.
* The resulting electromotive force provides energy.
* The principles of electrochemistry are used in living cells. (motor and battery)

**Biological Oxidations Often Involve Dehydrogenation**

* The carbon in living cells exists in a range of oxidation states.
* Oxidation is coincident with the loss of hydrogen.
* The more reduced compounds are richer in hydrogen than in oxygen.
* The more oxidized compounds have more oxygen and less hydrogen.
* Not all biological oxidation-reduction reactions involve carbon.
* For example, the nitrogen atoms are reduced

6H+ + 6e- + N2 2NH3

* In cells, electrons are transferred from one molecule to another in one of four different ways:
1. Directly as **electrons**.

Fe2+ + Cu2+ Fe3+ + Cu+

1. As **hydrogen atoms**. A hydrogen atom consists of a proton (H+) and a single electron (e-).

AH2 A + 2e- + 2H+

AH2 + B A + BH2

B is reduced by transfer of hydrogen atoms

1. As a **hydride ion** (:H-), which has two electrons. This occurs in the case of NAD-linked dehydrogenases.

NAD+ + 2e- + 2H+ NADH + H+

1. Through direct **combination with oxygen**.

R-CH3 + 1/2O2 R-CH2-OH

The hydrocarbon is the electron donor and the oxygen atom is the electron acceptor. The hydrocarbon is oxidized to an alcohol.

**Reduction Potentials Measure Affinity for Electrons**

* Walter Nernst derived an equation related to standard reduction potential (Eo) to actual reduction potential (E).

E = Eo + 0.026 V / n ln [electron acceptor] / [electron donor]

n is the number of electrons transferred per molecule

**Standard Reduction Potentials Can Be Used to Calculate Free-Energy Change**

Go = -nFEo or G= -nFE

F is the Faraday constant

**Cellular Oxidation of Glucose to Carbon Dioxide Requires Specialized Electron Carries**

* In many organisms, the oxidation of glucose supplies energy for the production of ATP.
* The complete oxidation of glucose :

C6H12O6 + 6O2 6CO2 + 6H2O Go = - 2,480 kJ/mol

* Electrons removed in these oxidation steps are transferred to coenzymes specialized for carrying electrons, such as
* NAD+ (Nicotinamide Adenine Dinucleotide)
* FAD (Flavin Adenine Dinucleotide)

**A Few Types of Coenzymes and Proteins Serve as Universal Electron Carriers**

* Some of them are
* NAD+
* NADP+ (Nicotinamide Adenine Dinucleotide Phosphate)
* FMN (Flavin Mononucleotide)
* FAD
* Quinones
* Iron-sulfur proteins
* Cytochromes
* NAD+ and NADP+ are the freely diffusible coenzymes of many dehydrogenases.
* Both of them accept two electrons and one proton. (**Fig. 13-24a).**

 

NAD+ + 2e- + 2H+ NADH + H+

NADP+ + 2e- + 2H+ NADPH + H+

* More than 200 enzymes use NAD+ or NADP+.
* They are called **oxidoreductase** or **dehydrogenase**.
* For example, alcohol dehydrogenase catalyzes

CH3CH2OH + NAD+ CH3CHO + NADH + H+

 Ethanol Acetaldehyde

* FAD and FMN serve as tightly bound prosthetic groups of flavoproteins.
* They can accept either one or two electrons and one or two protons (**Fig. 13-27)**.

 

FMN + 2e- + 2H+ FMNH2

FAD + 2e- + 2H+ FADH2