

Bioenergetics (فح ج 634)

Lecture 1

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Bioenergetics

- The energy around us
- Forms of energy.
- Ambient energy.
- Molecular energy.
- Molecular energy absorbance.

references

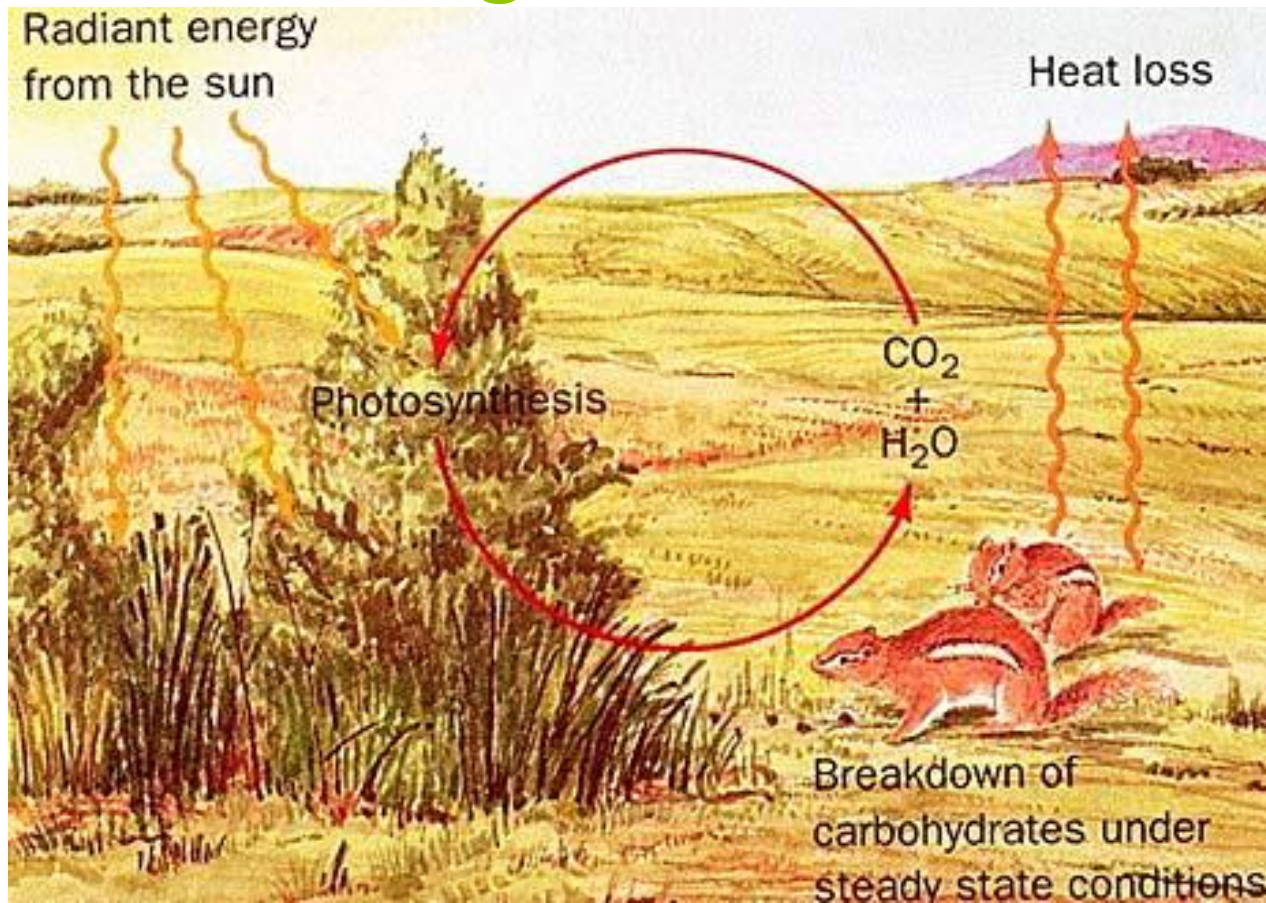
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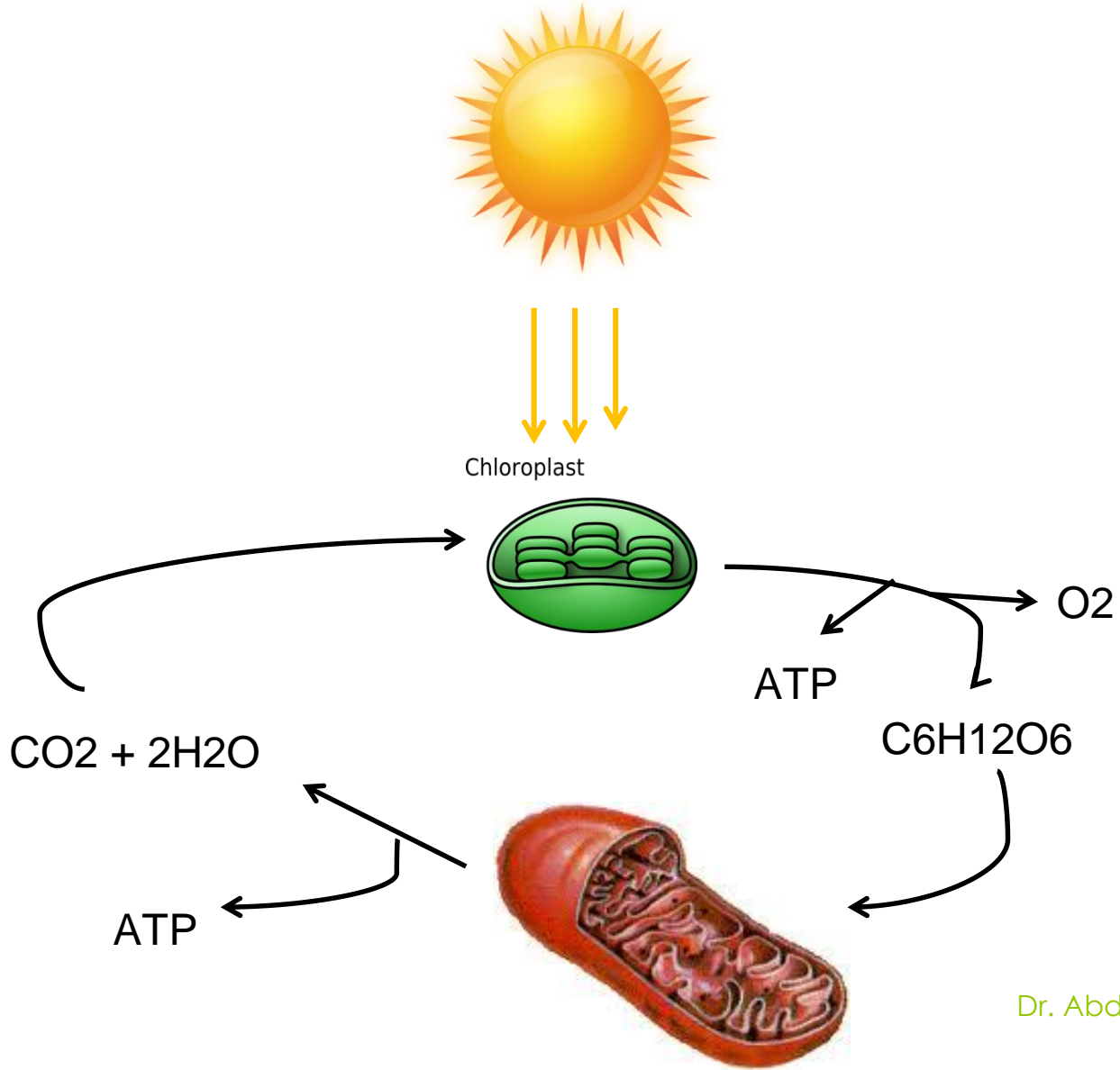
Bioenergetics



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Bioenergetics (continued)

Energetics is the study of energy requirements and the flow of energy within systems, while **Bioenergetics** (or biological energetics) is the study of the balance between energy intake in the form of food and energy utilization by animals for life-sustaining processes, tissue synthesis, osmoregulation, digestion, respiration, reproduction, locomotion, etc.

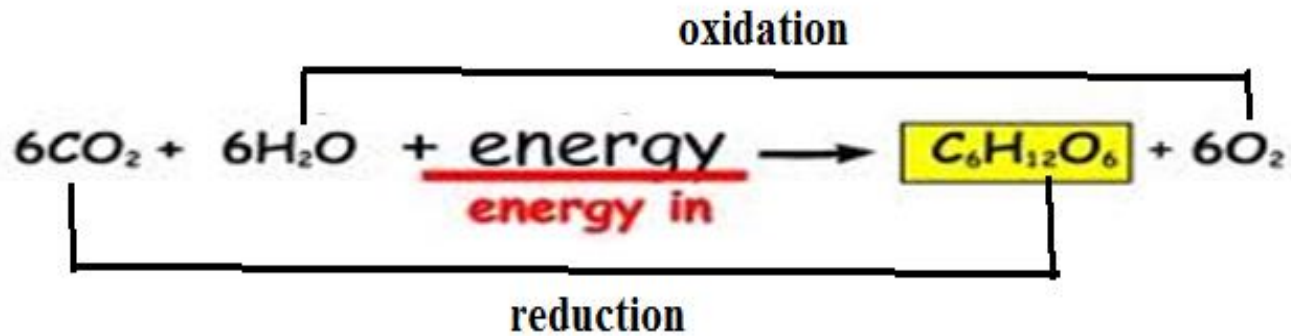


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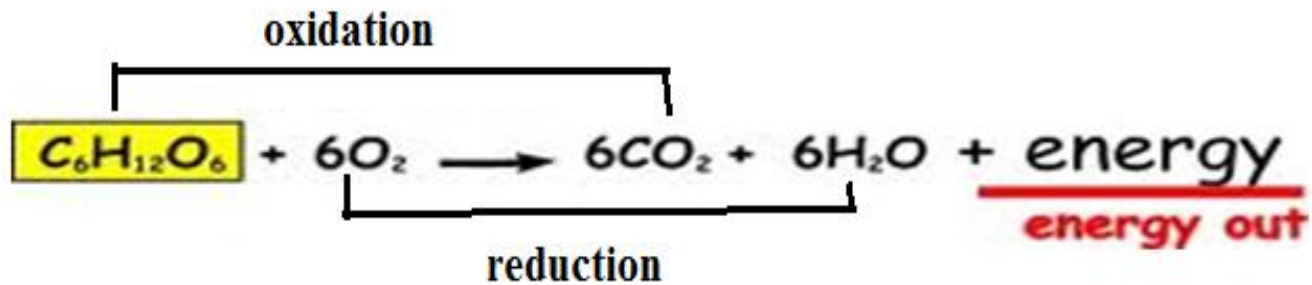
Bioenergetics (continued)

- Animals obtain their energy from chemical bonds of complex molecules they oxidize these bonds to lower energy states using oxygen from the air.
- some bonds have more energy than others.
- Oxidation is loss of electron
 - oxidizing agent: molecule that can accept electron
- Reduction is gain of electron
 - reducing agent : molecule that can donate electron

photosynthesis



respiration



The energy around us

- The word “energy” was first introduced in 1807, and defined as “ability to work” And found in many forms: heat, kinetic, electromagnetic, radiant, nuclear and chemical.
- Thermodynamics is the branch of chemistry and physics that deals with the energy flow in physical systems.

The energy around us

(continued)

The First Law of Thermodynamics states that energy in a system is neither created nor destroyed.

The Second Law of Thermodynamics deals with the question of whether a reaction will occur

The energy around us

(continued)

- Spontaneous reactions occur with an increase in the entropy of a system
- the free energy of a system is defined as the difference in heat content between the products and reactants, less the amount of entropy change (multiplied by the temperature of the system)

$$\Delta G = \Delta H - T\Delta S$$

- where ΔG is the amount of free energy released from the reaction, ΔH is the change in heat content, or enthalpy, T is the temperature in degrees Kelvin, and ΔS is the change in entropy.

The energy around us

(continued)

- Another way of stating the Second Law of Thermodynamics is that reactions occur in the direction in which the free energy change is negative.
- The change in free energy of a reaction in the standard state (with all reactants and products at 1M. pH = 7.0 at 25 °C) is related to the equilibrium constant for the reaction by the following relation:

$$\Delta G = -RT \ln K_{eq}$$

- where R is the gas constant, T is the temperature in degrees Kelvin, and K_{eq} is the equilibrium constant for the reaction

The energy around us

(continued)

- A reaction that is favored has $K_{eq} > 1$, (K_{eq}) is positive, so the free energy change of a favored reaction is negative; it is *exergonic*.
- A reaction that is unfavored has $K_{eq} < 1$. Conversely, the natural logarithm of a number less than 1 is negative; because the product of two negative numbers is positive, the free energy change of an unfavored reaction is positive; it is *endergonic*.

Forms of Energy

- Biophysical systems in living organisms must have a constant input of energy to remain alive, but will reach thermal equilibrium after death.
- Biophysical systems can neither create nor destroy energy, but they can manipulate energy by doing work or altering the internal energy of the system.
- Biophysical processes removed from equilibrium will produce an increase in entropy.

Forms of Energy (continued)

- A process is a transition between state functions. State functions are thermodynamic quantities, and are therefore, in the absence of external energy input, at equilibrium.
- The internal energy of a system is the sum of the different states comprising that system.

Forms of Energy (continued)

- Other processes that have little influence on normal physiological systems come into play when the body is exposed to unusual energetic input, such as magnetic fields during magnetic resonance imaging (MRI).

Ambient energy

- With the exception of a few molecules near our body surfaces, the constant temperature of the body produces an average energy that the molecules in the body are exposed to. This energy is the absolute temperature T (in degrees K) times the Boltzmann constant, k , 1.38×10^{-23} J/K.
- Except for those occasions when a molecule is involved in a reaction, molecules will be in equilibrium with the energy of the environment around us, E_0 ,

Ambient energy (continued)

$$E_o = kT = 310 \text{ K} \cdot 1.38 \times 10^{-23} \text{ J/K} \cdot \text{molecule} = 4.28 \times 10^{-21} \text{ J/molecule.} \quad (1.4)$$

This is the equilibrium energy of a single molecule. When we deal with an ensemble of molecules, we measure molecules on the molar scale, using Avogadro's number, N_A , to convert Boltzmann's constant to the gas constant, R ,

$$\begin{aligned} R &= N_A \cdot k = 6.02 \times 10^{23} \text{ molecule/mol} \cdot 1.38 \times 10^{-23} \text{ J/K} \cdot \text{molecule} \\ &= 8.31 \text{ J/K} \cdot \text{mol} \end{aligned} \quad (1.5)$$

and the molar equilibrium energy to

$$E_m = RT = 8.31 \text{ J/K} \cdot \text{mol} \cdot 310 \text{ K} = 2.58 \text{ kJ/mol.} \quad (1.6)$$

Ambient energy (continued)

- All systems will try to maximize entropy, always tending to the lowest energy state possible. All living systems on the earth will tend toward the energy of the environment around them, Global Thermal Equilibrium (GTE). All beings will reach GTE when they die. Until then, living beings must have a constant input of energy in order to counter entropy.

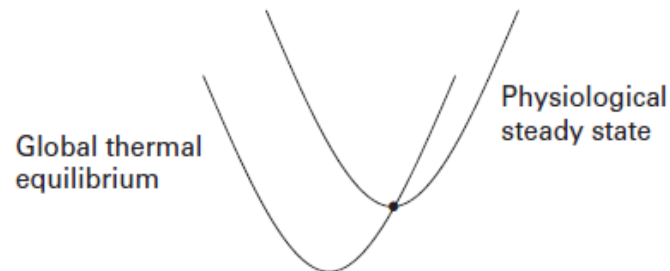


Figure 1.1 All living systems exist at a steady state whose minimum energy position (●) has a higher energy than the global equilibrium it is part of. To maintain this steady state, there must be a constant input of energy to offset entropy.

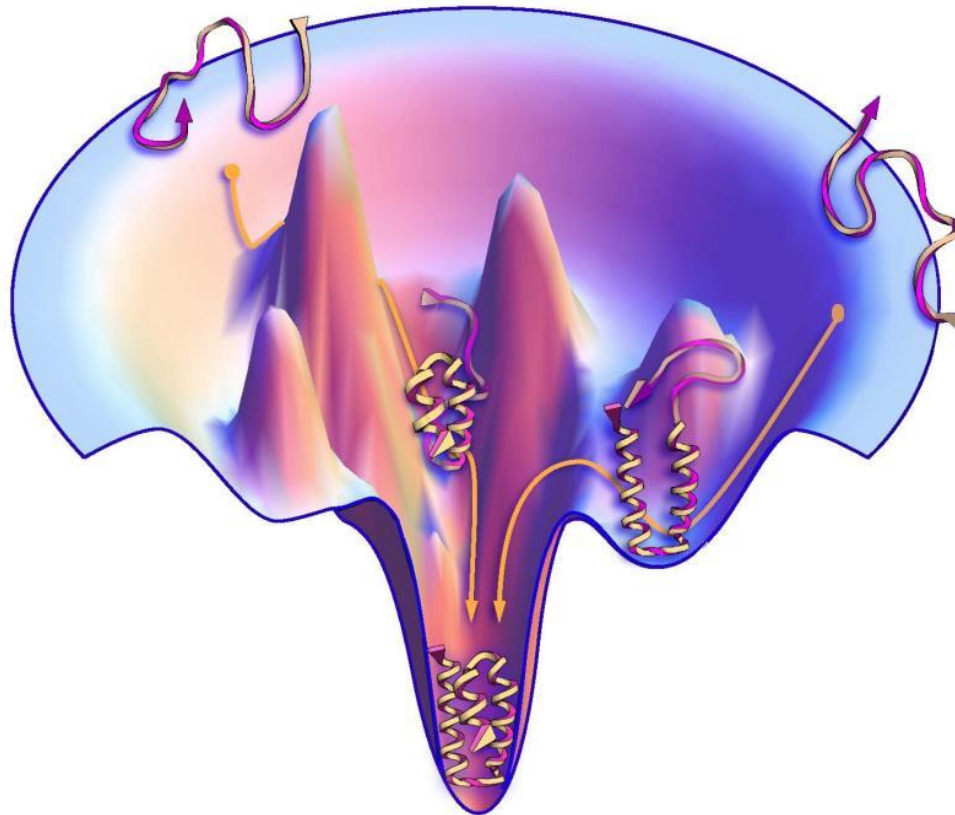
Molecular energy

- The energy associated with each atom and each bond is not continuous, but quantal, based on the electron shells occupied in the electron cloud around the nucleus.
- For a given atom, there would be a quantal energy distribution, with the lowest energy configuration being the most common, as Boltzmann demonstrated.

Molecular energy (continued)

- In a molecule not every bond will be at its lowest energy but it as a whole will seek its lowest overall energy, out of the many possible configurations of attractions and repulsions that will alter bond angles and the energy in the bonds. The larger the molecule, the greater the number of potential configurations and energy levels that are possible.

Molecular energy (continued)



Molecular energy (continued)

- The thermal energy of molecules must be distinguished from the chemical energy of molecules. All molecules, regardless of chemical structure, will see the same thermal energy kT .
- The different chemical structure of molecules means that different amounts of energy are trapped within the chemical bonds of different molecules. The organic part of a molecule will have its atoms connected by covalent bonds. Each of these bonds has an energy associated with it: the dissociation bond energy necessary to break the bond.

Molecular energy (continued)

Table 1.1 Average bond dissociation energies at 25 °C

Bond	Dissociation energy (kJ/mol)
C—C	344
C=C	615
C—H	415
C—N	292
C—O	350
C=O	725
N—H	391
O—O	143
O—H	463
O ₂	498

Source: Tinoco et al., 1995

- The ambient energy in the human body is 2.58 kJ/mol. This energy is far below that of any covalent bond in the body. This means that it is statistically unlikely that any covalent bond would spontaneously break due to the random thermal fluctuations around it.

Molecular energy absorbance

- When energy is absorbed by a molecule, it will either release the energy as heat, returning to its original configuration, or trap some of the energy within the molecule by altering its structure.
- The new structure will have its own energy minimum. It may be possible for the molecule to revert to its original structure, but this will be determined by the height of the energy barrier between the two states.

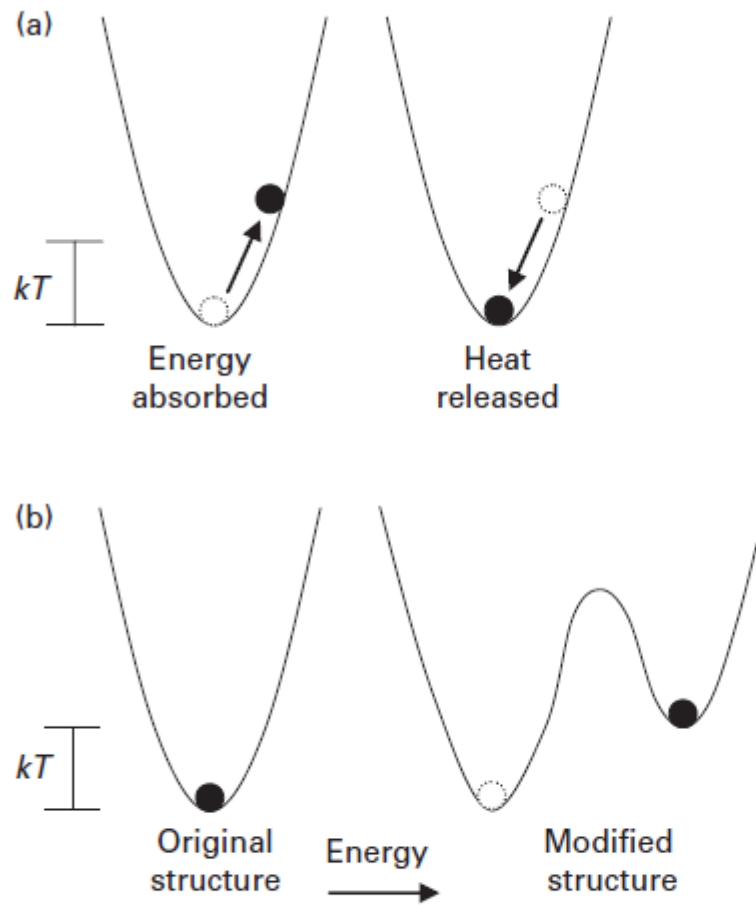


Figure 1.3 Energy absorbance within molecules. The molecule may absorb energy and radiate heat (a), or alter its chemical structure (b). The effect of kT on any state is measured from its local minimum relative to the lowest local energy barrier.

Molecular energy absorbance (continued)

- If the energy barrier is less than kT , then spontaneous reversion will occur.
- The equilibrium between the two states of the molecule will be determined by the relative basal energy states. The higher of the two minima will have fewer elements at equilibrium than the lower minimum.

Molecular energy absorbance (continued)

- The absorption of energy may be so great that no reversion to the original state can occur. This is the case when a molecule absorbs large amounts of heat, destroying its three-dimensional structure, as occurs in the thermal denaturation of a protein.
- The energy barrier between the original and the new state is so great that no enzyme is capable of lowering the energy barrier sufficiently to return the molecule to its original configuration.



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