General Biophysics (211 بف)

Lecture 6

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Topics

- The energy around us
- Forms of energy.
  - Ambient energy.
  - Molecular energy.
    - Molecular energy absorbance.
  - Molecular transduction.
- Light and its biological effects.
  - Light absorbance by matter.

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 ***<u>energy in a system is neither created nor destroyed</u>***.

The Second Law of Thermodynamics ***<u>deals with the question of whether a reaction will occur</u>***

- Spontaneous reactions occur with an increase in the entropy of a system

The energy around us
(continued)

- **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.

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.

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_o.

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.

Ambient energy (continued)

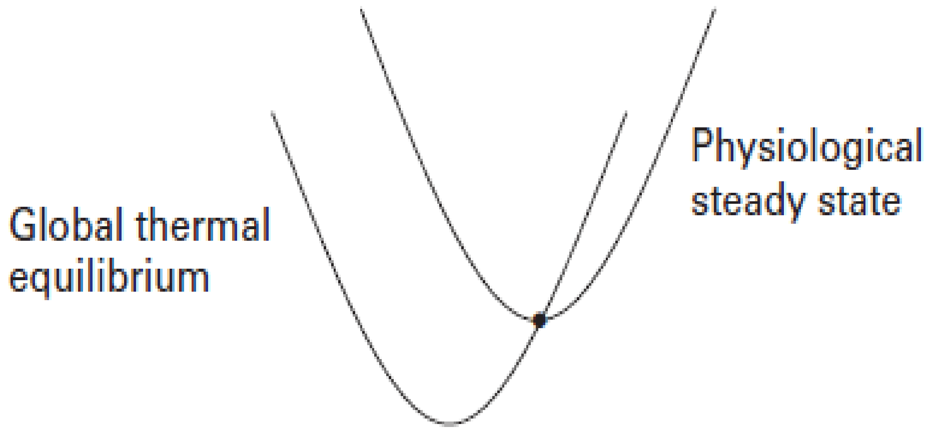


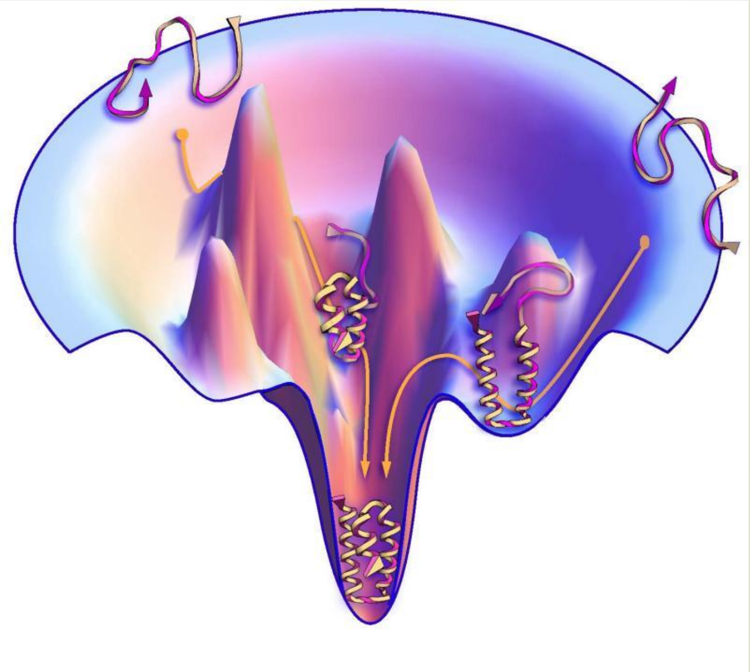
Figure 1.1 All living systems exist at a steady state whose minimum energy position (•) has a higher energy than the global equilibrium it is part of. To maintain this steady state, there must be a constant input of energy to offset entropy.

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.
- 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.

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)

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.

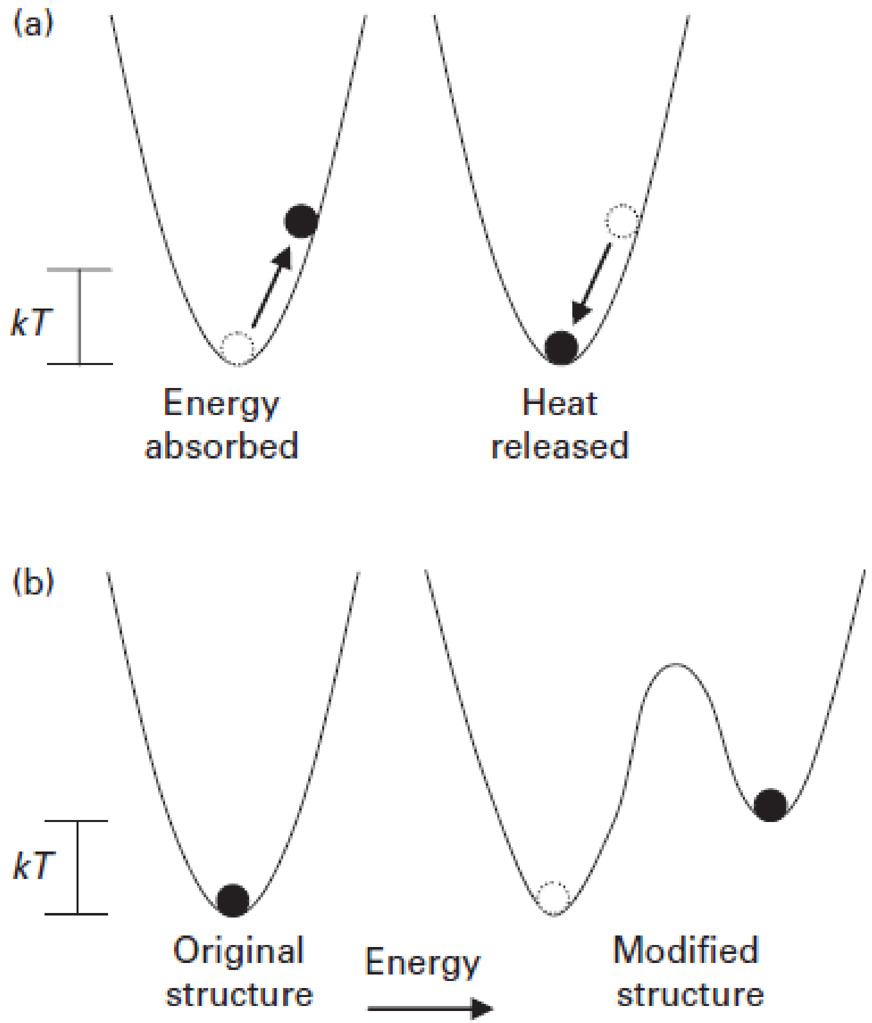


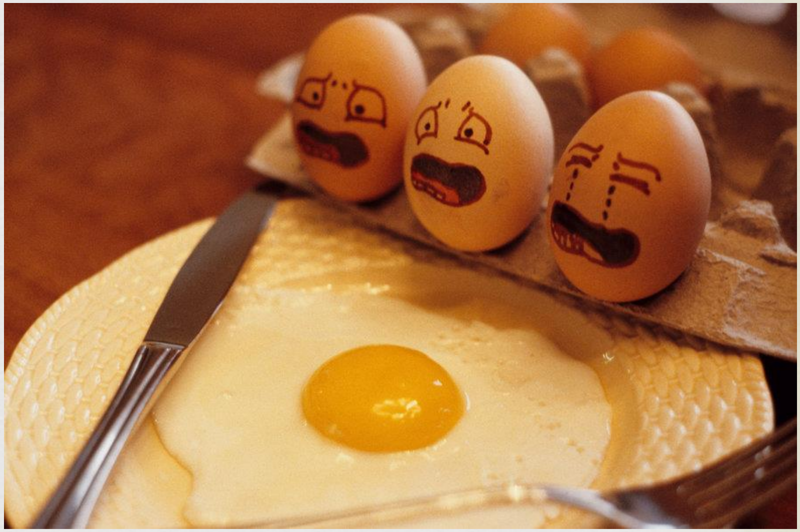
Figure 1.3 Energy absorbance within molecules. The molecule may absorb energy and radiate heat (a), or alter its chemical structure (b). The effect of *kT* on any state is measured from its local minimum relative to the lowest local energy barrier.

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.

Molecular transduction

- A particular bond in a molecule can absorb energy from the surrounding environment and alter its structure. This bond is sensitive to a particular wavelength of electromagnetic radiation, due to a match of the electron oscillation frequency of the bond and the external radiation frequency.

Molecular transduction (continued)

- Planck postulated that the energy ε of the quantum is not fixed, but will increase as the frequency ν of the oscillation increases, with Planck's constant (h) as the proportionality factor.

$$\epsilon = h\nu$$

- The frequency of electromagnetic radiation is inversely proportional to the wavelength λ of the electromagnetic wave, with the product equal to the speed of light c in a vacuum

$$c = \lambda\nu$$

Molecular transduction (continued)

- Quantum mechanics limits the states of electrons (Pauli exclusion principle).
- The ground state for an electron is the S_0 singlet state, from which a photon can excite an electron to the S_1 singlet state.
- The electron can spontaneously release this energy as a photon of light: this is ***fluorescence***. Or, there may be an energetic transfer to an adjacent triplet state T_1, from which a photon of light can be released at a different frequency: this is ***phosphorescence***.

Molecular transduction

(continued)

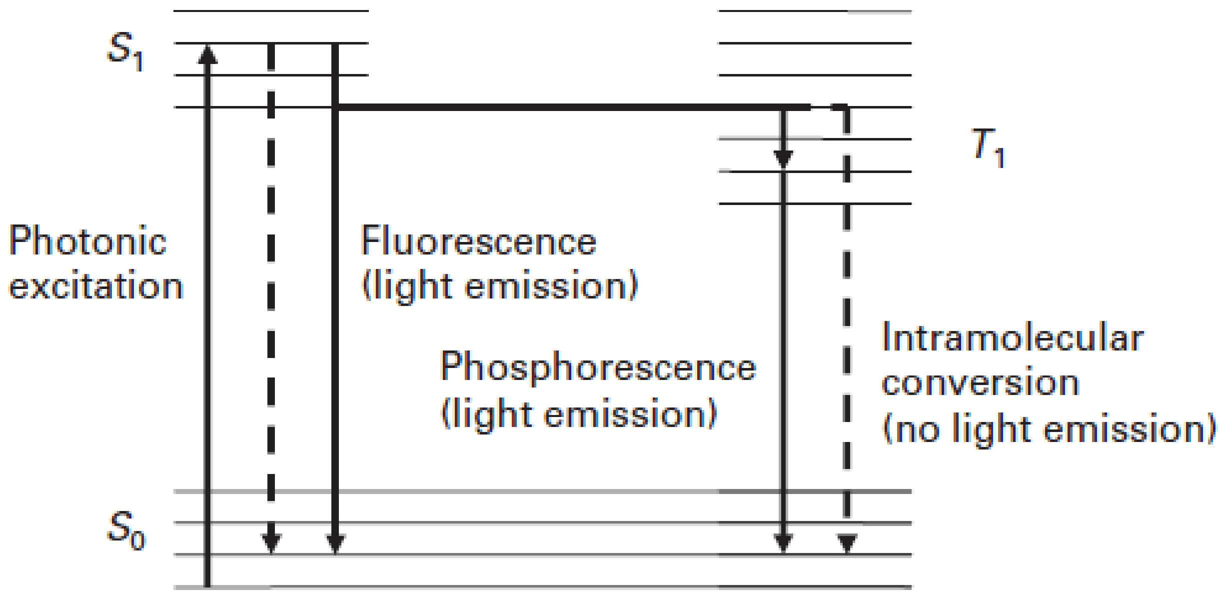


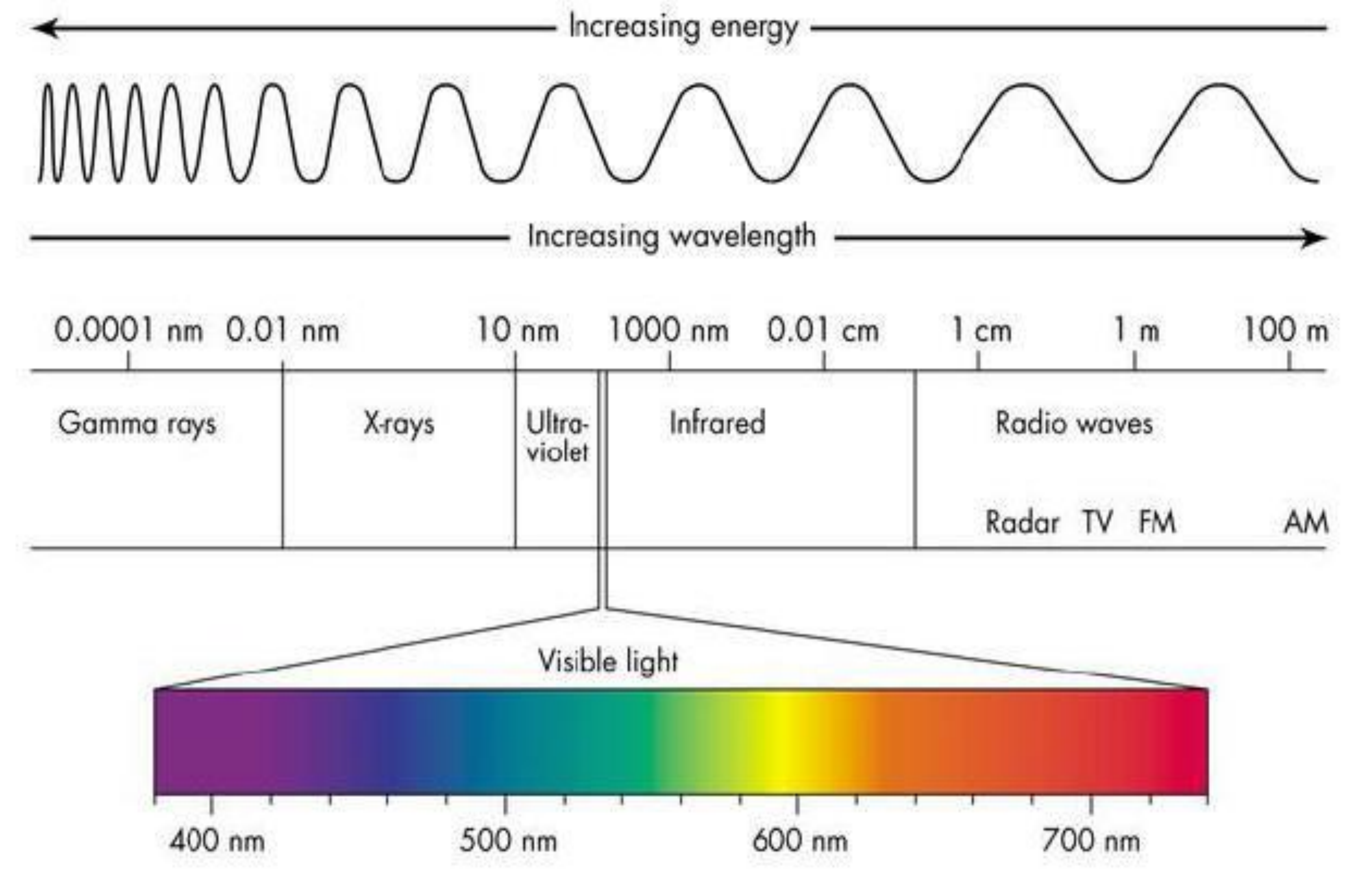
Figure 1.5 At the single atom level, the different quantum states (S_0, S_1, T_1) have thermal variations at each quantum level, indicated by the horizontal parallel lines. Fluorescence and phosphorescence do not play a role in human physiology. Intramolecular conversion occurs in phototransduction, and the destructive effects of ultraviolet and x-rays.

Molecular transduction
(continued)

- Fluorescent radiation (10^{-9} to 10^{-5} s) is faster than phosphorescent radiation (> 10^{-5} s) due to the greater stability of the T_1 state.
- The third path, indicated by the dashed lines in the figure, shows an energy release after quantum absorption of energy without light emission from either the S_1 or T_1 state. In this case, a portion of the energy remains within the molecule and alters its structure.

Light and its Biological Effects

- Light is an electromagnetic vibration. It has a dual nature; it can act as a ***wave*** and it behave more like a ***particle***.
- In phenomena such as: refraction diffraction and interference, light will be treated as a wave motion. On the other hand when light absorbed by matter with transformation of its energy into chemical energy or heat it will be treated as a particle or quantum.


Increasing energy
Increasing wavelength
0.0001 nm
0.01 nm
10 nm
1000 nm
0.01 cm
1 cm
1 m
100 m
Gamma rays
X-rays
Ultra-
violet
Infrared
Radio waves
Radar
TV
FM
AM
Visible light
400 nm
500 nm
600 nm
700 nm

Light absorption by matter