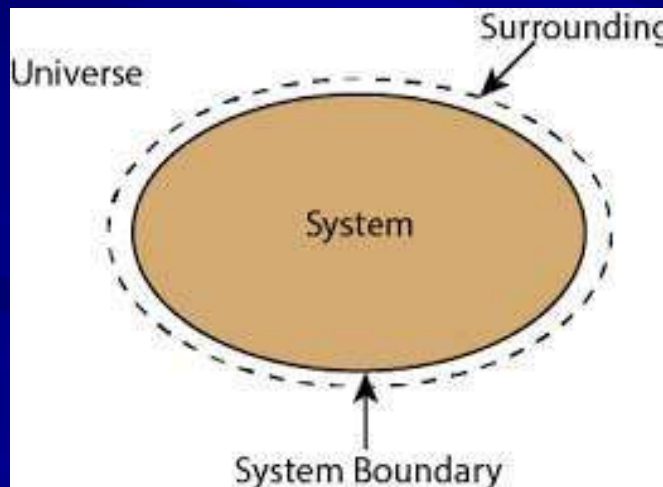# Basics of bioenergetics

Medical Chemistry

Definitions

Thermodynamics studies transformations of energy.

A thermodynamic system is an object or a group of interacting objects separated with a boundary from the surroundings

Homogeneous and heterogeneous thermodynamic systems

Homogeneous systems consist of a single phase They do not have a phase interface.

Example: water solutions of glucose, sucrose, sodium chloride etc.

Homogeneous and heterogeneous thermodynamic systems

Heterogeneous systems consist of several phases They have a phase interface. Examples:

Open, closed and isolated thermodynamic systems

Open, closed and isolated thermodynamic systems

Open systems exchange both matter and energy with the surroundings

Examples:

Open, closed and isolated thermodynamic systems

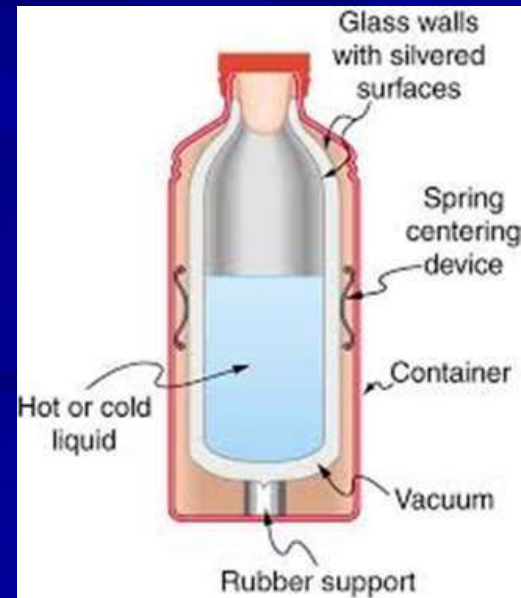**Closed systems exchange energy and do not exchange matter.**

Examples:

Open, closed and isolated thermodynamic systems

Isolated systems exchange neither mass nor energy with the surrounudings.

Example: a thermocapsulated cup

# Thermodynamic potentials

Internal energy, U

Enthalpy, H

Entropy, S

Gibbs energy, G

Internal energy, U

Internal energy of a system is the sum of the potential energy and the kinetic energy of all components of the system. In it, the kinetic is the energy of molecular movement. The potential energy is the energy in all the chemical bonds.

(a) Glucose, a simple carbohydrate

(b) Starch, a polysaccharide
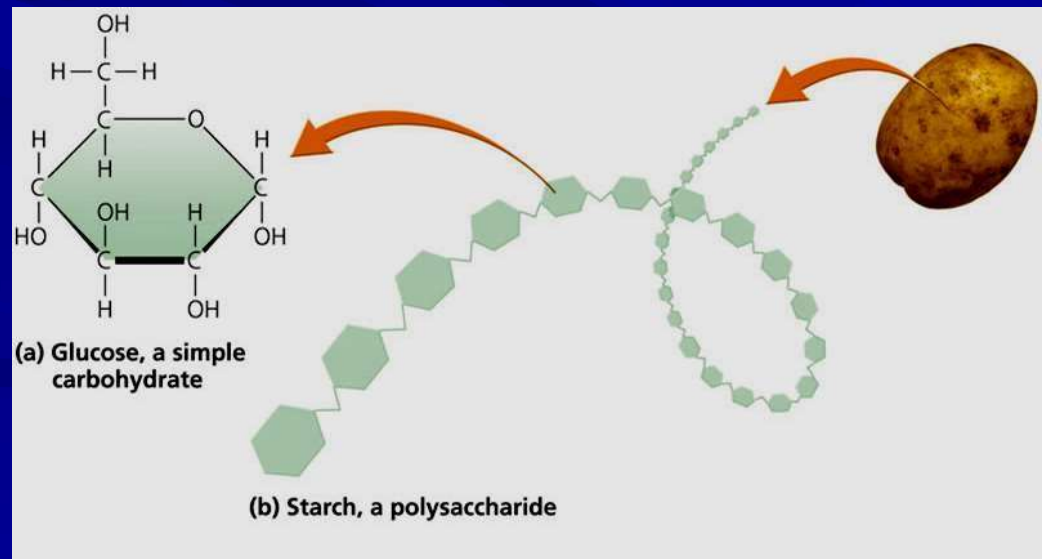
Internal energy, U

Internal energy excludes kinetic energy due to motion of the system as a whole and gravitational potential energy due to its elevation.

Potential energy

Energy in

Energy out
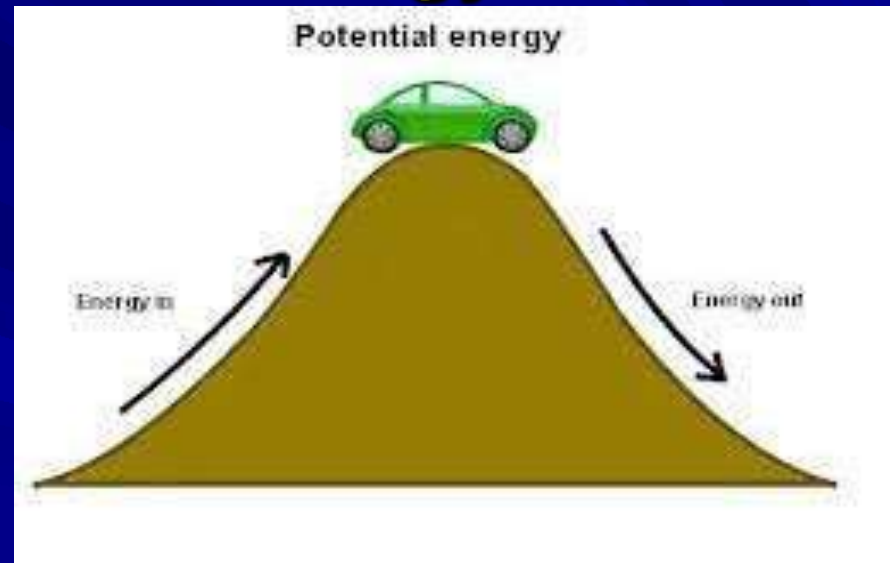
Internal energy cannot be measured

but its change ΔU can be measured

Enthalpy, H

Enthalpy is the total heat content of the system.

Enthalpy is the sum of internal energy and the work done by the system to stay in its boundaries:

$$H = U + pV$$
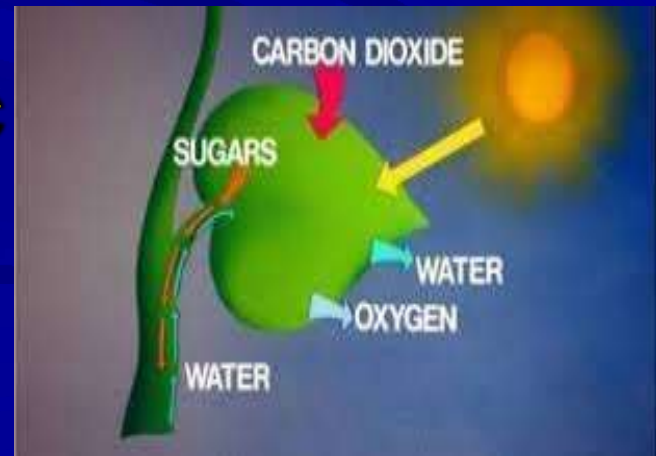
Enthalpy cannot be measured,

but its change ΔH can be measured.

Enthalpy, H

ΔH is the heat effect of a reaction.
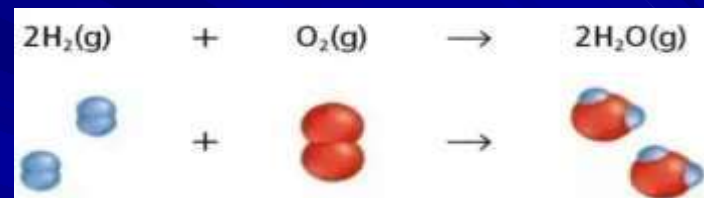
ΔH < 0: heat is released,

the reaction is exothermic

ΔH > 0: heat is absorbed,

the reaction is endothermic

Standard enthalpy of formation

Standard enthalpy of formation of a compound is the enthalpy change that occurs when one mole of a substance in its standard state is formed from the component elements in their standard states.

$$2H_2(g) \quad + \quad O_2(g) \quad \rightarrow \quad 2H_2O(g)$$

Standard enthalpy of formation of elements (simple substances) is equal to zero at standard conditions. Examples of simple substances: O_2, N_2, Mn, Fe, Br_2, K, C, etc.

Standard enthalpy of combustion

Standard enthalpy of combustion is of a compound is the enthalpy change that occurs when 1 mole of a substance reacts completely with oxygen under standard conditions.

$CH_4 + 2O_2 \longrightarrow CO_2 + 2H_2O$
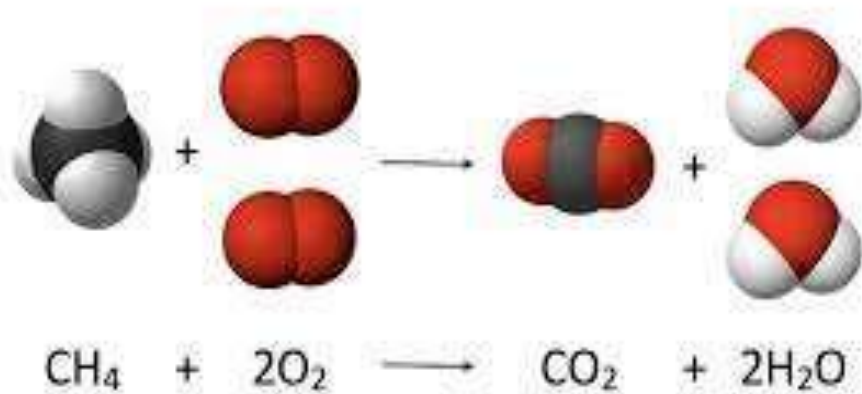
Hess' Law

The heat effect of a reaction depends only on the initial and final states of the system, and is independent of the pathway between these states.
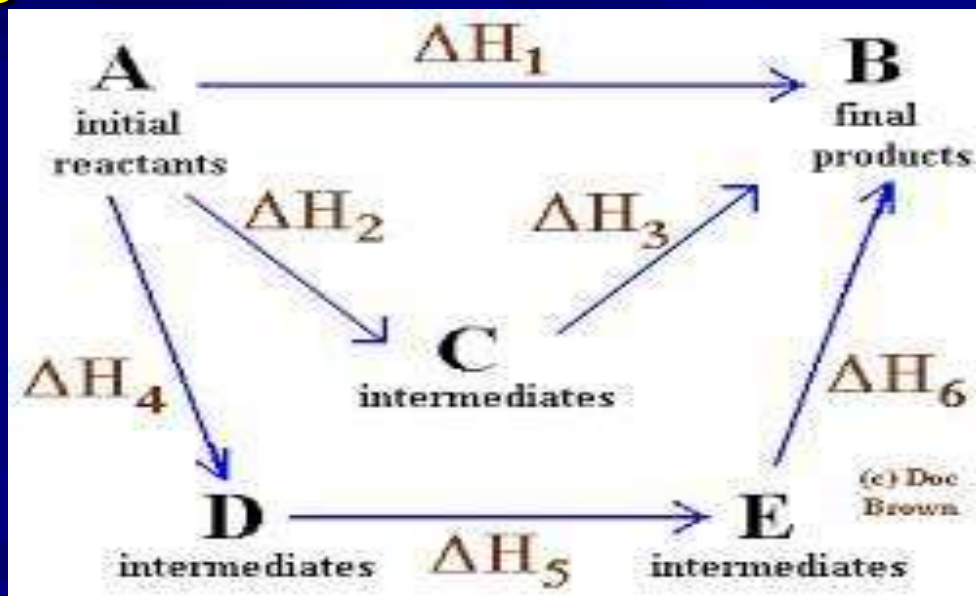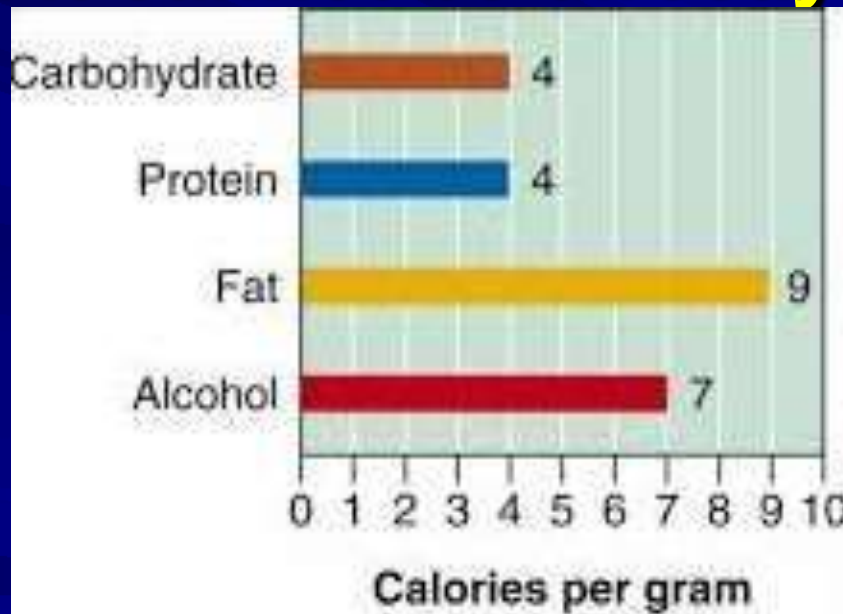

$$\Delta H_1 = \Delta H_2 + \Delta H_3 = \Delta H_4 + \Delta H_5 + \Delta H_6$$

Hess' Law

Hess law is a definition of the First Law of Thermodynamics.

It allows ΔH for a reaction to be calculated even when it cannot be directly measured.

Application: find energy values of food

First Law of Thermodynamics

Definition 1:

Law of Conservation of Energy

Energy can neither be created nor destroyed, it can only be transformed from one form to another

First Law of Thermodynamics

Definition 2:

In an isolated system, the sum of all types of energy is a constant value

First Law of Thermodynamics

Definition 3: Heat transferred to a system is used to do work and change internal energy of the system.

$$Q = \Delta U + A$$

- **Q is the heat exchanged between a system and its surroundings;**
- **ΔU is the total change in internal energy of a system;**
- **A is the work done by or on the system**

First Law of Thermodynamics

Definition 4:
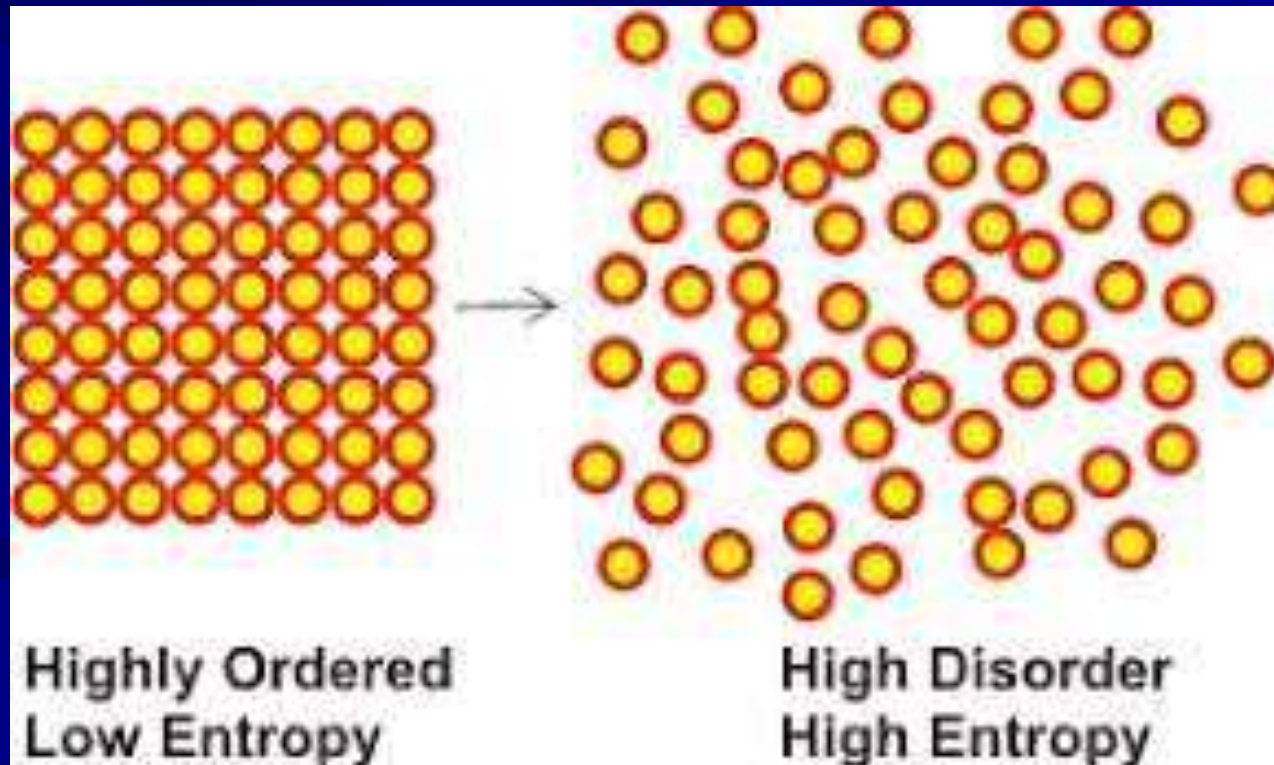
The perpetuum motion machines of the first kind are impossible.

No Energy = No Work

Entropy, S

Definition 1:

Entropy is the measure of randomness (disorder).

Highly Ordered
Low Entropy

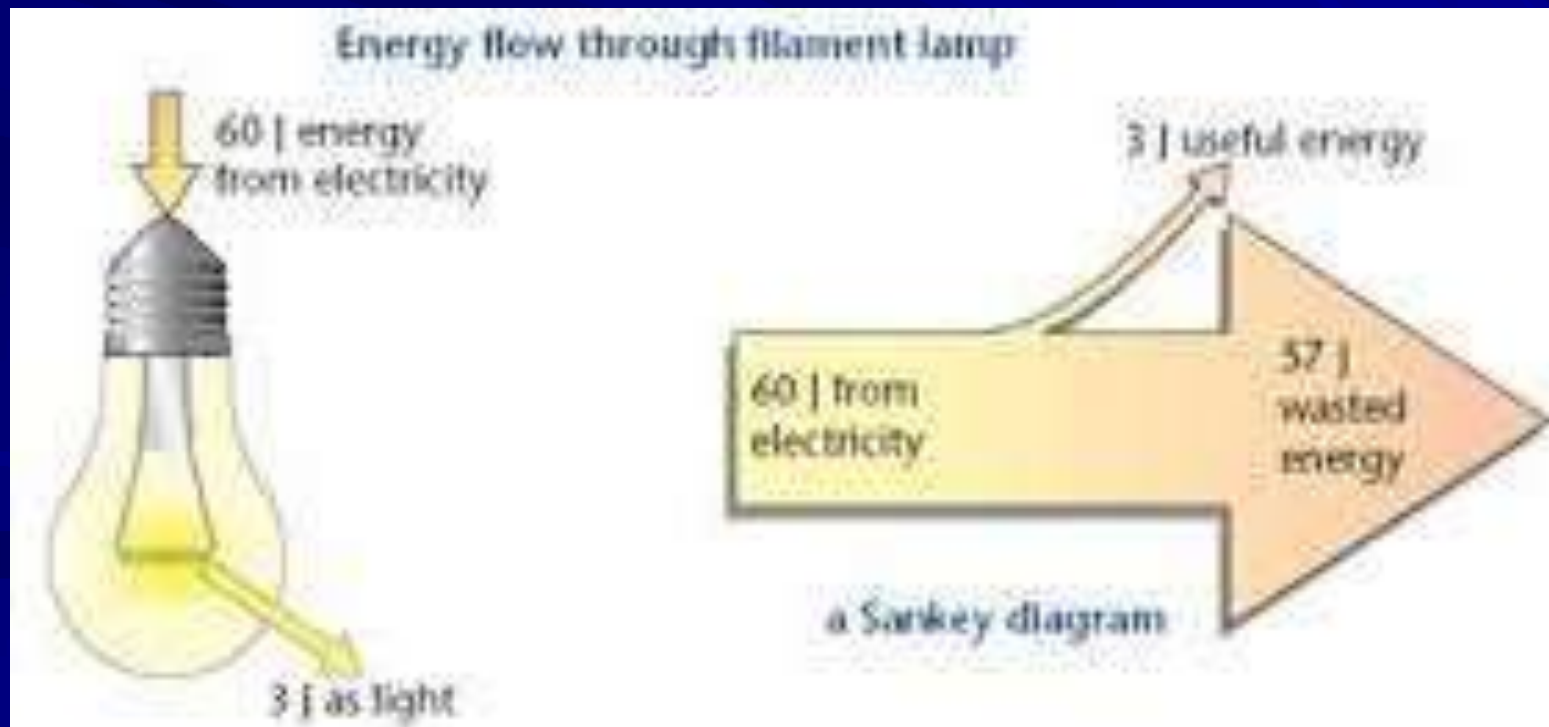High Disorder
High Entropy

Entropy, S

Definition 2:

Entropy is the energy that cannot be converted into work.

Entropy, S

Definition 3:

Entropy is the dissipated (wasted) energy

Energy flow through filament lamp

60 J energy from electricity

3 J useful energy

60 J from electricity

57 J wasted energy

a Sankey diagram

3 J as light

Entropy, S

Entropy increases from solid to liquid to gas.

Solid   Liquid   Gas
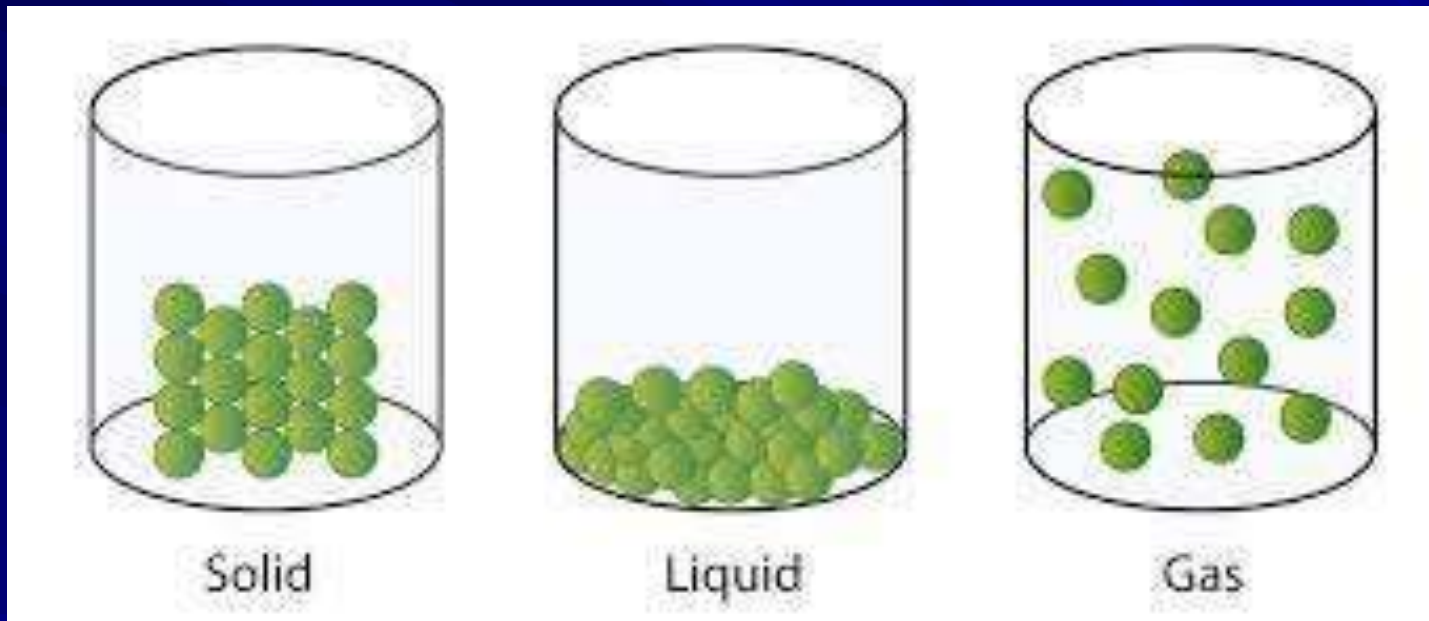
Entropy increases with an increase in temperature.

Entropy, S

Entropy of a system and its surroundings increases in spontaneous processes

Entropy increases with time.

low entropy   medium entropy   high entropy

Entropy, S

A change of entropy ΔS is the measure of irreversibility of a process

Second Law of Thermodynamics

Definition 1:

It is impossible to create a machine that can transform all heat into useful work.

Second Law of Thermodynamics

Definition 2:

All energy tends to transform into heat, and the heat tends to dissipate

Second Law of Thermodynamics

Definition 3:

Heat cannot flow spontaneously from a material at a lower temperature to a material at a higher temperature.

Second Law of Thermodynamics

Definition 4:

In an isolated system, entropy increases and reaches its maximum at equilibrium

i.e.

No work is done at equilibrium

and

Living organisms are non-equilibrium systems

Second Law of Thermodynamics

Definition 5:

Entropy is the arrow of time.

Gibbs energy, G

1. Gibbs energy is free energy

2. Gibbs energy is the energy that can be used to do work

$$G = H - TS$$

H is enthalpy

T is absolute temperature

S is entropy

Gibbs energy change, ΔG

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

ΔG is the only criterion of spontaneous processes

ΔG < 0: the process is spontaneous (exergonic)

ΔG > 0: the process is not spontaneous (endergonic)

ΔG = 0: the process is in equilibrium

Endergonic and exergonic processes in the organism

Exergonic processes: glycolysis, fatty acid oxidation, ATP hydrolysis

Endergonic processes: synthesis of glucose, fatty acids, proteins, ATP

Exergonic and endergonic processes are conjugated, i.e. an endergonic process only proceeds with energy from an exergonic process.