		Lectures
Bioenergetics	**:**	**3**
DNA replication	**:**	**2**
Transcription	**:**	**2**
Translation	**:**	**2**
Genes to proteins & Protein function	**:**	**1**
		10

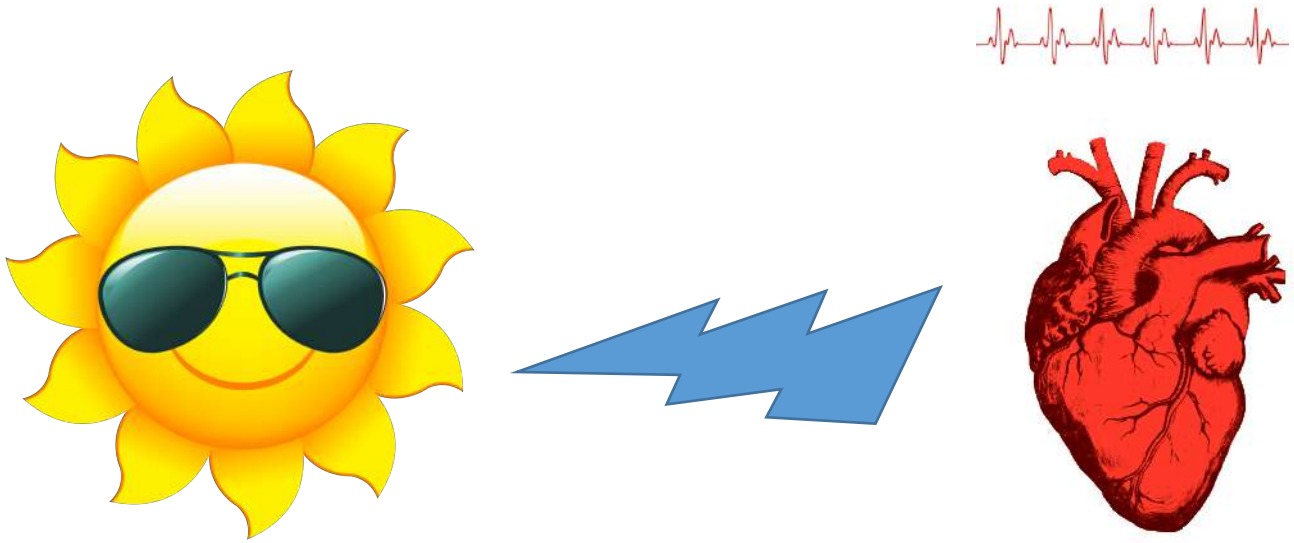
~~**Quiz 2**~~

- **Syllabus = First 4 Lectures**
- **Marks = 10**
- ~~**Date and Time: 24th March 2018 (Saturday)**~~
- ~~**Time : 8:50 AM – 9:10 AM (20 minutes)**~~
- **Venue : L1, L2, L3, L4**

Dr. P. Satpati,
BSBE, IIT Guwahati

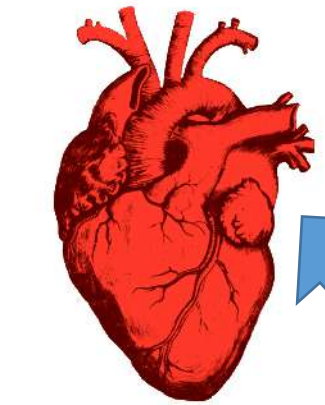
L1: Bioenergetics

Dr. P. Satpati,
BSBE, IIT Guwahati



Sun is the ultimate source of energy…

Photosynthesis:
Energy from sun is converted into chemical bonds (Glucose)
$6H_2O+6CO_2+ h\nu(Energy) \rightarrow C_6H_{12}O_6+6O_2$



ATP → ADP+ Pi + Energy

Cellular respiration:
Glucose broken down into usable form of Energy **ATP.**
$C_6H_{12}O_6+6O_2$
$\rightarrow 6H_2O+6CO_2+$ ATP(energy)

Bioenergetics:

Quantitative study of the *energy transductions* – changes of one form of energy into another – that occur in living cells. Nature and function of the chemical process underlying these transductions.

Biological energy transductions obey the laws of **Thermodynamics**

$h\nu$(Energy)→ $C_6H_{12}O_6$→ ATP(Energy)→ **USEFUL WORK**

The goals of this lesson

- Review the laws of thermodynamics
- Understand the quantitative relationships among free energy, enthalpy and entropy

Quantitative answers for the following questions

$$A+B \leftrightharpoons C$$

1. Will this happen spontaneously ? (Driving Force)
2. How much will this happen ?
3. Relation between 1 and 2 ?
4. How all this is related to biology ?
5. How fast will this happen ?

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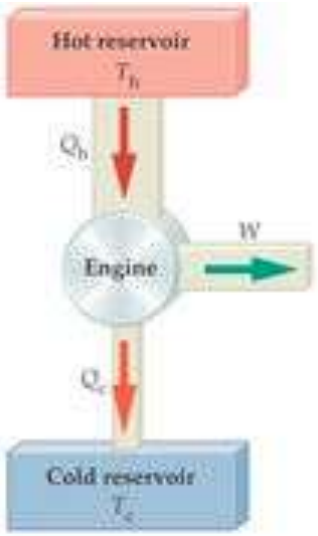
$$A+B \leftrightharpoons C$$

1. Will this happen spontaneously ? (Driving Force)
2. How much will this happen ?
3. Relation between 1 and 2 ?
4. How all this is related to biology ?
5. ~~How fast will this happen ? (KINETICS)~~

Energetics of Living System

Non-living

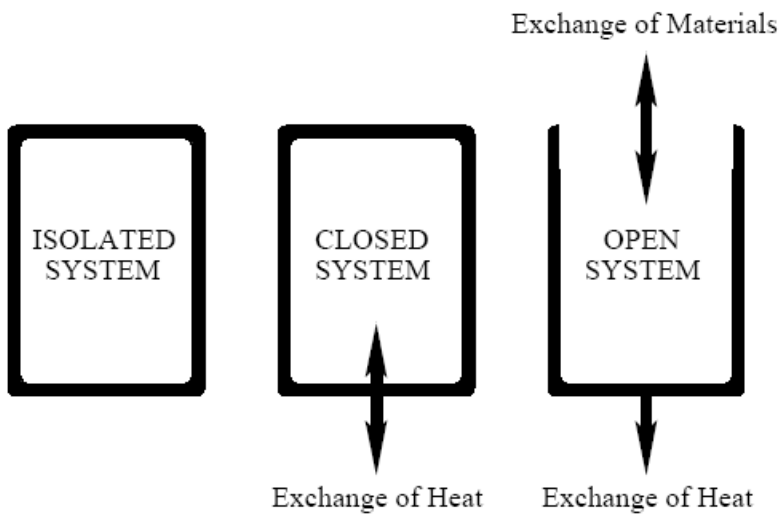
Heat Engine: Flow of Heat → Work



Living

Energy of chemical reactions

- Synthesis of complex molecules,
- Concentration gradient,
- Electrical gradient,
- Motion,
- Heat,
- Light



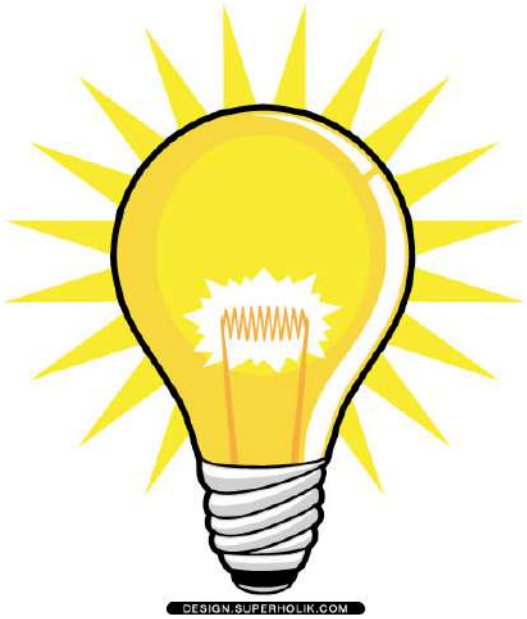
Chemical reactions in Lab: Closed system

Living cell: Open system

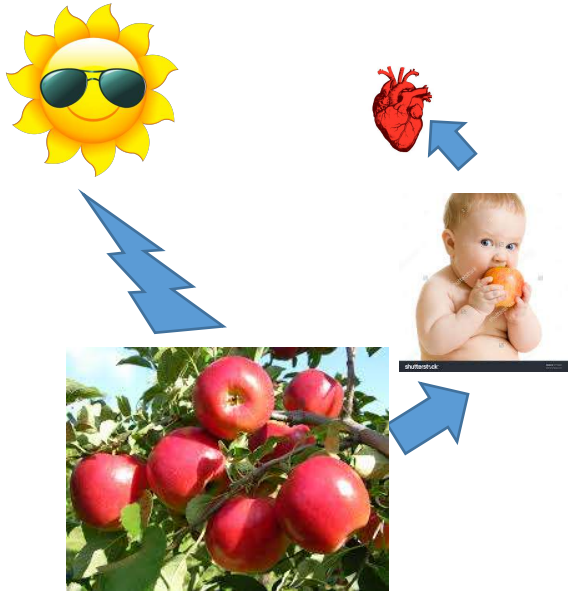
← Isothermal & Isobaric

Laws of thermodynamics

1. CONSERVATION OF ENERGY; energy may change its form, **but it can not be created or destroyed.**

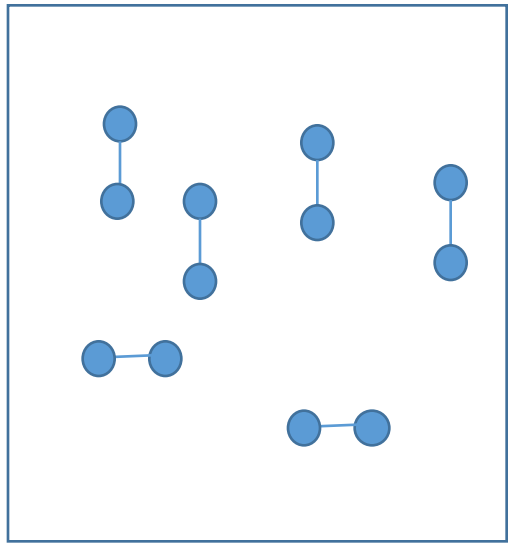


PE→ KE→ Light+Heat

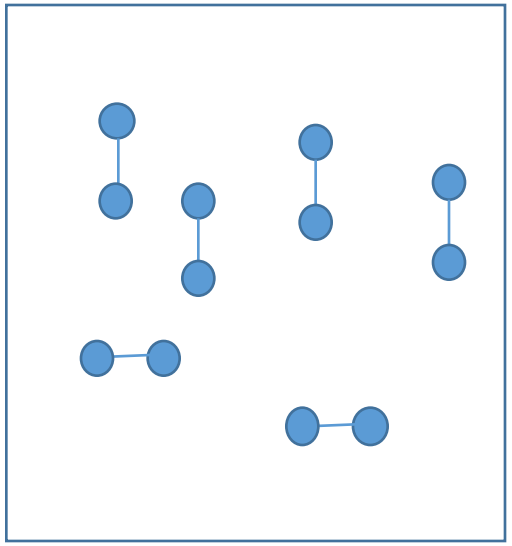


Laws of thermodynamics

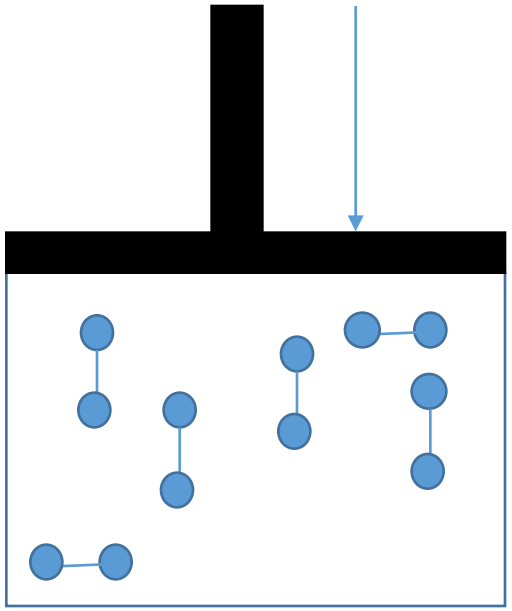
1. CONSERVATION OF ENERGY; energy may change form, **but it can not be created or destroyed.**



Energy
U = KE+PE



Heat (Q)

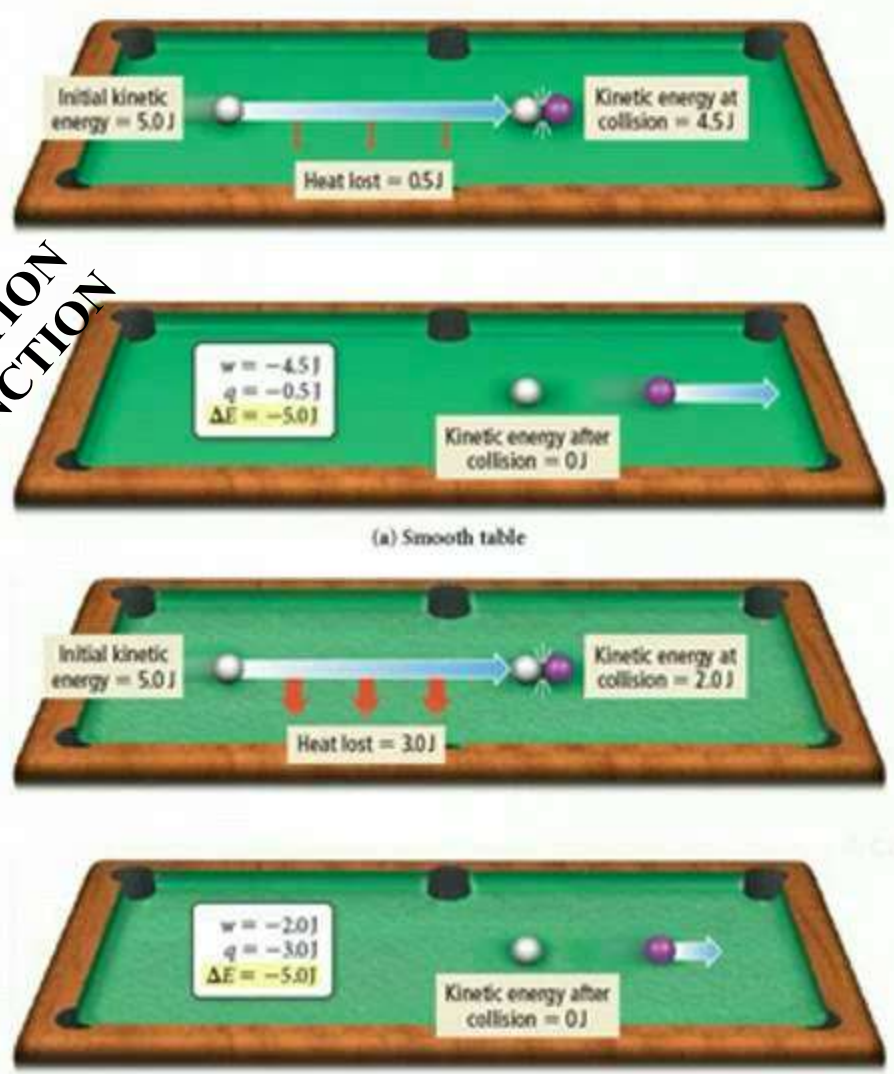


Work (W)

$$\Delta U = Q+W$$

Energy can produce heat, **work…**

$\Delta E = q + w$, q and w may change value (path) but ΔE stays the same



Smooth surface

Rough surface

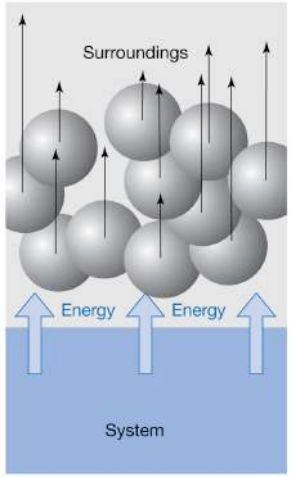
E=U = STATE FUNCTION
Q= PATH FUNCTION
W = PATH FUNCTION

$$\Delta U = Q+W$$

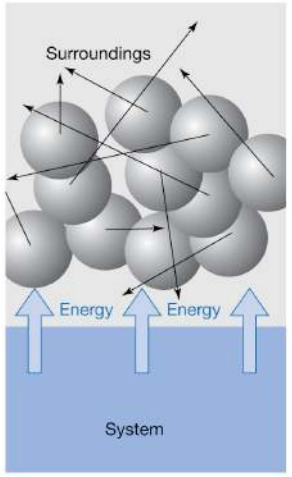
Biological Thermodynamics

Work (W) and Heat (Q)

$\Delta U = W + Q$



Work involves the non-random movement of particles



Heat involves the random movement of particles

Energy transfer to the motion of OBJECTS

Energy transfer to the motion of ATOMS/ MOLECULES

$$\Delta U = Q+W$$

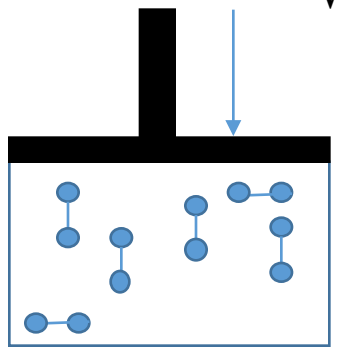
Q= + , heat added to the system
Q = - , Heat released by the system
W= +, Workdone on the system
W= - , Wordone by the system

$$=) \Delta U = Q+(W_{Mech}+W_{non\text{-}Mech})$$

[Say no non-mechanical work]

$$=) \Delta U = Q+W_{mech}$$

W_{mech}= Force x Distance
= Pressure x Area x Dist
= - P ΔV



$$=) \Delta U = Q- P \Delta V$$

$$=) \Delta U + P \Delta V = Q$$

[At constant Pressure]

$$=) \Delta U + \Delta PV = Q_p$$

$$=) \Delta(U + PV) = Q_p$$

$$=) \Delta H = Q_p$$

(H = U+ PV = Enthalpy = STATE FUNCTION)

In biology we usually interested in enthalpy change. Measured experimentally by determining the heat change at constant Pressure

$$=) \Delta U + P\,\Delta V = Q$$

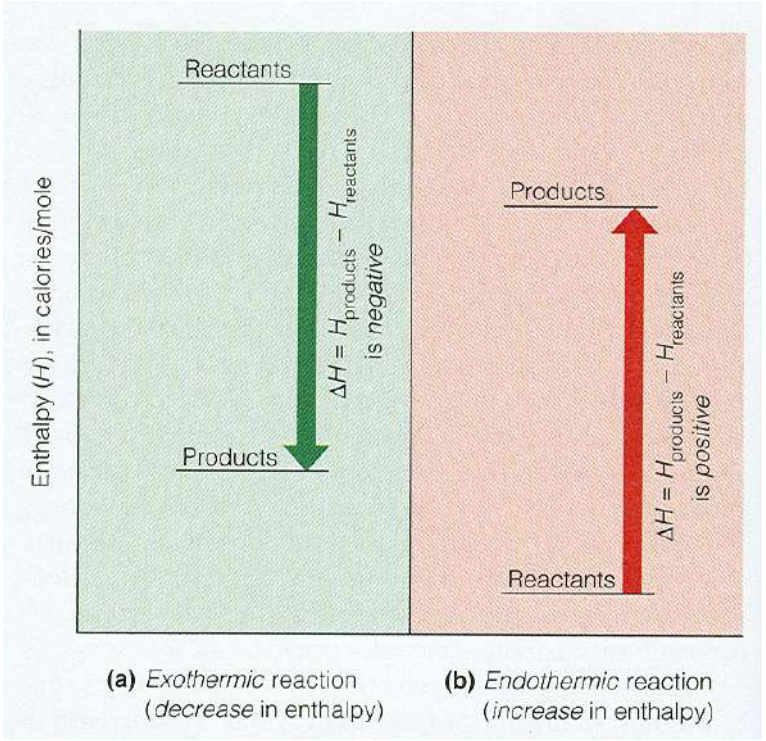
[At constant Volume]

$$=) \Delta U = Q_v$$

- Difference between $\Delta H \equiv Q_p$ and $\Delta U \equiv Q_v$ is small for reactions that involve liquid/solid.
- For Endothermic reactions ΔH is +ve. For exothermic it is –ve.
  Unit of H is kJ/mol
- Remember Hess's law for calculating ΔH of a reaction.

Biological Thermodynamics

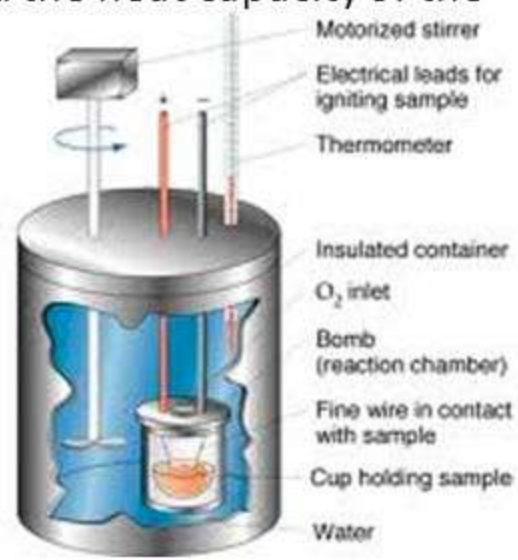
Enthalpy change (ΔH)



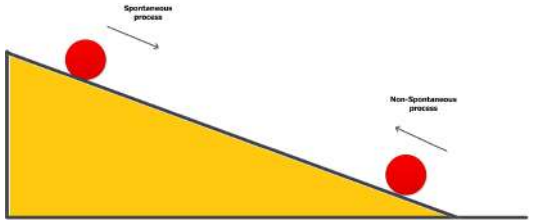
ΔH during a chemical reaction is the heat absorbed or released in the breaking and formation of bonds

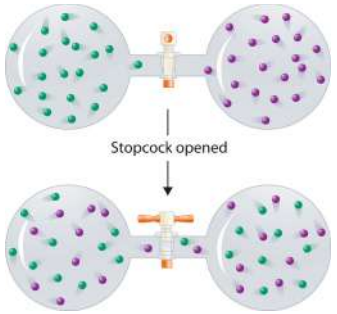
Calorimetry

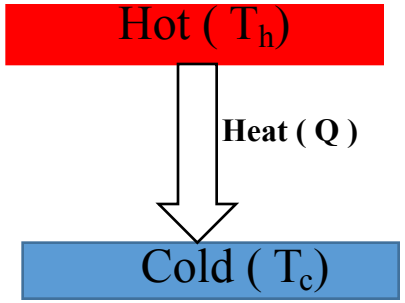
- **Calorimetry** is the measurement of the heat gained or lost in a chemical reaction.
  - A calorimeter is a device that isolates the outside environment.
    - Any loss or gain of energy in the products results in a change in temperature only in the calorimeter.
    - The rise (or drop) of temperature in the calorimeter is dependent on the amount of heat released or gained and the heat capacity of the surroundings
      - Bomb calorimeter
        - » $q = (mass_{water})(C_{water})(\Delta T)$



2. For any spontenious process, entropy=S of the universe increases

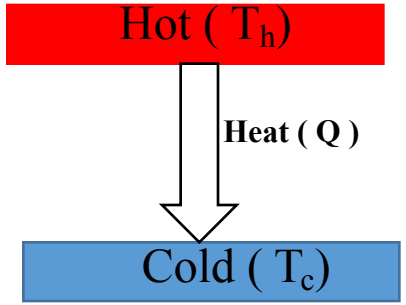




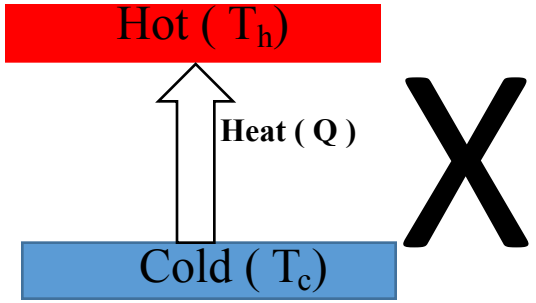


Things can happen in both direction : No restriction from 1st Law

2nd Law explain the arrow of Time



Lets define a quantity = S = $\frac{Q}{T} = \frac{Heat}{Temp}$



Case I: Heat flow from Hot → Cold

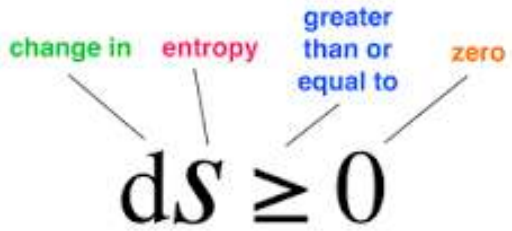
$\Delta S = -\frac{Q}{T_h} + \frac{Q}{T_c} > 0$

Case II: Heat Flow from Cold → Hot

$\Delta S = \frac{Q}{T_h} - \frac{Q}{T_c} < 0$

Case III (T_h=T_c), Equilibrium

$\Delta S = \frac{Q}{T_h} - \frac{Q}{T_c} = 0$

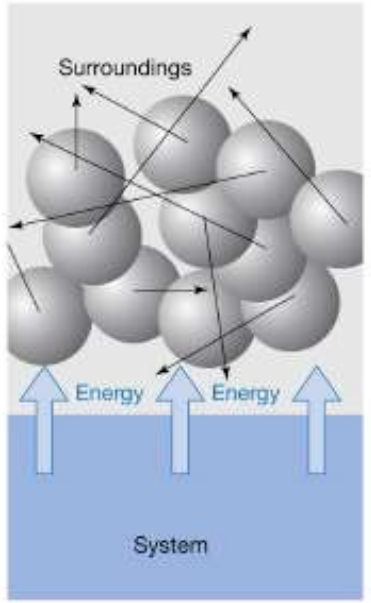


- Enengy is conserved for all cases I, II, III
- **$\Delta S_{universe} \geq 0$, Not only explain why things happen in one direction but also quantitative.**

What is entropy ?

$$S = \frac{Q}{T}$$

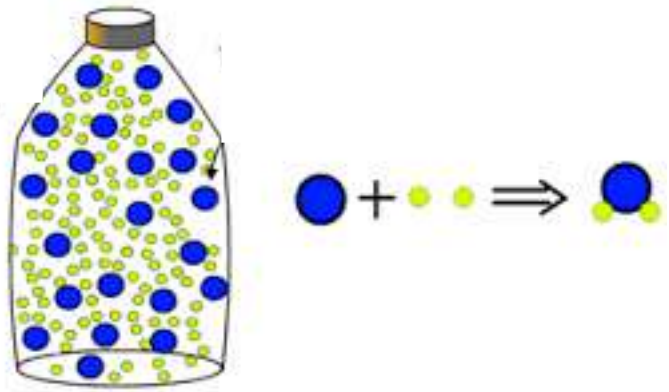
Average kinetic energy

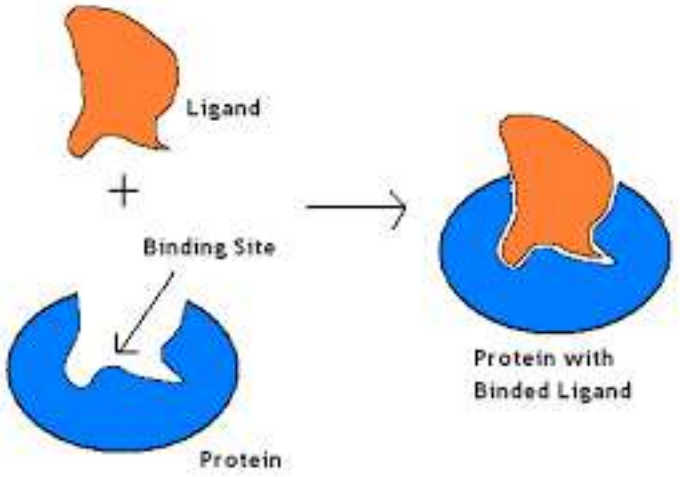


Heat involves the random movement of particles

Very strange quantity: (Randomness/Temp) and state function

Why do we need a quantative equation?





$$\Delta S_{universe} = \Delta S_{system} + \Delta S_{surroundings} \geq 0$$

Apparent contradiction of 2nd Law of thermodynamics ?

- crystallization
- Life on earth

$$\Delta S_{universe} = \Delta S_{system} + \Delta S_{surroundings} \geq 0$$

Need to calculate ΔSsurroundings all the time ?

$$\Delta S_{surrounding} = \frac{Q_{surrounding}}{T} = \frac{-Q_{system}}{T}$$

[At constant Pressure]

$$\Delta S_{surrounding} = \frac{-Q_{system}}{T} = \frac{-Q_p}{T} = \frac{-\Delta H_{system}}{T}$$

Lets try to get rid of surrounding entropy ?

2nd Law, $\Delta S_{system} + \Delta S_{surroundings} \geq 0$

$$=) \quad \Delta S_{system} - \frac{\Delta H_{system}}{T} \geq 0$$

$$=) \quad T\,\Delta S_{system} - \Delta H_{system} \geq 0$$

$$=) \quad -(-T\,\Delta S_{system} + \Delta H_{system} \geq 0$$

$$=) \quad (-T\,\Delta S_{system} + \Delta H_{system}) \leq \quad 0$$

At constant pressure and temperature ?

$$=) \quad \Delta(H_{system} - TS_{system}+) \leq \quad 0$$

$$=) \quad \Delta(H - TS) \leq \quad 0$$

No Surrounding term; System only term.
predict spontaneity based on system (G).

$$=) \quad \Delta G \leq \quad 0 \quad (2^{nd} \text{ law in terms of system})$$

(G = H - TS = Gibbs Free Energy = STATE FUNCTION)

At constant volume and temperature ?

$$\Delta S_{surrounding} = \frac{-Q_{system}}{T} = \frac{-Q_v}{T} = \frac{-\Delta U_{system}}{T}$$

2nd Law, $\Delta S_{system} + \Delta S_{surroundings} \geq 0$

$$=) \quad \Delta S_{system} - \frac{\Delta U_{system}}{T} \geq 0$$

$$=) \quad \Delta(U_{system} - TS_{system}+) \leq \quad 0$$

$$=) \quad \Delta(U - TS) \leq \quad 0$$

$$=) \quad \Delta A \leq \quad 0$$

(A = U - TS = Hemloltz Free Energy = STATE FUNCTION)

Property of Gibbs Free Energy ? What's the big deal ?

$$G = H - TS$$

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

Substituting , $H = U + PV$

$$\Rightarrow \quad \Delta G = \Delta(U + PV) - T\Delta S - S\Delta T$$

$$\Rightarrow \quad \Delta G = \Delta U + P\Delta V + V\Delta P - T\Delta S - S\Delta T$$

1st Law , $\Delta U = Q + W$

$$\Rightarrow \quad \Delta G = (Q + W) + P\Delta V + V\Delta P - T\Delta S - S\Delta T$$

Now, $W = W_{Mech} + W_{nonMech} = -(P\Delta V + W_{nonMech})$

$$\Rightarrow \quad \Delta G = Q - (P\Delta V + W_{nonMech}) + P\Delta V + V\Delta P - T\Delta S - S\Delta T$$

Definition of entropy: For a reversible process $\Delta S = Q/T$

$$\Rightarrow \quad \Delta G = Q - (P\Delta V + W_{nonMech}) + P\Delta V + V\Delta P - T\Delta S - S\Delta T$$

$$=) \quad \Delta G = -W_{nonMech} + V\Delta P - S\Delta T$$

At constant pressure, Temp

$$=) \quad \Delta G_{P,\,T} = -W_{nonMech}$$

Free Energy:

It is the portion of a system's energy that is able to perform work when temperature and pressure is uniform throughout the system, as in a living cell

- Free energy also refers to the amount of energy actually available to break and subsequently form other chemical bonds

Summary

- First Law

- As we know for a spontaneous process, as $\Delta S_{total} > 0$ or $\Delta G < 0$.
- for A → B,
  If ΔG for A → B is (-)ve, spontaneous.
  If ΔG for A B is (+)ve, the reverse will proceed.
  $\Delta G = 0$ at equilibrium.
- ΔG could be used for doing work (Heart beat, muscle etc, Drive another chemical reactions etc)

Summary

$$A + B \leftrightharpoons C$$

Quantitative answers for the following questions

1. Will this happen spontaneously ? (Driving Force) .
   Answer: magnitude and sign of ΔG
2. How much will this happen ?
3. Relation between 1 and 2 ?
4. How all this is related to biology

BT 101 Textbooks:

[1] J. L. Tymoczko, J. M. Berg and L. Stryer, Biochemistry, 5th Ed, W. H. Freeman & Co

[2] D. L. Nelson and M. M. Cox, Lehninger Principles of Biochemistry, Macmillan Worth

[3] Gordon G. Hammes, Thermodynamics and kinetics for biological sciences,WILEY-INERSCIENCE John Wiley & sons.