Mass Transfer: Concept of Fick's law of diffusion

MSE-S405
(Heat and Mass Transfer)

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Fick's Law of Diffusion

Diffusion velocity →

During the Diffusion process, the motion of various species takes place with respect to bulk or avg. velocity of the mixr. By this concept we can define mass diffusion & molar diffusion velocities based on avg. velocities —

(a) Mass diffusion velocity —

Mass diffusion velocity of component, $A = u_A - u_{mass}$

$B = u_B - u_{mass}$

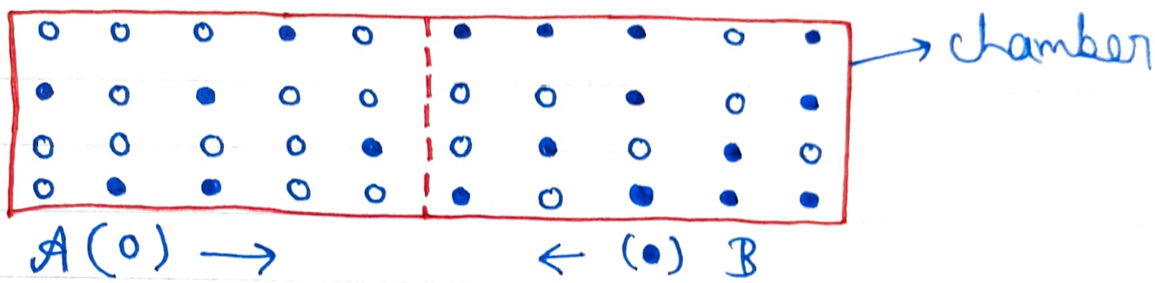
(b) Molar diffusion velocity —

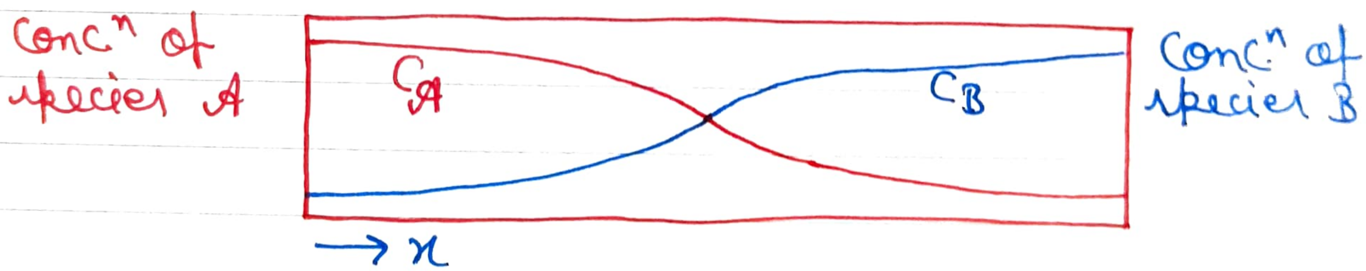
Molar diffusion velocity of component, $A = u_A - u_{molar}$

$B = u_B - u_{molar}$

FICK'S LAW →

In order to understand the mass diffusion (transport process), consider a chamber in which two different gases A & B, at the same tempr. & pressure are initially separated by a partition. The left one has a high concn (more molecules/area) of gas A whereas the right compartment is rich in gas B. When the partition wall is removed a driving potential comes into existence which tends to equalize the concⁿ diffᶜᵉ. Mass transfer by diffusion will be in the dirⁿ of dec^g concⁿ & subsequently there will be a net transport of species A to the right & of species B to the left. After a sufficient long period, equiᵐ condiⁿ prevail i.e., uniform concⁿ of species A & B are achieved & then the mass diffusion ceases.





It has been observed through experiments that molecular diffusion is governed by Fick's law, which is expressed as —

$$N_A = \frac{m_A}{A} = -D_{AB}\frac{dC_A}{dx}$$

N_A → mass flux of A i.e., amount of species A that is transferred per unit time & per unit area $\perp^r$ to the dir^n of transfer, (Kg/s-m² or Kg mole/s-m²)

m_A → Mass flow rate of species A by diffusion (Kg/s)

A → Area through which mass is flowing (m²)

D_{AB} → Diffusion $coff^t$ or mass diffusivity for binary mix^r of species A & B (m²/s).

C_A → $conc^n$ or molecules per unit vol^m of species A (Kg/m³)

$\frac{dC_A}{dx}$ → $conc^n$ of gradient of A, this acts as driving potential

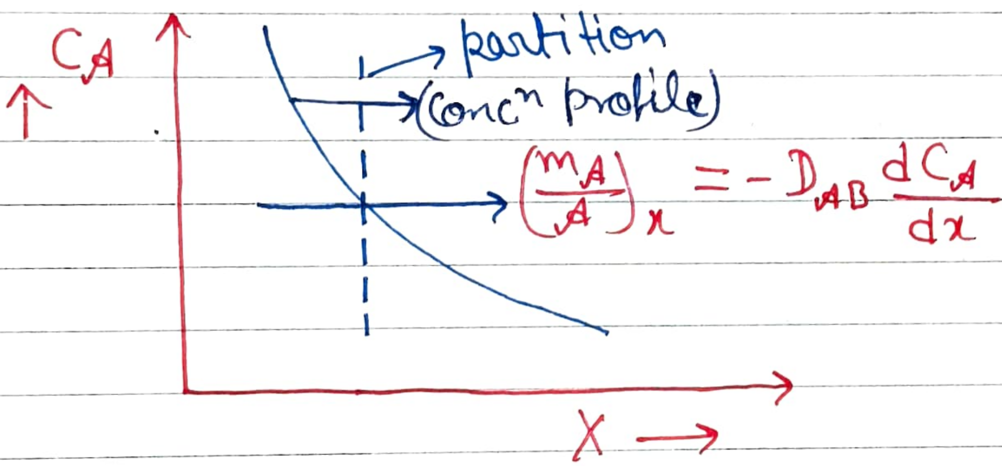
-ive → -ive sign indicates that diffusion takes place in the dir^n opposite to that of inc^g $conc^n$

The diffusion rate for B is —

$$\left\{ N_B = \frac{m_B}{A} = -D_{BA}\frac{dC_B}{dx} \right\}$$

It may be noted that diffusion coffᵗ i.e., D_{AB} or D_{BA}, is dependent upon the tempʳ, pressure & nature of the components of the systᵗ.

Physical mechanism of diffusion →



We observe that the concⁿ of species A (moles/volᵐ) on left of partition is much greater than the concⁿ of species A on the right side of the partition. so, the more molecules of A cross the plane per unit time from left to right than in the opposite direction. It results into the net mass transfer of A from high concⁿ region to low concⁿ region till the equilibrium established.

Q:- A steel rectangular container having walls 16 mm thick is used to store gaseous hydrogen at elevated pressure. The molar concentrations of hydrogen in the steel at the inside & outside surfaces are 1.2 Kg mole/m^3 & zero respectively. Assuming the diffusion coff^t for hydrogen in steel as 0.248×10^{-12} m^2/s, then calculate the molar diffusion flux for hydrogen through the steel.

A:- $$N_A = D_A \frac{(C_{A1} - C_{A2})}{L}$$

$$\Rightarrow N_A = 0.248 \times 10^{-12} \times \frac{(1.2 - 0)}{0.016}$$

$$\Rightarrow N_A = 1.86 \times 10^{-11} \ \frac{\text{Kg-mole}}{m^2\text{-Sec.}}$$

Ans