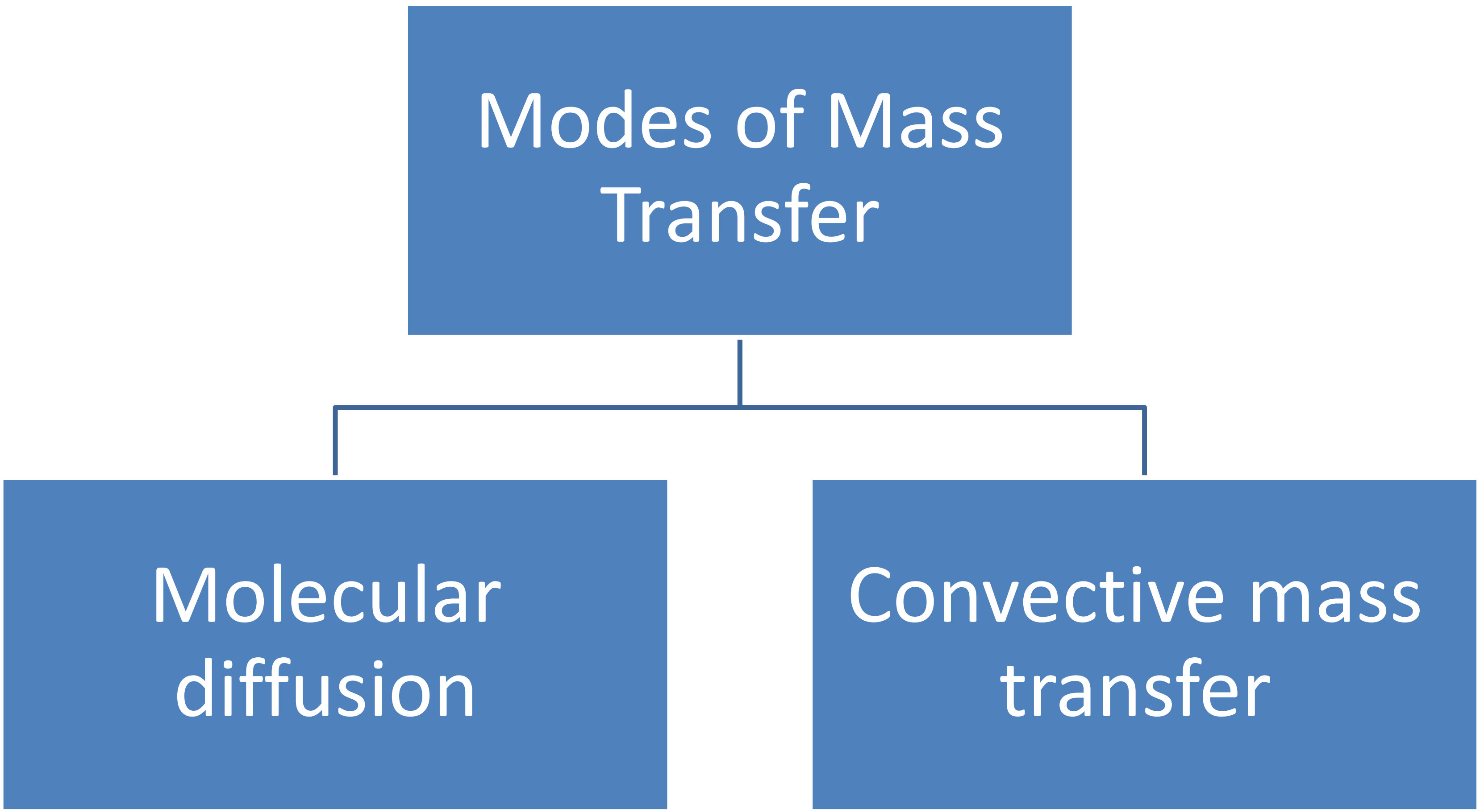
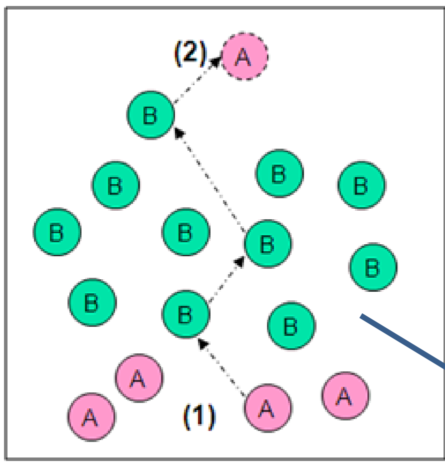
Modes of Mass Transfer


Modes of Mass Transfer
Molecular diffusion
Convective mass transfer

Molecular Diffusion

- *Definition*: The diffusion of molecules when the whole bulk fluid is not moving but stationary. Diffusion of molecules is due to a concentration gradient. Movement of molecules through a stagnant fluid take place as a result of random movements of these molecules "see the schematic

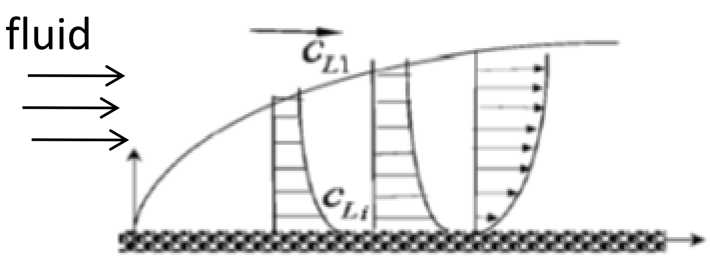


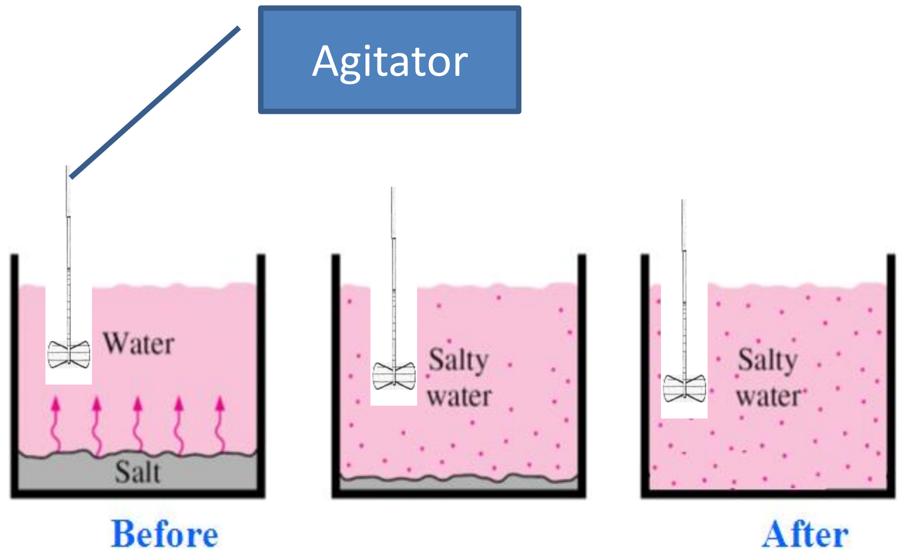
Schematic diagram of molecular diffusion process.

Due to the random path, molecular diffusion is often called random-walk process.

Convective Mass Transfer

Definition: The diffusion of molecules when the bulk fluid is moving and diffusion of molecules takes place

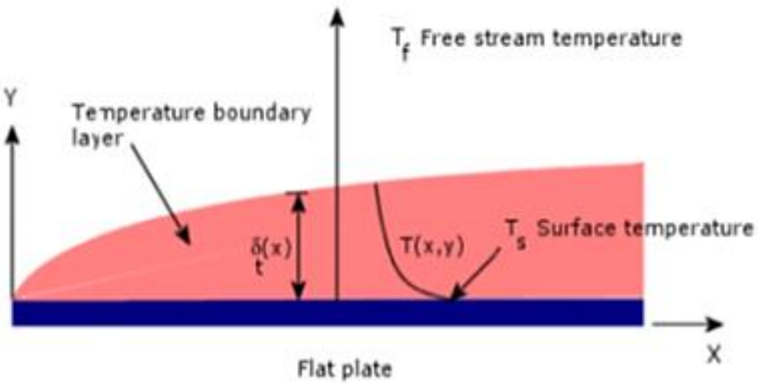




Comparison between Convective Heat Transfer and Mass Transfer

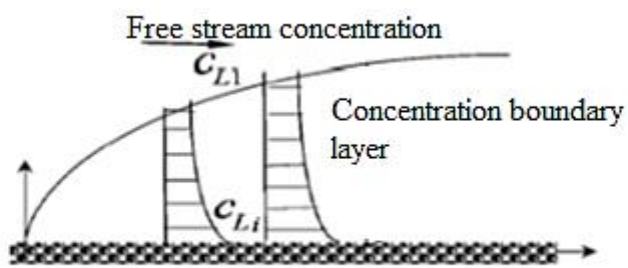
When a fluid is flowing outside a solid surface in forced convection motion and diffusion takes place. This is similar to convective heat transfer.

Convective Heat Transfer



$$q = h(T_s - T_\infty)$$

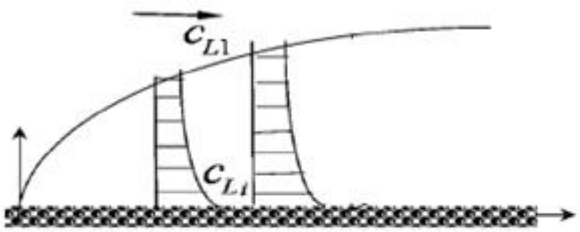
Convective Mass Transfer



$$N_A = k_c(c_{L_i} - c_{L_1})$$

Convective Mass Transfer

$$N_A = k_c(c_{L_i} - c_{L_1})$$



k_c	mass transfer coefficient (m/s)
c_{L1}	bulk fluid concentration
c_{Li}	concentration of fluid near the solid surface

k_c depends on:

- System geometry
- Fluid properties
- Flow velocity

COMPARISON BETWEEN THE TWO MASS TRANSFER MECHANISMS

Mechanisms of Mass Transfer

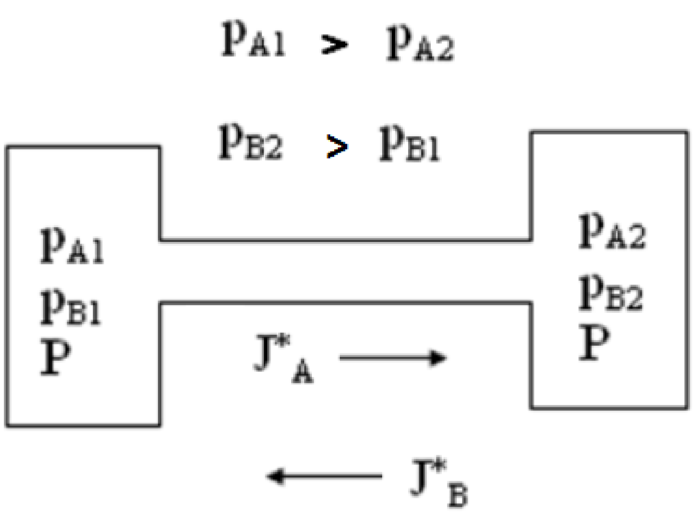
Mass transfer occurs by two basic mechanisms which act simultaneously:
1) molecular diffusion and ***2) Convective mass transfer***

Molecular Diffusion	Convective Mass Transfer
▪ Caused by random microscopic movement of individual molecules in gas/liq/solid as a result of thermal motion or concentration differences. ▪ Extremely slow ▪ Occurs in solids and fluids that are stagnant or in laminar flow. ▪ Mass transfer under turbulent-flow but across an interface or near solid surface, the conditions near surface can be assumed laminar. ▪ Mathematically described by Fick's law: $J_{A,z} = -D_{AB}\, dC_A/dz$	▪ Caused by random macroscopic fluid bulk motion (dynamic characteristics). ▪ *Orders of magnitude* faster than molecular diffusion. ▪ Involves transport of materials at the interface between moving fluids (liq-gas) or at interface between a moving fluid and a solid surface (liq-solid, gas-solid). ▪ Mathematically described in a manner analogous to Newton's law : $N_A = k_c\, \Delta C_A$

Molecular Diffusion in Gases

(1) Equi-molar counter diffusion in gases

Two gases A and B are contained in two connected chambers. Total pressure is constant P under steady state conditions.



Molecular Diffusion in Gases

(1) Equi-molar counter diffusion in gases

(P is constant, therefore the total concentration c is also constant).

since $P = p_A + p_B =$ constant, then

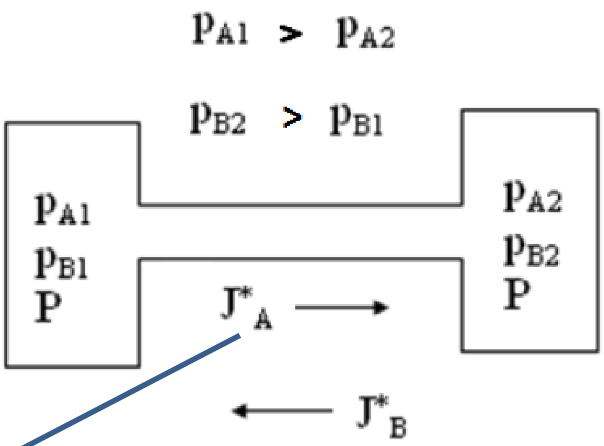
$$c = c_A + c_B$$

$$dc_A = -dc_B$$

$$J^*_{AZ} = -J^*_{BZ}$$

$$J^*_A = -D_{AB}\frac{dc_A}{dz} = -J^*_B = -(-)D_{BA}\frac{dc_B}{dz}$$

$$D_{AB} = D_{BA}$$



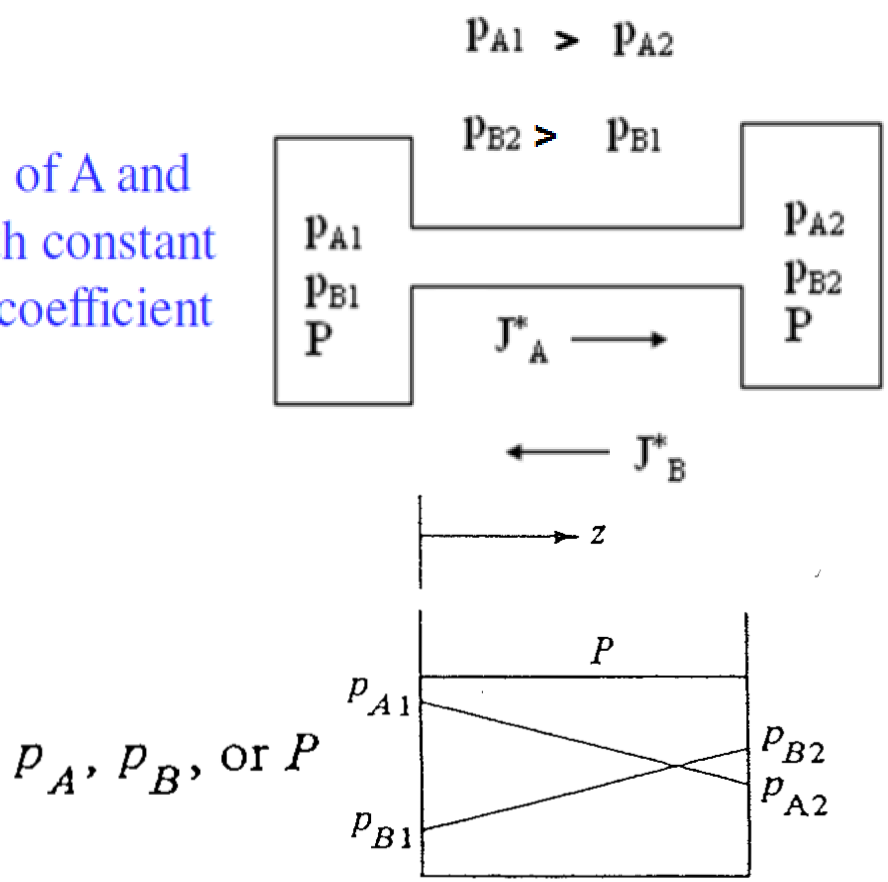
Important constrain:
When the total pressure of the system is constant , the net moles of A diffusing to the right must equal the net moles of B to the left. This means $J^*_{Az} = -J^*_{Bz}$

Molecular Diffusion in Gases

(1) Equi-molar counter diffusion in gases

For a binary gas mixture of A and B, under steady state with constant pressure, the diffusivity coefficient

$D_{AB} = D_{BA}$



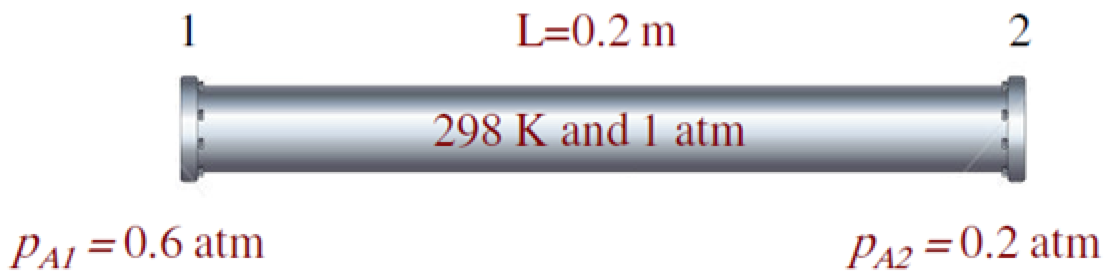
Equimolar counterdiffusion of gases A and B

Example 1: Molecular Diffusion of He in N_2

A mixture of He and N_2 gas is contained in a pipe at 298 K and 1 atm total pressure which is constant throughout. At one end of the pipe at point 1 the partial pressure p_{A1} of He is 0.6 atm and at the other end 0.2 m, $p_{A2} = 0.2$ atm.

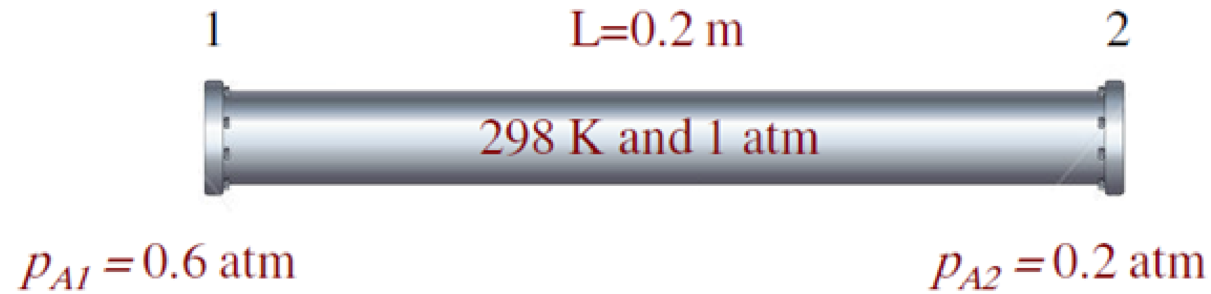
Calculate the flux of He at steady state if D_{AB} of the He-N_2 mixture is 0.687×10^{-4} m^2/s.

Example 1: Molecular Diffusion of He in N_2



Solution

Example 1: Molecular Diffusion of He in N_2



Solution

$$J^*_{A_Z} = -D_{AB} \frac{C_{A2} - C_{A1}}{z_2 - z_1}$$

Assuming ideal gas law: $pV = nRT \longrightarrow \frac{n}{V} = C = \frac{p}{RT}$

Example 2: Equi-molar Counter Diffusion

Ammonia gas (A) is diffusing through a uniform tube 0.10 m long

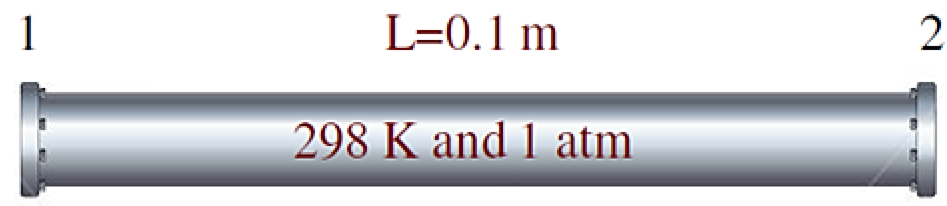
containing N_2 gas (B) at 1.0132 x 10^5 Pa pressure and 298 K.

At point 1, p_{A1} = 1.013 x 10^4 Pa and at point 2, p_{A2} = 0.507 x 10^4 Pa.

The diffusivity D_{AB} = 0.230 x 10^{-4} m^2/s.

(a) Calculate the flux J^*_A at steady state
(b) Repeat for J^*_B

Example 2: Equi-molar Counter Diffusion



$p_{A1} = 1.013 \times 10^4$ Pa $\qquad p_{A2} = 0.507 \times 10^4$ Pa

Solution

$$J^*_{A_z} = -D_{AB}\frac{p_{B2} - p_{B1}}{RT(z_2 - z_1)} = D_{AB}\frac{p_{A1} - p_{A2}}{RT(z_2 - z_1)}$$

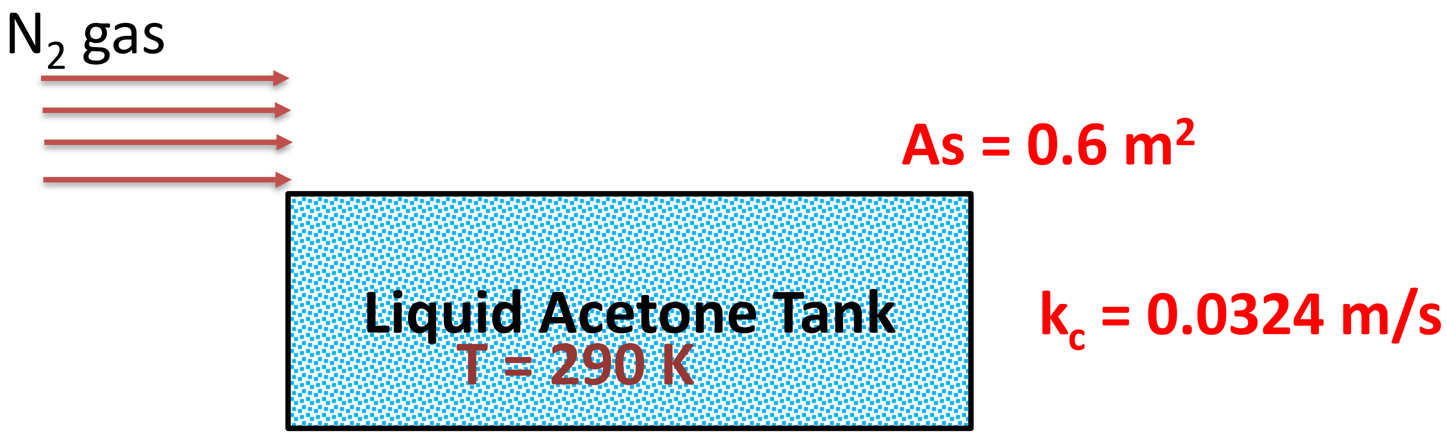
z_2-z_1 = 0.10 m, and T = 298 K.

Since the total pressure is constant, D_{AB}=D_{BA} for this binary gas system.

Example 3

A pure nitrogen carrier gas flows parallel to the 0.6 m^2 surface of a liquid acetone in an open tank. The acetone temperature is maintained at 290 K. If the average mass-transfer coefficient, k_c, for the mass transfer of acetone into the nitrogen stream is 0.0324 m/s, determine the total rate of acetone release in units of kg.mol/s.

Schematic



- Find the total rate of acetone in kg mol/s

Solution

Summary

Mass transfer (Diffusion) is defined as the microscopic transport of one component from a region to another under effect of a driving force. The **Diffusion** is a slow microscopic process. It can be accelerated by agitation or convection (macroscopic).