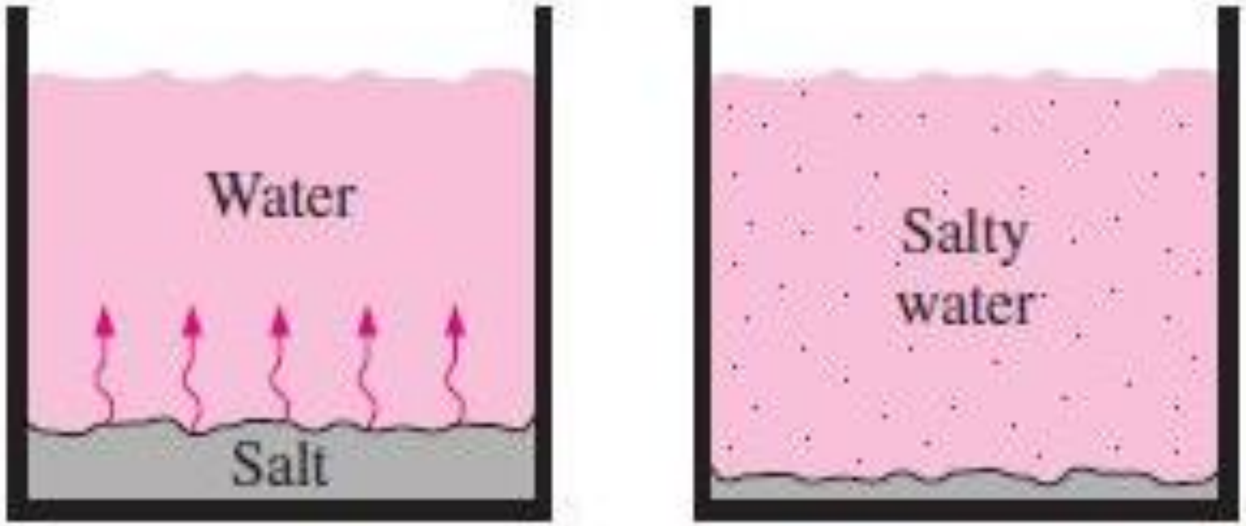
MASS TRANSFER

- When a system contains 2 or more components whose concentrations vary from point to point, there is a natural tendency for the mass to be transferred, minimizing the concentration differences within the system.
- This process of transfer of mass as a result of the concentration difference is called **Mass Transfer.**
- The flow of mass is always in the direction of decreasing concentration; that is, from the region of high concentration to the region of low concentration.
- The species simply creeps away during redistribution, and thus the flow is a ***diffusion process***.



(*a*) Before (*b*) After

FIGURE 14–1
Whenever there is concentration difference of a physical quantity in a medium, nature tends to equalize things by forcing a flow from the high to the low concentration region.

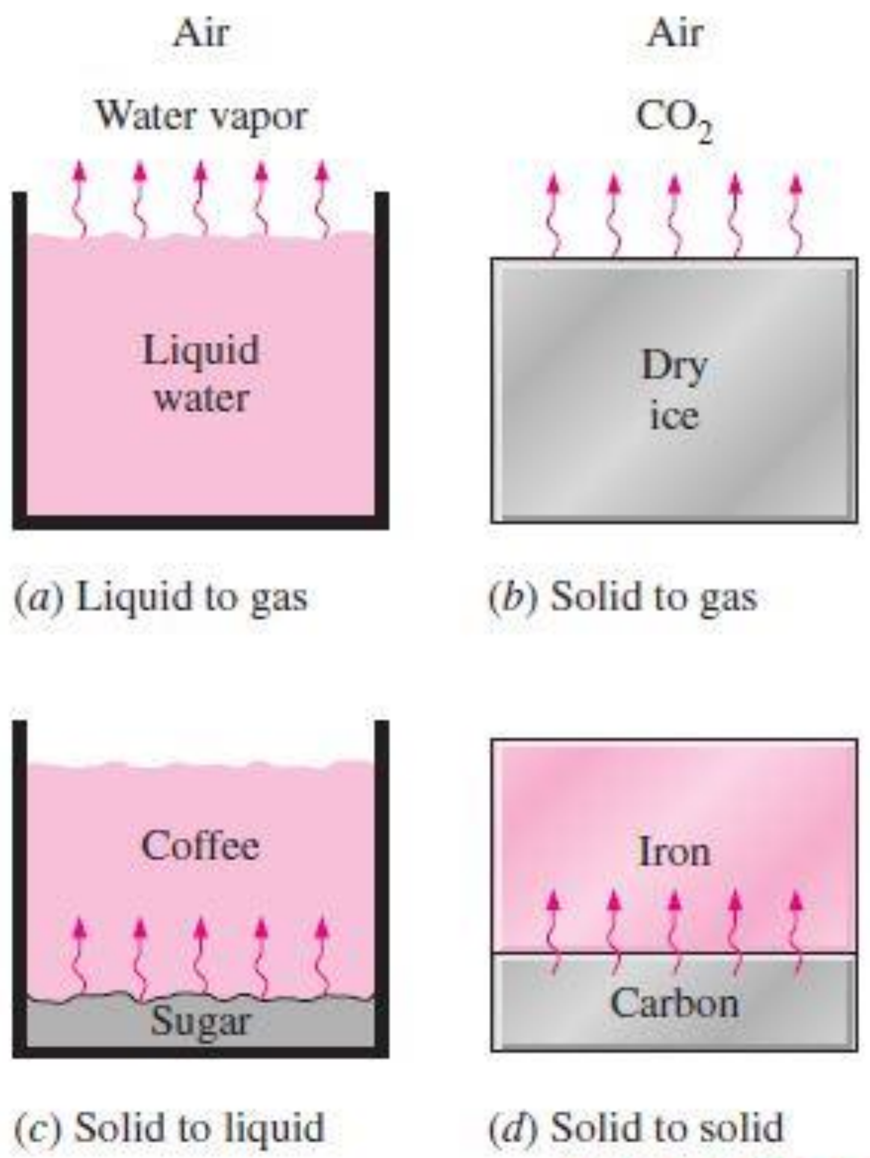


FIGURE 14–3
Some examples of mass transfer that involve a liquid and/or a solid.

- Diffusion rates of gases depend strongly on *temperature* since the temperature is a measure of the average velocity of gas molecules.
- The diffusion rates will be higher at higher temperatures.
- Another factor that influences the diffusion process is the *molecular spacing.*
- The larger the spacing, in general, the higher the diffusion rate.
- Therefore, the diffusion rates are typically much higher in gases than they are in liquids and much higher in liquids than in solids.

MODES OF MASS TRANSFER

1. DIFFUSION MASS TRANSFER(Molecular or Eddy diffusion)

It is the transport of molecules from high concentration region to a region of lower concentration in a system of a mixture of liquids or gases or solids.

when one of the diffusing fluids is in turbulent motion, the eddy diffusion takes place.

2. CONVECTIVE MASS TRANSFER

It involves transfer between a moving fluid and a surface, or b/w two relatively immiscible moving fluids.

3. MASS TRANSFER BY CHANGE OF PHASE

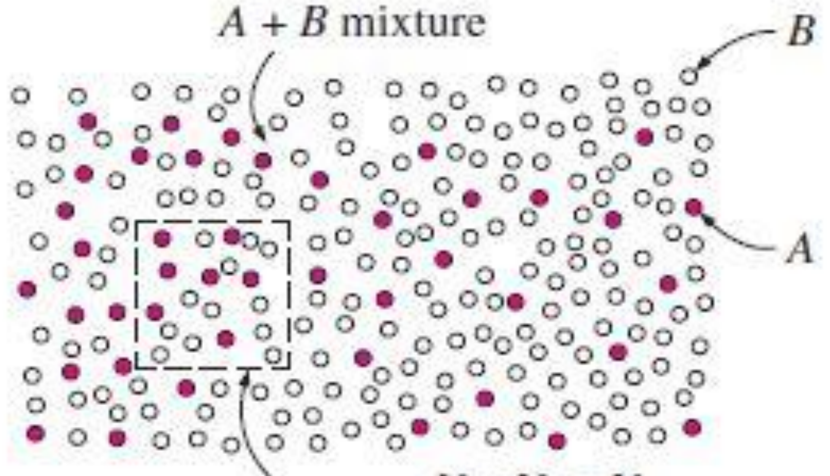
Mass transfer occurs whenever a change from one phase to another takes place. It occurs due to simultaneous action of convection and diffusion.

MASS DIFFUSION

- **Fick's law of diffusion** states that the rate of diffusion of a chemical species at a location in a gas mixture (or liquid or solid solution) is proportional to the ***concentration gradient*** of that species at that location.

- The **concentration** of a species can be expressed in several ways:

1. **Mass Basis**
2. **Mole Basis**



$$V = V_A = V_B$$

$$m = m_A + m_B$$

$$\rho = \rho_A + \rho_B$$

$$C = C_A + C_B$$

Mass basis:

$$\rho_A = \frac{m_A}{V}, \ \rho = \frac{m}{V}, \ w_A = \frac{\rho_A}{\rho}$$

Mole basis:

$$C_A = \frac{N_A}{V}, \ C = \frac{N}{V}, \ y_A = \frac{C_A}{C}$$

Relation between them:

$$C_A = \frac{\rho_A}{M_A}, \ w_A = y_A \frac{M_A}{M}$$

Mass Basis

- On a *mass basis,* concentration is expressed in terms of **mass density (ρ_A)(**or ***mass concentration***), which is mass per unit volume.

$$\rho_A = \frac{m_A}{V} \text{ kg/m}^3$$

- The *density of a mixture* at a location is equal to the sum of the *densities of its constituents* at that location.
- **Mass Fraction:**

$$w_A = \frac{\rho_A}{\rho}$$

ρ = total mass density of the mixture

- Mass fraction of a species ranges between 0 and 1
- The sum of the mass fractions of the constituents of a mixture be equal to 1

Mole Basis

- On a *mole basis,* concentration is expressed in terms of **Molar concentration(C_A)**(or ***molar density***), which is defined as the number of moles of species 'A' per unit volume of the mixture.
- Its unit is **kmole/m³**

$$\boldsymbol{C_A = \frac{N_A}{V} = \frac{\rho_A}{M_A}} \qquad \text{since, } N = \frac{m}{M} = \frac{\rho V}{M}$$

- **Mole Fraction:**

$$\boldsymbol{y_A = \frac{C_A}{C} = \frac{N_A}{N}}$$ **where C = total mole concentration of the mixture**

- The mole fraction of a species ranges between 0 and 1.
- The sum of the mole fractions of the constituents of a mixture is unity.

$$\boldsymbol{w_A = \frac{\rho_A}{\rho} = \frac{C_A M_A}{CM} = y_A \frac{M_A}{M}}$$

- By Dalton's law of partial pressures,

$$\mathrm{P} = P_A + P_B$$

Also we have, $P_A = \rho_A R_A T = \rho_A \frac{G}{M_A} T$

So, $\rho_A = \frac{P_A M_A}{GT}$ and

$C_A = \frac{\rho_A}{M_A} = \frac{P_A}{GT}$, where G=Universal gas constant=8314 J/kmole.K

- From perfect gas law, we have,

$$P_A V = N_A G T$$

ie, $C_A = \frac{N_A}{V} = \frac{P_A}{GT}$ Also, pressure fraction $\frac{P_A}{P} = \frac{N_A}{N} = y_A$

FICK'S LAW OF DIFFUSION

- Fick's law of diffusion states that the rate of mass diffusion of a chemical species in a stagnant medium in a specified direction is proportional to the local concentration gradient in that direction.
- Mass flux = Constant of proportionality x Concentration gradient

$$\frac{\boldsymbol{m_A}}{\boldsymbol{A}} = -\boldsymbol{D_{AB}}\frac{\boldsymbol{d\rho_A}}{\boldsymbol{dx}} \quad \text{kg}/m^2\text{.s and}$$

$$\frac{\boldsymbol{m_B}}{\boldsymbol{A}} = -\boldsymbol{D_{BA}}\frac{\boldsymbol{d\rho_B}}{\boldsymbol{dx}} \quad \text{kg}/m^2\text{.s}$$

- D_{AB} = Diffusion coefficient or Mass diffusivity of A to B. Its unit is $\boldsymbol{m^2/_s}$

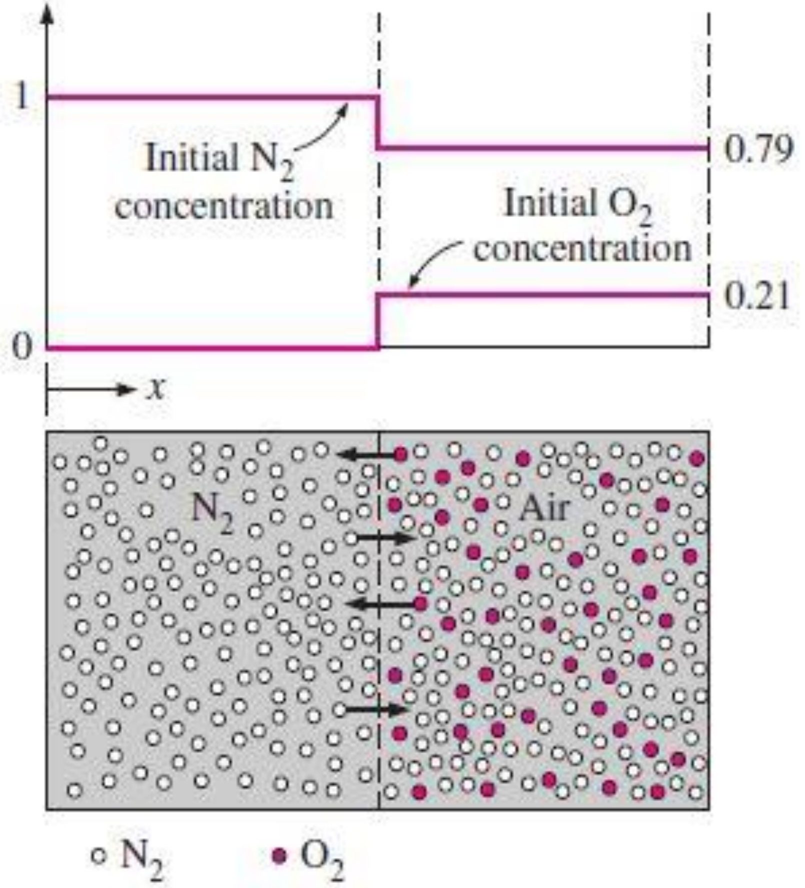


FIGURE 14–2
A tank that contains N_2 and air in its two compartments, and the diffusion of N_2 into the air when the partition is removed.

Diffusion Coefficient

- Fick's law describes the mass transport due to concentration gradient.
- The unit of Diffusion coefficient(D) is identical to those of Thermal diffusivity (α) and Kinematic viscosity(ϑ).Thus Diffusion coefficient is a **transport property.**
- The diffusion coefficients, in general, are ***highest in gases*** **and** ***lowest in solids***.
- The diffusion coefficients of gases are several orders of magnitude greater than those of liquids.
- Diffusion coefficients ***increase with temperature.***

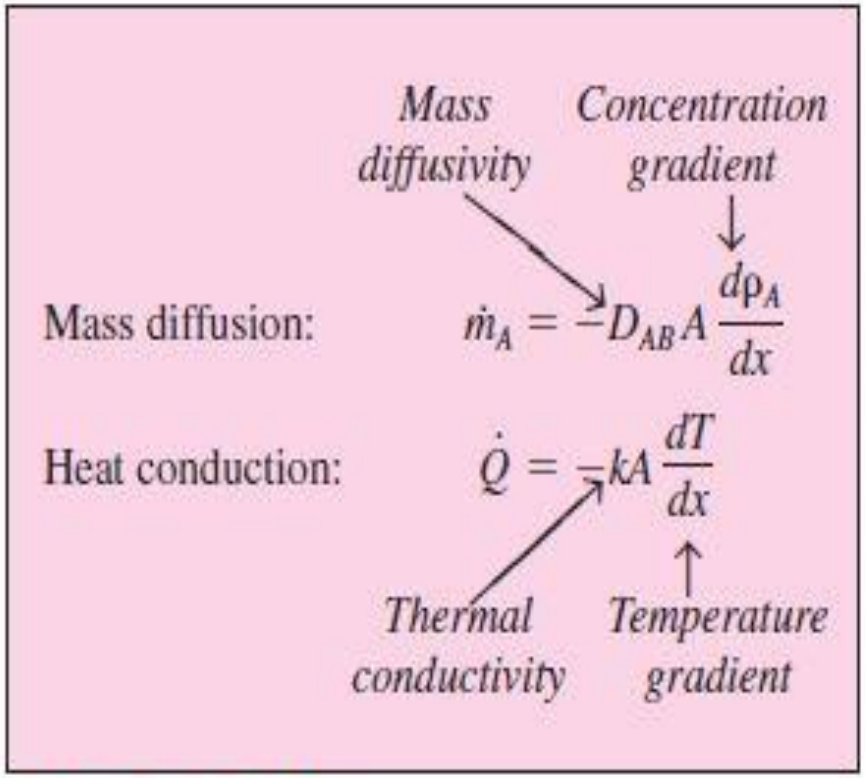


FIGURE 14–11
Analogy between Fourier's law of heat conduction and Fick's law of mass diffusion.

Various expressions of Fick's law

Mass basis:

$$\dot{m}_{\text{diff}} = -\rho A D_{AB} \frac{dw_A}{dx}$$

$$= -\rho A D_{AB} \frac{d(\rho_A/\rho)}{dx}$$

$$= -A D_{AB} \frac{d\rho_A}{dx} \text{ (if } \rho = \text{constant)}$$

in kg/m^2.s

Mole basis:

$$\dot{N}_{\text{diff, }A} = -CAD_{AB} \frac{dy_A}{dx}$$

$$= -CAD_{AB} \frac{d(C_A/C)}{dx}$$

$$= -AD_{AB} \frac{dC_A}{dx} \text{ (if } C = \text{constant)}$$

in kmole/m^2.s

Fick’s law in terms of Partial Pressures

$$\frac{m_A}{A} = -D_{AB}\frac{M_A}{GT}\frac{dP_A}{dx}$$

$$\frac{m_B}{A} = -D_{BA}\frac{M_B}{GT}\frac{dP_B}{dx}$$