15/09

Assignment 1

Section 1

Q.1 1. Mass average velocity

For an n-component mixture the mass average velocity (u) →

$$u = \frac{\sum \rho_i u_i}{\sum \rho_i} = \frac{\sum \rho_i u_i}{\rho}$$

small u

where ρ_i = density of species i
u_i = absolute velocity of the ith component.

2. Molar average velocity

→ molar concentration is the weighting factor instead of density

$$U = \frac{\sum c_i u_i}{\sum c_i} = \frac{\sum c_i u_i}{c}$$

capital U

c_i = molar conc. of species i

3. n, i & j

n_i = mass flux w.r.t stationary observer

$$\boxed{n_i = \rho_i \cdot u_i}$$

u_i → abs. velocity

ρ_i → density

i_i = mass flux w.r.t observer moving with mass average velocity $\boxed{i_i = \rho_i (u_i - u)}$

j_i = mass flux w.r.t observer moving with molar average velocity

$$\boxed{j_i = \rho_i (u_i - U)}$$

4. N, J & I

Same as before, only molar not mass

N_i = molar flux w.r.t. stat. observer

$$\therefore \boxed{N_i = c_i \cdot u_i}$$

I = molar flux w.r.t observer moving with mass avg. $\vec{v}$

$$\boxed{I_i = c_i (u_i - u)}$$

I_i

J = molar flux w.r.t observer moving with molar avg. $\vec{v}$

$$\boxed{J_i = c_i (u_i - U)}$$

capital U (molar avg. $\vec{v}$)

Q2. Fick's law →

The molar flux of a species relative to an observer moving with the molar average velocity is proportional to the concentration

gradient of the species.
for a binary mix, if A, B are the components, then

$$J_A \propto \frac{dC_A}{dx} \Rightarrow \boxed{J_A = -D_{AB}\frac{dC_A}{dx}}$$

where D_{AB} is the diffusity of A in a mixture of A & B.

By definition of J_A,

$$J_A = C_A(u_A - U)$$

$$\therefore J_A = C_A\left(u_A - \frac{(C_A u_A + C_B u_B)}{C_A + C_B}\right)$$

$$\therefore J_A = C_A\left(u_A - \frac{N_A + N_B}{C}\right)$$

$$(\because C_A u_A = N_A)$$

$$\therefore J_A = N_A - \frac{(N_A + N_B)}{C} \cdot C_A$$

$$\cancel{= \frac{N_A(C_A + C_B) - (N_A C_A + N_B C_A)}{C_A + C_B}}$$

$$\cancel{= \frac{N_A \cdot C_B - N_B C_A}{C_A + C_B}}$$

$$\boxed{J_A = N_A - \frac{C_A}{C}(N_A + N_B)}$$

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Q.3 Diffusivity (D_{ij})

→ Diffusivity is the rate of diffusion

~~It is the~~

It is a physical constant for one material diffusing in another. Hence it depends on the properties of the substances, such as the molecular size, as well as external properties - Temperature & Pressure

(4)

Unit → $\frac{(length)^2}{time}$, S.I → $\frac{m^2}{sec}$

Q.4 Show that $D_{AB} = D_{BA}$

① $J_A = -D_{AB} \frac{dC_A}{dx}$ → Fick's Law

② $J_A = N_A - \frac{C_A}{C}(N_A + N_B)$ → derived previously

comparing ① & ②

③ $-D_{AB} \frac{dC_A}{dx} = N_A - \frac{C_A}{C}(N_A + N_B)$

Similarly for B,

$-D_{BA} \frac{dC_B}{dx} = N_B - \frac{C_B}{C}(N_A + N_B)$

where $c = c_A + c_B$

$\Rightarrow c_B = c - c_A$

$\Rightarrow \dfrac{dc_B}{dx} = -\dfrac{dc_A}{dx}$ (c is a const.)

(4) $\therefore +D_{BA}\dfrac{dc_A}{dx} = N_B - \dfrac{c_B}{c}(N_A+N_B)$

(3) + (4)

$\rightarrow (D_{BA}-D_{AB})\dfrac{dc_A}{dx} = (N_A+N_B)\left(1-\dfrac{(c_A+c_B)}{c}\right)$

$\Rightarrow (D_{BA}-D_{AB})\dfrac{dc_A}{dx} = 0$

$\Rightarrow \boxed{D_{BA} = D_{AB}}$ since $\dfrac{dc_A}{dx} \neq 0$.

Q.5 Ernest Einstein equation

A generalized driving force in mass transfer is the chemical potential (μ)

Consider a binary mixture

μ_A = chemical potential of component A.

$\mu_A = \mu_A^0 + RT\ln(a_A)$

where a_A = activity of A = $\gamma_A \cdot c_A$

$$\therefore \mu_A = \mu_A^\circ + RT \ln(\gamma_A C_A)$$

$$\frac{d\mu_A}{dx} = 0 + \frac{RT}{\cancel{\gamma_A} C_A} \cdot \cancel{\gamma_A} \cdot \frac{dC_A}{dx}$$

$$\therefore \frac{dC_A}{dx} = \frac{C_A}{RT} \frac{d\mu_A}{dx} \quad (1)$$

from Fick's law

$$J_A = -D_{AB} \frac{dC_A}{dx} \quad (2)$$

(1) & (2) →

$$\therefore J_A = \frac{-C_A D_{AB}}{RT} \cdot \frac{d\mu_A}{dx}$$

$$\boxed{J_A = -\frac{C_A D_{AB}}{RT} \frac{d\mu_A}{dx}}$$

→ Ernst-Einstein eqn

Q6. (1) Chapman-Enskogg correlation
aka Hirschfelder

$$D_{AB} = \frac{0.001858\, T^{3/2} \left(\frac{1}{M_A} + \frac{1}{M_B}\right)^{1/2}}{P \cdot \sigma_{AB}^2 \cdot \Omega_D}$$

cm^2/s

T = temp. (in Kelvin)

P = absolute pressure (atm)

σ_{AB} = collision diameter (Å)

depends on temp.

Ω_D = collision integral

M_A, M_B = molecular weights of A & B

σ_{AB} can be calculated using →

$\sigma_{AB} = \frac{\sigma_A + \sigma_B}{2}$, the values of σ_A & σ_B can be obtained for various ~~liquids~~ gases

The collision integral Ω_D is a function of $\frac{KT}{\varepsilon_{AB}}$ K = Boltzman const.

$$\therefore \Omega_D = f\left(\frac{KT}{\varepsilon_{AB}}\right)$$

$\varepsilon_{AB} = \sqrt{(\varepsilon_A \cdot \varepsilon_B)}$ $\varepsilon_A, \varepsilon_B$ can be obtained for various gases

② Fuller correlation

$$D_{AB} = \frac{10^{-3} \cdot T^{1.75} \left(\frac{1}{M_A} + \frac{1}{M_B}\right)^{1/2}}{P\left[(\Sigma \vartheta_A)^{1/3} + (\Sigma \vartheta_B)^{1/3}\right]^2}$$

Σ → summation

D_{AB} → cm^2/s

T → kelvin

P → pressure in atm.

M_A, M_B = molecular weights of A & B

ϑ_A, ϑ_B = molar volumes

Q.7 Correlations for liquid phase diffusivity

① Stokes-Einstein eqⁿ

$$\boxed{D_{AB} = \frac{kT}{6\pi r \mu_B}}$$

r = radius of solute particles
μ_B = viscosity of solvent.
k = Boltzmann const.
T = Temp. (Kelvin)

② Wilke - Chang eqⁿ

$$\cancel{D_{AB} = \frac{\mu_B}{T}}$$

$$\cancel{D_{AB} = \frac{T}{\mu_B} \times \frac{(\phi_B M_B)^{1/2}}{V_A^{0.6}}}$$

~~m^2/s~~

$$D_{AB} = \frac{1.173\times10^{-16} \times (\phi \cdot M_B)^{1/2} \cdot T}{\mu \cdot v_A^{0.6}}$$

diffusivity of solute A in solvent B (infinitely dilute solⁿ) (in m^2/s)

μ = solution viscosity

v_A = solute molar volume

ϕ = association factor for the solvent.

Q.8

Q.9

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Q.8 Relationship to estimate gas mixture diffusivity from binary diffusivity

$$D_{1-mix} = \frac{1}{\frac{y_2'}{D_{1-2}} + \frac{y_3'}{D_{1-3}} + \cdots + \frac{y_n'}{D_{1-n}}}$$

D_{1-n} → binary diffusivity
y_n' → mole fraction n in gas phase, evaluated on a component free basis.

Q.9 (i) Knudsen (pore) diffusivity
↳ D_{KA}.

$$D_{KA} = \frac{d_{pore} \cdot u}{3} = 4850 \cdot d_{pore} \cdot \sqrt{\frac{T}{M_A}}$$

Proof

$D_{AA} = \frac{1}{3} \lambda u$ for general gas phase diffusion.

$\lambda = d_{pore}$ for Knudsen diffusion.

from kinetic theory of gas, we have

$$u = \sqrt{\frac{8 K_N T}{\pi M_A}}$$

$$\therefore \boxed{D_{KA} = 4850 \, d_{pore} \sqrt{\frac{T}{M_A}}}$$

K_n = Knudsen number $= \frac{\lambda}{d_{pore}}$ | ★ $K_n > 1$ for Knudsen diffusivity to occur.

Q10 Surface diffusivity

↳ Surface diffusivity is the transport of adsorbed molecules on a surface in the presence of a concentration gradient.

$$\boxed{J_s = -D_s \cdot \frac{dc_s}{dz}}$$

D_s → surface diffusivity

Section 2

Q.1 Example 2.1 from B.K.D.

Gas mix → $N_2 = 5\%$ $NH_3 = 76\%$
$H_2 = 15\%$ $Ar = 4\%$

Diameter = 254 mm

$P = 4.05$ bar $\cong 4.05$ atm.

velocities 0.03, 0.035, 0.03, 0.02

find U, u, volume average velocity

↳ volume average velocity = molar average velocity

$$U = \frac{1}{c}(c_1 u_1 + c_2 u_2 + c_3 u_3 + c_4 u_4)$$

$$= y_1 u_1 + y_2 u_2 + y_3 u_3 + y_4 u_4$$

$$= 0.05 \times 0.03 + 0.15 \times 0.035 + 0.76 \times 0.03 + 0.04 \times 0.02$$

$\therefore \boxed{U = 0.0303 m/s}$

mass average velocity

$$u = \frac{1}{\rho}(\rho_1 u_1 + \rho_2 u_2 + \rho_3 u_3 + \rho_4 u_4)$$

$$\rho_i = \frac{P_i}{RT} \cdot M_i \quad , \quad \rho = \frac{P}{RT} \cdot M \rightarrow \text{avg. molecular weight}$$

mass density of the i^{th} component

$$\therefore \frac{\rho_i}{\rho} = \frac{P_i}{P} \cdot \frac{M_i}{M} = y_i \frac{M_i}{M}$$

total mass density

$$M = \sum y_i M_i = 0.05 \times 28 + 0.15 \times 2 + 0.76 \times 17 + 0.04 \times 40$$

$$\boxed{M = 16.22}$$

$$u = \frac{1}{M} \sum_{i=1}^{4} y_i M_i u_i$$

$$= \frac{0.05 \times 28 \times 0.03 + 0.15 \times 2 \times 0.035 + 0.76 \times 17 \times 0.03 + 0.04 \times 40 \times 0.02}{16.22}$$

$$\boxed{u = 0.029 m/s}$$

mass average velocity

Section 3

Q. 1 O_2 $y_{O_2} = 0.21$ $M_{O_2} = 0.032\ \frac{kg}{mol}$

N_2 $y_{N_2} = 0.79$ $M_{N_2} = 0.028\ \frac{kg}{mol}$

mass fraction x

$$x_{O_2} = \frac{\text{mass of } O_2}{\text{mass of air (kg)}}$$

average molecular weight

$$= 0.21 \times 0.032 + 0.79 \times 0.028$$

$$= \boxed{0.02884\ gm}$$

$$y_{O_2} = \frac{n_{O_2}}{n_{O_2} + n_{N_2}} = 0.21 \quad n \rightarrow \text{number of moles}$$

$$\Rightarrow \boxed{0.79\, n_{O_2} = 0.21\, n_{N_2}}$$

$$\text{mass of } O_2 = n_{O_2} \times M_{O_2}$$

$$= 0.032\, n_{O_2}$$

$$\therefore x_{O_2} = \frac{0.032\, n_{O_2}}{0.032\, n_{O_2} + 0.028\, n_{N_2}}$$

$$= \frac{0.032}{0.032 + \frac{0.79}{0.21} \times 0.028}$$

$$\boxed{x_{O_2} = 0.233}$$

rest must be N_2

$$\therefore \boxed{x_{N_2} = 0.767}$$

$\frac{775}{10^3\ cm^2}$

Q.2 $D_{CO_2, air}$ $T = 293\ K$, $P = 1\,atm$, $\Omega_D = 1.047$

$$D_{AB} = \frac{1.858 \cdot T^{3/2} \left(1/M_A + 1/M_B\right)^{1/2} \times 10^{-7}}{P \cdot \sigma_{AB}^2 \cdot \Omega_D}$$

↓

Chapman Enskogg eqn.

$$\sigma_{AB} = \frac{\sigma_A + \sigma_B}{2}$$

$$\therefore \sigma_{CO_2, air} = \frac{3.996 + 3.617}{}$$

$$\boxed{\sigma_{CO_2, air} = 3.8065}\ \mathring{A}$$

$$\varepsilon_{AB} = \sqrt{\varepsilon_A \cdot \varepsilon_B}$$

$$\varepsilon_{CO_2, air} = \sqrt{190 \times 97} = 135.757$$

$$D_{AB} = \frac{1.858 \times (293)^{3/2} \left(\frac{1}{44} + \frac{1}{29}\right)^{1/2} \times 10^{-7}}{1 \times (3.8065)^2 \times 1.047}$$

$$D_{AB} = 0.0000147\ \frac{m^2}{s}$$

$$\boxed{D_{AB} = 0.147\ \frac{cm^2}{s}}$$

Q.3
$$D_{AB} = \frac{T^{1.75} \left(\frac{1}{M_A} + \frac{1}{M_B}\right)^{1/2} \times 10^{-3}}{P \times \left((\Sigma \vartheta_A)^{1/3} + (\Sigma \vartheta_B)^{1/3}\right)^2}$$

$\Sigma v_{CO_2} = v_C + 2 \cdot v_O$

$= 16.5 + 2 \times 5.48$

$\therefore \Sigma v_{CO_2} = 27.46 \frac{cm^3}{g\,mol}$

$\Sigma v_{air} = 20.1 \frac{cm^3}{g\,mol}$

$$\therefore D_{AB} = \frac{(293)^{1.75} \left(\frac{1}{44} + \frac{1}{29}\right)^{1/2} \times 10^{-3}}{1 \times \left((27.46)^{1/3} + (20.1)^{1/3}\right)^2}$$

$$\boxed{D_{AB} = 0.15085 \frac{cm^2}{s}}$$

Q.4. $y_{SiH_4} = 0.0075$

$y_{H_2} = 0.015$

$y_{N_2} = 0.9775$

$T = 900K$, $P = 100\ Pa = \frac{100}{1.01325 \times 10^5}$ atm

$\frac{\varepsilon_A}{K} = 207.6\ K$ (silane) $T = 900K$, $P = 100\ Pa$

$\sigma_A = 4.08\ \mathring{A}$

$\frac{\varepsilon_{H_2}}{K} = 59.7\ K$, $\sigma_{H_2} = 2.827\ \mathring{A}$

$\frac{\varepsilon_{N_2}}{K} = 71.4\ K$, $\sigma_{N_2} = 3.789\ \mathring{A}$

$SiH_4 - N_2$

$\Omega_D = 0.8$

$\therefore D^{o}_{SiH_4-N_2} = 1.09 \times 10^{-3} \frac{cm^2}{s}$

$SiH_4 - H_2$

$\Omega_D = 0.87968$

$\therefore D^{o}_{SiH_4-H_2} = 4.06 \times 10^{-3} \frac{cm^2}{s}$

$y'_{N_2} = \frac{0.9775}{0.015 + 0.9775}$, $y'_{H_2} = \frac{0.015}{0.015 + 0.9775}$

$\therefore D^{o}_{A-mix} = \frac{1}{y'_{H_2}/D_{A-H_2} + y'_{N_2}/D_{A-N_2}} = \boxed{1.1 \times 10^{-3} \frac{cm^2}{s}}$

Q.5 $C_6H_{14}O_6$ in H_2O

$T = 283\,K$,

$\phi_{H_2O} = 2.26$

$\mu_{H_2O} = 0.001005 \frac{kg}{m.s}$

$M_{H_2O} = 18 \frac{gm}{mol}$

$$D_{AB} = \frac{1.173 \times 10^{-16} \times \left(\frac{2.26 \times \cancel{1000}}{18}\right)^{1/2} \times 283}{0.001005\,(v_m)^{0.6}}$$

$$\cancel{v_m = 6.v_C + 7.v_{H_2} + 6.v_O}$$

$$\cancel{= 6 \times 14.8 + \frac{}{7 \times 14.1}}$$

$$v_m = 6.v_C + 14 v_H + 6 v_O$$

$$= \frac{6 \times 14.8}{1000} + \frac{14 \times 3.7}{1000} + \frac{6 \times 7.4}{1000}$$

$$v_m = 0.185 \frac{m^3}{Kmol}$$

$\therefore D_{AB} = 0.579 \times 10^{-9} \frac{m^2}{S}$

actual value $= 0.56 \times 10^{-9}$

error $= \frac{0.579 - 0.56}{0.56} \times 100 = 3.39\%$

$\hookrightarrow \therefore$ within 5% limit

$$Q9\quad D_{AB} = \frac{7.5\times10^{-8}\,(\varphi\,M_{Bw})^{1/2}\cdot T}{\mu\cdot \vartheta^{0.6}}\ \frac{m^2}{sec}$$

$$= \frac{7.5\times10^{-8}\times(2.26\times18)^{1/2}\times 288}{1.14\times(103.6)^{0.6}}$$

$$\boxed{D_{AB} = 5.564\times10^{-6}\ \frac{m^2}{sec}}$$

Q.6. Silane

$C_S = 0.01$ (1 mol %)

$T = 298\,K$

$P = 101.3\ KPa$

in carrier gas (He): $D_{S,He} = 0.571\ \frac{cm^2}{s}$

$\sigma_{SiH_4} = \sigma_S = 4.08\ \mathring{A}$ $\qquad \frac{\varepsilon}{K} = 207.6K$

$M_S = 32\ \frac{g}{mol}$

$d_{pore} = 10\mu m$

↳ using the Chapman-Enskogg correlation for gas phase diffusivity, we have →

$$D_{AB} = \frac{0.001858\,T^{3/2}\left(\frac{1}{M_A}+\frac{1}{M_B}\right)^{1/2}}{P\cdot\sigma_{AB}^2\cdot\Omega_D}$$

$$\therefore \frac{D_{S,He}\ @\ 900K,\ 100Pa}{D_{S,He}\ @\ 298\,K,\ 101.3\,KPa} = \frac{T_1^{3/2}\cdot P_2\cdot\Omega_{D_2}}{T_2^{3/2}\cdot P_1\cdot\Omega_{D_1}} \quad (1)$$

$\sigma_S = 4.08\ \text{Å}$ (given), $(\varepsilon/K)_S = 207.6\ K$

$\sigma_{He} = 2.551\ \text{Å}$ (from Table 2.2 in BKD)

$(\varepsilon/K)_{He} = 10.22\ K$

$\therefore \sigma_{S,He} = \dfrac{4.08 + 2.551}{2} = 3.3155\ \text{Å}$

$\left(\dfrac{\varepsilon}{K}\right)_{S,He} = \sqrt{10.22 \times 207.6} = 46.1\ K$

$\therefore \dfrac{K}{\varepsilon} = 0.0217$

$\left(\dfrac{KT}{\varepsilon}\right)\Big|_{T=900K} = 19.53 \Rightarrow \Omega_{D_{900}} = 0.67$

$\left(\dfrac{KT}{\varepsilon}\right)_{T=298} = 6.46$

$\Rightarrow \Omega_{D_{298}} = 0.8$

$\therefore$ substituting in (1), we get

$D_{S,He}$ @ 900K, 100Pa $= 3.3 \times 10^{3}\ \dfrac{cm^2}{s}$

Now we use the eq^n for knudsen diffusivity

$D_{K,SiH_4} = d_{pore} \times 4850 \times \sqrt{\dfrac{900}{32}}$

$= 25.721\ \dfrac{cm^2}{sec}$

$$\frac{1}{D_{SiH_4,e}} = \frac{1}{D_{K,SiH_4}} + \frac{1}{D_{SiH_4,He}}$$

$$= \frac{1}{25.721} + \frac{1}{3.3\times10^{3}}$$

$$\boxed{\therefore D_{SiH_4,e} = 25.522 \ \frac{cm^2}{sec}}$$

$$\lambda = \frac{kT}{\sqrt{2}\,\pi\,\sigma_{sm}^2 \cdot P} = 1.68\times10^{-4} m$$

$\therefore Kn$ = Knudsen number $= \dfrac{\lambda}{d_{pore}}$

$$= \frac{1.68\times10^{-4}}{10\times10^{-6}} = 16.8 > 1$$

$\therefore$ Since $\boxed{Kn > 1}$, Knudsen diffusivity will occur.

Q. 7. $T = 1073 K$, $P = 1.5\times10^{5}$ Pa

$(\varepsilon/k)_s = 358 K$, $\sigma_s = 5.08$ Å, $\Omega_D = 0.74$

(a) $SiCl_4$ in H_2 $\quad M_s = 169.89$

$$D_{SiCl_4,H_2} = \frac{0.001858 \times (1073)^{3/2}\left(\frac{1}{2} + \frac{1}{169.89}\right)^{1/2}}{\frac{1.5\times10^{5}}{101.325\times10^{3}} \times (4.024)^2 \times 0.74}$$

σ_{SiCl_4,H_2}

$= \dfrac{5.08 + 2.968}{2}$

$= 4.024$ Å

$= \quad$ ~~$2.58\times10^{-5} \ \frac{cm^2}{s}$~~

~~ans corr~~ for part (a)

$= \boxed{2.61} \ cm^2/s$

(b) 0.4 mol $SiCl_4$, 0.4 mol H_2, Q.8

0.2 mol HCl

$\sigma_{HCl} = 3.339\ \mathring{A}$ $\left(\frac{\varepsilon}{K}\right)_{HCl} = 344.7\ K$

$\varepsilon_{SiH_4, HCl} = \sqrt{344.7 \times 358}$
$= 351.28\ K$

$\frac{KT}{\varepsilon} = 3.054$

$\Omega = 0.945$

$$D_{SiCl_4, HCl} = \frac{0.001858 \times (1073)^{3/2} \times 0.0182}{\frac{1.5 \times 10^5}{101.325 \times 10^3} \times 17.71 \times 0.945}$$

$$\boxed{D^o_{SiCl_4, HCl} = 0.479\ \frac{cm^2}{sec}}$$

$$D^o_{SiCl_4-mix} = \frac{1}{\frac{0.333}{D^o_{SiCl_4-H_2}} + \frac{0.667}{D^o_{SiCl_4 HCl}}} = 1.559\ \frac{cm^2}{s}$$

$$\therefore \boxed{D^o_{SiCl_4-mix} = 1.559\ \frac{cm^2}{S}}$$

$\frac{K}{\varepsilon}$

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Q.8 $H_2S \rightarrow 3\ \%$
$SO_2 \rightarrow 5\ \%$
$N_2 \rightarrow 92\ \%$ } vol.

$P = 1.013 \times 10^5\ Pa$

$T_{c_{H_2S}} = 373.2\ K$

$V_{c_{H_2S}} = 98.5\ \frac{cm^3}{mol}$

$T = 350\ K$

(1) In $H_2S - N_2$ mixture

$$\sigma_{H_2S, N_2} = \frac{3.88 + 3.681}{2} = 3.7805\ \mathring{A}$$

$$\frac{\varepsilon_{H_2S, N_2}}{K} = \sqrt{287.4 \times 91.5} = 162.1638\ K$$

$$\frac{KT}{\varepsilon} = \frac{162.1638}{\times 350} = 2.158$$

$$\Rightarrow \boxed{\Omega_0 = 1.048}$$

$$\therefore D_{H_2S, N_2} = \frac{0.001858\ (350)^{3/2} \left(\frac{1}{34} + \frac{1}{28}\right)^{0.5}}{1 \times (3.7805)^2 \times 1.048}$$

$$\boxed{D_{H_2S, N_2} = 0.207\ \frac{cm^2}{sec}}$$

(2) $H_2S - SO_2$

$$\sigma_{H_2S, SO_2} = \frac{4.112 + 3.88}{2} = 3.996\ K$$

$$\frac{\varepsilon_{H_2S, SO_2}}{K} = \sqrt{287.4 \times 335.4} = 310.437$$

$$\therefore \Omega_D = 1.273$$

$32 + 32$

$$\therefore D_{H_2S-SO_2} = \frac{0.001858 \times (350)^{3/2} \left(\frac{1}{34} + \frac{1}{64}\right)^{0.5}}{1 \times (3.996)^2 \times 1.273}$$

$$\boxed{D_{H_2S-SO_2} = 0.127 \ \frac{cm^2}{s}}$$

$$y'_{SO_2} = 0.0515$$

$$y'_{N_2} = 0.9485$$

$$\Rightarrow D_{H_2S-mix} = \frac{1}{\frac{0.0515}{0.207} + \frac{0.9485}{0.127}}$$

$$\boxed{D_{H_2S-mix} = 2.00 \ \frac{cm^2}{sec}}$$

Q. 9 $$D_{AB} = \frac{7.5 \times 10^{-8} (\phi_B \cdot M_B)^{1/2} \cdot T}{v_A^{0.6} \cdot \mu_B}$$

$v_A = 103.6$

$\mu_B = 1.14 \ cP$

$\phi_B = 2.26$

$T = 288 \ K$

$M_B = 18 \ \frac{gm}{mol}$ (water)

$$\therefore \boxed{D_{AB} = 7.46 \times 10^{-6} \ \frac{cm^2}{s}}$$

Q.10 CH_4 in H_2O

$T = 573\ K$, $P = 0.5\ atm$

$d_{pore} = 200\ nm = 200 \times 10^{-9}\ m$

$= 0.2\ \mu m$ = ~~$200 \times 10^{3}\ \mu m$~~

= ~~2×15~~ ~~$2 \times 10^{5}\ \mu m$~~

$$D_{AB} = \frac{0.00185 \times (573)^{3/2} \left(\frac{1}{16} + \frac{1}{18}\right)^{0.5}}{0.5 \times \sigma_{AB}^2 \times \Omega_D}$$

$$\sigma_{AB} = \frac{3.758 + 2.641}{2} = 3.213\ \mathring{A}$$

$\Omega_D = 0.9878$

$$\therefore \boxed{D_{AB} = 1.717\ \frac{cm^2}{s}}$$

$$\lambda = \frac{KT}{\sqrt{2}\,\pi\,(\sigma_A^2) \cdot P} = \frac{1.38 \times 10^{-16} \times 10^{-7} \times 573}{\sqrt{2} \times \pi \times (3.822)^2 \times (0.5 \times 10^5)}$$

$$\boxed{\lambda = 2.4365 \times 10^{-7}\ m}$$

$$D_{KA} = 4850\, d_{pore} \cdot \sqrt{\frac{T}{M_A}}$$

$$= 4850 \times 200 \times 10^{-7} \times \sqrt{\frac{573}{16}}$$

$$\boxed{D_{KA} = 0.58\ \frac{cm^2}{s}}$$

$$\frac{1}{D_{Ae}} = \frac{1-\alpha y_A}{D_{AB}} + \frac{1}{D_{KA}}$$

where $\alpha = 1 + \frac{N_B}{N_A} = 5$

$y_A = 0.2$

$$\therefore \frac{1}{D_{A,e}} = \frac{\cancel{1 - 5\times 0.2}}{D_{AB}} + \frac{1}{D_{KA}}$$

$$\boxed{D_{A,e} = D_{KA} = 0.58 \ \frac{cm^2}{s}}$$

$$K_n = \frac{\lambda}{d_{pore}} = \frac{2.4365\times10^{-7}}{2\times10^{-7}} = 1.22$$

$K_n = 1.22 > 1$

$\Rightarrow$ Knudsen diffusion is imp.