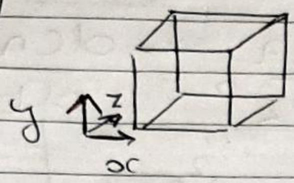
Assignment 2

Q01.1)



Rate of moles in − Rate of moles out + Rate of generation = Rate of accumulation

$$\Rightarrow \left[N_{Ax}\Big|_{x=x} - N_{Ax}\Big|_{x=x+dx}\right]\cdot \Delta y \cdot \Delta z$$

$$+ \left[N_{Ay}|_{y=y} - N_{Ay}|_{y=y+dy}\right]\Delta x \cdot \Delta z$$

$$+ \left[N_{Az}|_{z=z} - N_{Az}|_{z=z+dz}\right]\Delta x \cdot \Delta y$$

$$+ R_A \cdot \Delta x \cdot \Delta y \cdot \Delta z = \frac{d}{dt}\left(C_A \cdot \Delta x \cdot \Delta y \cdot \Delta z\right)$$

$$\Rightarrow \boxed{-\frac{\delta N_A}{\delta x} - \frac{\delta N_A}{\delta y} - \frac{\delta N_A}{\delta z} + R_A = \frac{d}{dt}(C_A)}$$

for steady state, binary, non-reactive

$\because \frac{dC_A}{dt} = 0$, $\because$ only x, $\because R_A = 0$

$$\Rightarrow \boxed{-\frac{dN_A}{dx} = 0} \qquad \because N_A = -N_B \text{ (no bulk M.T.)}$$

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

$$\Rightarrow \frac{d}{dx}\left(-D_{AB}\cdot\frac{dC_A}{dx}\right) = 0 \Rightarrow \boxed{\frac{d^2C_A}{dx^2} = 0}$$

Fick's 2nd law

Q.1.2) Steady state diffusion in binary gas mixture

(1) Diffusion of A through non-diffusing B

General eqn for flux of gases (binary mixture)

$$N_A = (N_A + N_B)\frac{P_A}{P} - \frac{D_{AB}}{RT}\cdot\frac{dP_A}{dx}$$

if B does not diffuse

$\Rightarrow \quad N_B = 0$

$$\Rightarrow N_A = N_A\cdot\frac{P_A}{P} - \frac{D_{AB}}{RT}\cdot\frac{dP_A}{dx}$$

$$N_A\int_0^l dx = \int_{P_{A0}}^{P_{Al}} \frac{-D_{AB}\cdot P}{RT(P-P_A)}\cdot dP_A$$

Since area is constant, steady state

$$\therefore \boxed{N_A = \frac{D_{AB}\cdot P}{RT\cdot l}\cdot \ln\left(\frac{P-P_{Al}}{P-P_{A0}}\right)}$$

$P = P_{A0} + P_{B0} = P_{Al} + P_{Bl}$

$P - P_{Al} = P_{Bl}, \quad P_{A0} - P_{Al} = P_{Bl} - P_{B0}$

$$\therefore N_A = \frac{D_{AB}\cdot P}{RT\cdot l}\cdot\frac{P_{A0}-P_{Al}}{P_{A0}-P_{Al}}\cdot\ln\left(\frac{P_{Bl}}{P_{B0}}\right)$$

$$\Rightarrow N_A = \frac{D_{AB}\cdot P}{RT\cdot l} \cdot \frac{P_{A0} - P_{Al}}{(P_{Bl} - P_{B0})/\ln(P_{Bl}/P_{B0})}$$

$$\boxed{N_A = \frac{D_{AB}\cdot P}{RT\cdot l} \cdot \frac{P_{A0} - P_{Al}}{P_{BM}}}$$

② Equimolar counter diffusion

A, B diffuse at equal rates but in opposite directions

$$\Rightarrow N_A = -N_B$$

$$\Rightarrow N_A + N_B = 0$$

$$N_A = (N_A + N_B)\cdot \frac{P_A}{P} - \frac{D_{AB}}{RT}\cdot\frac{dP_A}{dx}$$

$$\therefore N_A = -\frac{D_{AB}}{RT}\frac{dP_A}{dx}$$

$$\therefore N_A \cdot \int_0^l dx = -\frac{D_{AB}}{RT}\int_{P_{A0}}^{P_{Al}} dP_A$$

$$\therefore N_A \cdot \cancel{8} = -\frac{D_{AB}}{RTl}(P_{Al} - P_{A0})$$

$$\therefore \boxed{N_A = \frac{D_{AB}}{RTl}(P_{A0} - P_{Al})}$$

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③ Non-equimolar counter diffusion

$$N_A = -\frac{N_B}{2}.$$

$$\therefore N_A = -N_A \cdot \frac{P_A}{P} - \frac{D_{AB}}{RT} \cdot \frac{dP_A}{dx}.$$

$$\therefore N_A \left(1 + \frac{P_A}{P}\right) = -\frac{D_{AB}}{RT} \frac{dP_A}{dx}.$$

$$\therefore N_A \int_0^l dx = -\frac{D_{AB}}{RT} \cdot P \int_{P_{A0}}^{P_{Al}} \frac{dP_A}{P+P_A}$$

$$\therefore \boxed{N_A = -\frac{D_{AB}}{RTl} \cdot P \cdot \ln\left(\frac{P_A + P_{Al}}{P_A + P_{A0}}\right)}$$

Q. 1.3 Steady state diffusion in binary liquid mixture.

① A through non-diffusing B.

$$N_B = 0$$

$$\therefore N_A = N_A \cdot x_A - D_{AB}\left(\frac{\rho}{M}\right)_{avg} \cdot \frac{dx_A}{dZ}$$

$$N_A \int_0^l dz = -D_{AB}\left(\frac{\rho}{M}\right)_{avg} \int_{x_{A0}}^{x_{Al}} \frac{dx_A}{1-x_A}$$

$$= \frac{+D_{AB}(\rho/m)_{avg}}{l} \cdot \ln\left(\frac{1-x_{Al}}{1-x_{A0}}\right)$$

$$1 = x_{A0} + x_{B0} = x_{Al} + x_{Bl}$$

$$\therefore x_{A0} - x_{Al} = x_{Bl} - x_{B0}.$$

$$\therefore N_A = \frac{D_{AB}(\rho/m)_{avg}}{l} \frac{(x_{A0} - x_{Al})}{(x_{Bl} - x_{B0})} \cdot \ln\left(\frac{x_{Bl}}{x_{B0}}\right)$$

$$\therefore \boxed{N_A = \frac{D_{AB}}{l}\left(\frac{\rho}{M}\right)_{avg}\frac{(x_{A0}-x_{Al})}{x_{BM}}}$$

(2) Equimolar counter diffusion

$N_A = -N_B$

$$\rightarrow N_A\int_0^l dz = -D_{AB}\left(\frac{\rho}{M}\right)_{avg}\int_{x_{A0}}^{x_{Al}} dx_A$$

$$\Rightarrow N_A = \frac{-D_{AB}\cdot\left(\frac{\rho}{M}\right)_{av}}{l}(x_{Al}-x_{A0})$$

(3) $N_A = -\frac{N_B}{2}$ ∴ counter

$$\therefore N_A = (N_A - 2N_A)\cdot x_A - D_{AB}\left(\frac{\rho}{M}\right)_{av}\cdot\frac{dx_A}{dz}$$

$$\therefore N_A = \frac{-D_{AB}\left(\frac{\rho}{M}\right)_{av}}{1+x_A}\frac{dx_A}{dz}$$

$$\cancel{N_A = \frac{D_{AB}\left(\frac{\rho}{M}\right)_{av}}{l}}$$

$$N_A\int_0^l dz = -D_{AB}\left(\frac{\rho}{M}\right)_{av}\int_{x_{A0}}^{x_{Al}}\frac{dx_A}{1+x_A}$$

$$\therefore \boxed{N_A = \frac{-D_{AB}\left(\frac{\rho}{M}\right)_{av}}{l}\ln\left(\frac{x_{Al}+1}{x_{A0}+1}\right)}$$

Q 1.4 Fick's law for mass flux →

$$\boxed{J_A = -D_{AB} \cdot \frac{dC_A}{dz}} \quad (1)$$

mass flux (molar flux)

conc. grad.

Fourier's law of heat conduction

$$\boxed{q_z = -k \frac{dT}{dz}}$$

heat/thermal flux

temperature gradient

Newton's law of viscosity

$$\boxed{\tau_{zx} = -\mu \frac{du_x}{dz}}$$

Shear stress a.k.a. momentum flux

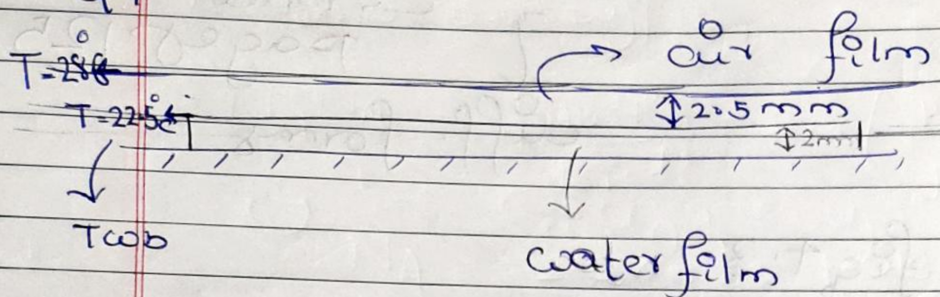
velocity gradient

Hence mass, heat and momentum transfer are analogous.

Assignment 2

Section 2

Q.1 $T_{amb} = 28°C$



$$T_{water} = T_{wet\ bulb}$$

$$T_{amb} = 28°C$$

Time taken for water to completely evaporate

(a) Relative humidity of air = 60%

$$D_{H_2O,\,air} = 0.853 \ \frac{ft^2}{hr} \quad \text{at } 1\,atm,\ 0°C$$

$$\ln(P_v) = 13.8573 - \frac{5160.2}{T}$$

P_v → vapour pressure of water

→ 82.4°F

at RH = 60%, $T_{Dry\ bulb} = 28°C$,

$$T_{wet\ bulb} = 71.5°F = 22.5°F$$

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$T_{wb} = 22.5^{\circ}C = T_{water}$

$\therefore P_v = 0.0374$ bar

@ $28^{\circ}C$,

water A   air B

diff.   not diff

$T = 28^{\circ}C$

$T = 22.5^{\circ}C$ ↑↑↑ water diffuses } 2.5 mm air film

use the mean to obtain the steady state flux of vapour =

using fuller correlation,

$$D_{AB} = \frac{1.0133 \times 10^{-7}\, T^{1.75} \left(\frac{1}{M_A} + \frac{1}{M_B}\right)^{0.5}}{P\left((\Sigma v)_A^{1/3} + (\Sigma v)_B^{1/3}\right)^2} \quad \frac{m^2}{s}$$

given that $D_{AB} = 0.853 \frac{ft^2}{hr}$ at $P = 1atm$, $T = 273K$

$$\therefore \frac{0.853}{D_{AB}} = \frac{(273)^{1.75}}{(273 + 25.25)^{1.75}}$$

at $25.25^{\circ}C$,

$\therefore D_{AB} = 0.99581 \frac{ft^2}{hr}$

$$\boxed{D_{AB} = 2.57 \times 10^{-5} \frac{m^2}{s}}$$

now, from the eqn for diff. of A thru' non-diff B,

$$N_A = \frac{D_{AB} \cdot P}{RT \cdot l} \ln\left(\frac{P - P_{Al}}{P - P_{A0}}\right)$$

$$\therefore N_A = \frac{2.5 \times 10^{-5} \times 1.013 \times 10^{3}}{8.314 \times 298.2 \times 2.5 \times 10^{-3}} \times \ln\left(\frac{P - P_{Al}}{P - P_{A0}}\right)$$

$$P_{Al} = R.H \times P_v @ 28°C = 0.6 \times 0.037 \text{ bar}$$

$$= 0.02244$$

$$P_{A0} = 0.02718$$

$$\therefore \boxed{N_A = 3.623 \times 10^{-5} \frac{kg}{m^2 \cdot s}}$$

$\therefore$ for $1 m^2$, $3.623 \times 10^{-5} \frac{kg}{s}$ evap. rate

$$2 mm \times 1 m^2 = 2 \times 10^{-3} m^3$$

$$\equiv 2 \, kg$$

$$\therefore \text{time} = \frac{2}{3.623 \times 10^{-5}} s$$

$$= \boxed{15.33 \text{ hrs}}$$

(b) water also penetrates the floor @ $0.1 \frac{kg}{m^2 \cdot h} = 2.77 \times 10^{-5} \frac{kg}{m^2 s}$

total rate of dissappearance of H_2O
$= 2.77 \times 10^{-5} + 3.623 \times 10^{-5}$
$= 6.4 \times 10^{-5} \frac{kg}{m^2 s}$

$\therefore$ time $= \frac{2}{6.4 \times 10^{-5}} = \boxed{8.68 \text{ hrs}}$

Q. 2.3 $0.1 atm - P_{A1}$

1 cm NH_3

$0.9 atm - P_{A0}$

$T = 298\ K$, $P = 1 atm$

$$N_A = \frac{D_{AB} \cdot P}{RTl} \ln\left(\frac{P - P_{A1}}{P - P_{A0}}\right)$$

A = ammonia, B - air

$D_{AB} = 0.214 \frac{cm^2}{s} = 2.14 \times 10^{-5} \frac{m^2}{s}$

$$N_A = \frac{2.14 \times 10^{-5} \times 1.0}{0.0821 \times 298 \times 10^{-2}} \times \ln\left(\frac{1.0 - 0.1}{1.0 - 0.9}\right)$$

$$\boxed{N_A = 1.922 \times 10^{-5} \frac{mol}{m^2 s}}$$

Since air is not diffusing,

$N_B = 0$

$N_A = C_A \cdot u_A$

$$U = \frac{C_A u_A + C_B u_B}{C}$$

$$\Rightarrow U = \frac{C_A \cdot u_A}{C} = \frac{N_A}{C}$$

$$\Rightarrow U = \frac{N_A RT}{P} = \boxed{0.47 \frac{cm}{s}}$$

average molar $\vec{v}$

$C_A u_A = N_A$

$$\therefore u_A = \frac{N_A}{C_A} = \frac{U \cdot C}{C_A} = \frac{U}{y_A}$$

at bottom end, $y_A = \frac{P_{A0}}{P}$

$= \frac{0.9}{1}$

$$\therefore u_{A0} = \frac{0.47}{0.9} = 0.522 \frac{cm}{s}$$

$u_B = 0$ everywhere.

mass avg $\vec{v} = u = \frac{\rho_A u_A + \rho_B u_B}{\rho}$

$$PV = nRT$$

$$\Rightarrow \rho = \frac{PM}{RT} \leftarrow P = \frac{m}{M}\frac{1}{V} RT$$

$$\therefore u = \frac{\rho_A u_A}{\rho} = \frac{u_A \cdot \frac{P_A M_A}{RT}}{\rho}$$

$$= \frac{0.522 \times 17}{17+29} =$$

$$u = \frac{0.522 \times \frac{P_A}{RT} \times 17}{\rho}$$

$$\rho = M_A y_A + M_B y_B$$
$$= 17 \times 0.9 + 29 \times 0.1$$
$$= 18.2$$

$$\therefore u = \frac{0.522 \times 17 \times 0.9}{18.2}$$

$$u = 0.439 \frac{cm}{s}$$

mass avg. $\vec{v}$

(d) $$J_A = C_A (u_A - u)$$
$$= \frac{P_A}{RT} (u_A - u)$$
$$= \frac{0.9 (0.522 - 0.439)}{82.1 \times 298}$$

$$\boxed{J_A = 3.05 \times 10^{-6} \frac{mol}{cm^2 \cdot s}}$$

$$N_A = \frac{D_{AB} \cdot P}{RT \cdot l} \left(\frac{P - P_{Al}}{P - P_{A0}} \right)$$

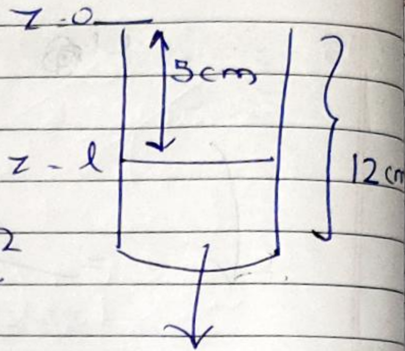
for sonce PAl

Q 2.4 $T = 25^\circ C$

$P = 1 atm$

$A = O_2, \quad B = N_2$

$D_{AB} = 0.21 \frac{cm^2}{s}$



$O_2 \rightarrow$ soluble, $N_2 \rightarrow$ not liquid

$\Rightarrow$ Diff. of O_2 in non-diff N_2

$$N_A = \frac{D_{AB} \cdot P}{RTl} \cdot \ln \left(\frac{P - P_{Al}}{P - P_{A0}} \right)$$

$$= \frac{0.21 \cancel{\frac{cm^2}{s}} \times 10^{-4} \times 101.325 \times 10^3 \frac{kg}{m^2}}{8.314 \times \frac{kg\, m^2}{\cancel{K} \cdot mol\, s^2} \times 298\cancel{K} \times 5 \times 10^{-2} m} \ln ( )$$

$$= \frac{0.21 \times 10^{-4} \times 101.325 \times 10^3}{8.314 \times 298 \times 10^{-2} \times 5} \ln ( )$$

$$= 1.71 \times 10^{-5} \frac{kg\,mol}{m^2 s} \times \ln \left(\frac{1 - 0}{1 - 0.21} \right)$$

$$= 4.05 \times 10^{-6} \frac{kg\,mol}{m^2 s}$$

$$\boxed{N_A = 1.29 \times 10^{-4} \frac{Kg}{m^2 S}}$$

16 gms/~~kgmol~~
1 gmol
1 kg mol = 1000 gms
= 1000

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$$\text{area} = \frac{\pi \times (1.5\times10^{-2})^2}{4} = 1.767 \times 10^{-4}\ m^2$$

$$\therefore \boxed{\text{rate of absorb} = 2.279 \times 10^{-8}\ \frac{kg}{s}}$$

$$\cancel{N_A = + \frac{D_{AB}\, P}{R T l} \ln\left(\frac{P - P_{Al}}{P - P_{A0}}\right)} \quad (1)$$

(b) $$N_A = (N_A + \underbrace{N_B}_{0}) \frac{P_A}{P} - \frac{D_{AB}}{RT} \frac{dP_A}{dz}$$

$$\therefore N_A \left(1 - \frac{P_A}{P}\right) = -\frac{D_{AB}}{RT} \frac{dP_A}{dz}$$

$$\therefore \frac{dP_A}{dz} = N_A \frac{RT}{D_{AB}} \left(\frac{P_A}{P} - 1\right)$$

$$= \frac{N_A RT (P_A - P)}{D_{AB} \cdot P}$$

$P_A = 0.113$ bar from (1)

$$\rightarrow \boxed{\frac{dP_A}{dz} = -4.15\ \frac{bar}{m}}$$

(c) u_A, $u_B \rightarrow 0$ everywhere

midway: $z = 2.5\,cm$

$$u_A = \frac{N_A}{C_A} = \frac{N_A RT}{P_A}$$

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~~N_A at $x = 2.5cm$~~

~~$= \frac{0.21\times10^{-4} \times 1.013}{0.0831\times 298\times 2.5\times10^{-2}} \times \ln\left(\frac{1.013-}{}\right.$~~

$\therefore u_A = \frac{4.05\times10^{-6} \times 0.0831 \times 298}{0.113}$

$\boxed{u_A = 8.88\times10^{-4} \frac{m}{s}}$

$u_B = 0$

$\therefore U = \frac{1}{c}(C_A \cdot u_A + C_B \cdot u_B)$

$= \frac{C_A \cdot u_A}{c} = \frac{N_A}{c}$

$= \frac{4.05\times10^{-6} \times 0.0831 \times 298}{1.013}$

$\boxed{U = 9.9\times10^{-5} \frac{m}{s}}$

$v_{A,d} = u_A - U$

$\boxed{v_{A,d} = 7.889\times10^{-4} \frac{m}{s}}$

$v_{B,d} = u_B - U$

$\boxed{v_{B,d} = -9.9\times10^{-5} \frac{m}{s}}$

at $z = 0$,

$u_A = \frac{N_A}{C_A} = \frac{N_A RT}{P_A}$

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$\therefore u_A = \dfrac{4.05\times10^{-6}\times 0.0831\times 298}{0.21\times 1.013}$

$\boxed{u_A = 4.71\times10^{-4}\ \dfrac{m}{s}}$

$U = \dfrac{1}{C}\cdot C_A u_A = \dfrac{4.05\times10^{-6}\times 0.0831\times 298}{1.013}$

$\boxed{U = 9.9\times10^{-5}\ \dfrac{m}{s}}$

→ molar avg $\vec{v}$ will be const.

$\therefore v_{A,d} = u_A - U$

$\boxed{v_{A,d} = 3.724\times10^{-4}\ \dfrac{m}{s}}$

$\boxed{v_{B,d} = -9.9\times10^{-5}\ \dfrac{m}{s}}$

at $z = 0.05\,m$.

$\cancel{4.05\times10^{-6} = \dfrac{0.21\times10^{-4}\times}{0.0831\times298}}$ P

→ $P_{Al} = 0$

$\Rightarrow u_A = \infty$

$\therefore U = 9.9\times10^{-5}$

$\therefore v_{Ad} = \infty$

$v_{BD} = -9.9\times10^{-5}$

(d) $v = 9.9\times10^{-5}$ m/s

$\therefore v_{obs} = 19.8\times10^{-5}$ m/s

$$F_A = C_A \cdot (u_A + v_{obs})$$

$$= \frac{P_A}{RT}(u_A + v_{obs})$$

$$= \frac{0.0113}{0.08314\times298}\left(8.8\times10^{-4} + 19.8\times10^{-5}\right)$$

$$= \cancel{(1.024\ldots)}$$

$$= 4.95\times10^{-6}\ \frac{\text{kgmol}}{m^2\cdot s}$$

$$F_B = C_B(\cancel{u_B}^{0} + v_{obs})$$

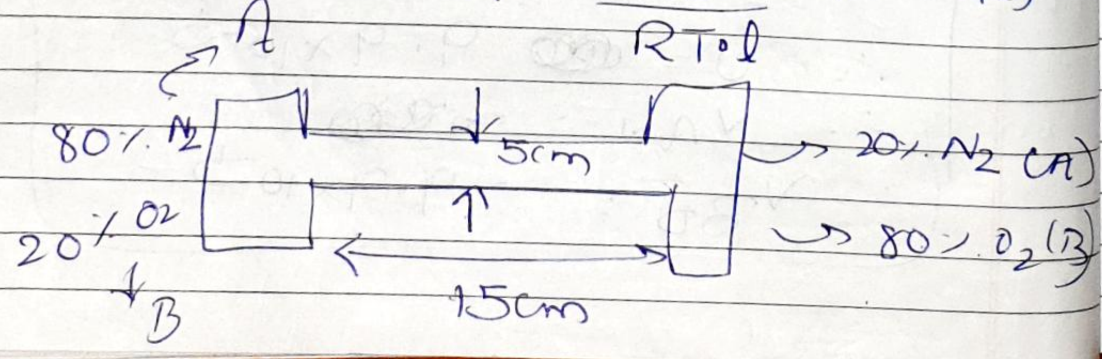
$$= \frac{P_B}{RT}\times v_{obs}$$

$$= \frac{(1.013 - 0.0113)}{0.08314\times298}\times 19.8\times10^{-5}$$

$$F_B = 7.19\times10^{-6}\ \frac{\text{kgmol}}{m^2\cdot s}$$

Q. 2.6 Equimolar C-D.

$$N_A = \frac{D_{AB}}{RT\cdot l}(P_{A0} - P_{Al})$$



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$T = 293K$, $P = 2 atm$

(a) $\cancel{N_A = 0}$

$$\frac{D_{AB_1}}{D_{AB_2}} = \frac{(316)^{1.75} \times 2}{(293)^{1.75} \times 1}$$

$\cancel{D_{AB_1}}$ 0.23

$\therefore D_{AB_2} = D_{AB}$ @ our conditions $= 0.1 \frac{cm^2}{s}$

$$N_A = \frac{0.1 \times 10^{-4}}{0.08314 \times 293 \times 0.15}(0.8 \times 2 - 0.2 \times 2) \times 1.013$$

$$N_A = 3.33 \times 10^{-6} \frac{kgmol}{m^2 \cdot s}$$

$$= 9.31 \times 10^{-5} \frac{kg}{m^2 \cdot s}$$

in the pipe, rate of transport →

$$A = \frac{\pi \times (5 \times 10^{-2})^2}{4} = 0.00196 \; m^2$$

$\therefore$ Rate trans. $N_2 = 0.0182 \times 10^{-5} \frac{kg}{s}$

$$\boxed{= 1.82 \times 10^{-7} \frac{kg}{s}}$$

(b) $N_B = -N_A$

$$= -3.3 \times 10^{-6} \frac{kgmol}{m^2 s}$$

$$\boxed{N_B = -1.8 \times 10^{-7} \frac{kg}{sec}}$$

(c) $N_A = \cancel{(N_A + N_B)}^{0} \frac{c_A}{c} - D_{AB} \frac{d c_A}{dx}$

$= - \frac{D_{AB}}{RT} \frac{d p_A}{dx}$

$\therefore \frac{dp_A}{dx} = - \frac{3.33 \times 10^{-6} \times 0.0831 \times 2}{1 \times 10^{-5}}$

$\boxed{\frac{dp}{dx} = -8.11 \ \frac{bar}{m}}$

$\therefore P - 0.8 \times 2 = -8.11 \times 0.05$

$\boxed{P = 1.2 \ bar}$

(d) $N_A = -N_B$ (not $J_A = -J_B$)

$n_T = N_A \cdot M_A + N_B \cdot M_B$

$= 3.3 \times 10^{-6} (28 - 32)$

$\boxed{n_T = 1.32 \times 10^{-5} \ \frac{mol}{m^2 s}}$

Q 2.7 $M_A = 32$, $M_B = 18$

$\Delta H_A = 274.6 \times 32$

$= 8787 \ \frac{K\,cal}{kg\,mol}$

$\Delta H_B = 557.7 \times 18 = 10039 \ \frac{Kcal}{Kgmol}$

$N_A \cdot \Delta H_A = -N_B \cdot \Delta H_B$

$\therefore \boxed{\frac{N_B}{N_A} = -0.875}$

$N_A = (N_A + N_B)\frac{P_A}{P} - \frac{D_{AB}}{RT}\frac{dP_A}{dz}$

$\therefore N_A(1 - 0.1247 y_A) = -\frac{D_{AB}}{RT}\frac{dP_A}{dz}$

$\therefore \int_0^l N_A dz = -\frac{D_{AB}}{RT} \cdot \int_{y_{A0}}^{y_{A1}} \frac{dy_A}{1 - 0.1247 y_A}$

$\therefore \boxed{N_A = 4.65 \times 10^{-5} \ \frac{kg\,mol}{m^2 \cdot s}}$

$\therefore N_B = -0.875 N_A$

$\therefore \boxed{N_B = -4.07 \times 10^{-5} \ \frac{kg\,mol}{m^2 S}}$

2.19 $d_{pore} = 100\mathring{A}$, $T = 600K$.

$M = 28 \frac{gm}{mol}$.

$D_K = 4850 \cdot d_{pore} \cdot \sqrt{\frac{T}{M}}$.

$$\boxed{D_K = 2.245 \frac{cm^2}{S}}$$

— x —

Section 3

Q 3.1 Steady state molecular diffusion

$$Na_z = \frac{C \cdot D_{AB}}{z_2 - z_1} \ln\left(\frac{1 - y_{A2}}{1 - y_{A1}}\right)$$

$$\Rightarrow Na_z = \frac{P \cdot D_{AB}}{RT(z_2 - z_1)} \ln\left(\frac{1 - y_{A2}}{1 - y_{A1}}\right)$$

$$y_{A1} = \frac{P_A}{P} = \frac{115.1 \text{ mm Hg}}{760 \text{ mm Hg}}$$

$$\boxed{y_{A1} = 0.152}$$

$$z_2 - z_1 = 5 - 0.2 = 4.8 m$$

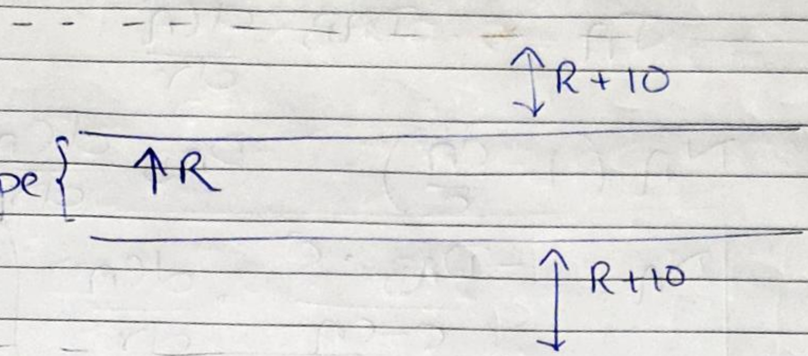
$$\therefore Na_z = 1.197 \times 10^{-8} \frac{kgmol\ TCE}{m^2 \cdot S}$$

$$\therefore \omega = N_{A_z} \cdot \frac{\pi D^2}{4} = 131.4 \frac{kg}{mol} \times 3600 \times 24 \times N_{A_z} \times \frac{\pi}{4}$$

= ~~0.423~~

$$\boxed{\omega = 0.423 \ \text{kg} \ \frac{\text{TCE}}{\text{day}}}$$

Q.2



(a)
(1) Steady state → const w.r.t time
(2) Homogeneous, single phase with 2 non-reacting species
(3) diff. only in radial dir.

(b) $\nabla N_A + \frac{dC_A}{dt} = R_A$

$$\therefore \frac{1}{r}\frac{d}{dr}(rN_{Ar}) = 0$$

↳ radial component

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

Since B does not diffuse,

$N_B = 0$

$$\therefore N_A\left(1-\frac{C_A}{C}\right) = J_A$$

from Fick's law

$$J_A = -D_{AB}\frac{dC_A}{dr}$$

$$\therefore N_A\left(1-\frac{C_A}{C}\right) = -D_{AB}\frac{dC_A}{dr}$$

$$\therefore \boxed{N_A = \frac{-D_{AB}\cdot C}{C-C_A}\cdot\frac{dC_A}{dr}}$$

Q.3. C_{A_1} @ $z=0$ $= 0.1\ \frac{mol}{m^3}$

C_{A_2} @ $z = 4mm$ $= 0.02\ \frac{mol}{m^3}$

$\mu_B = 1.4\ cP$

$$D_{AB} = 13.26\times10^{-5}(\mu_B)^{-1.14}\times(V_A)^{-0.5}$$

$$V_A = 2(V_C)+6(V_H)+1\times V_O$$

$$= 2\times14.8+6\times3.7+7.4$$

$$= 59.2\ \frac{cm^3}{mol}$$

$$\therefore \boxed{D_{AB} = 8.2\times10^{-6}\ \frac{cm^2}{s}}$$

→ Counter diffusion (equimolar)

$\Rightarrow N_A = -N_B$

$\Rightarrow N_A = \frac{D_{AB}}{L}(C_{A_1} - C_{A_2})$

$= \frac{8.2\times10^{-6}\times10^{-4}}{4\times10^{-3}}(0.1-0.02)$

$$\boxed{N_A = 1.64\times10^{-8}\ \frac{mol}{m^2 s}}$$

let $C_A = K_1 \cdot z + K_2$

@ $z = 0$, $C_A = C_{A_1} = 0.1$

$\Rightarrow K_2 = 0.1$

@ $z = 0.004m$, $C_A = C_{A_2} = 0.02$

$\Rightarrow 0.02 = 0.004 K_1 + 0.1$

$\Rightarrow K_1 = -2$

$$\therefore \boxed{C_A = -20z + 0.1}$$

→ Diffusion in air

$N_A = \frac{D_{AB}\cdot C}{l}\ln\left(\frac{C - C_{A_1}}{C - C_{A_2}}\right)$

$= \frac{D_{AB}\cdot P}{RTl}\ln\left(\frac{C - C_{A_1}}{C - C_{A_2}}\right)$

$= \frac{D_{AB}P}{RTl}\ln\left(\frac{P - P_{A_1}}{P - P_{A_2}}\right)$

$\therefore P_{A_1} = C_{A_1} RT = 0.1 RT$

$C = \frac{P}{RT} = \frac{10^5}{8.314 \times 283} = 43.05 \frac{mol}{m^3}$

$P_{A_2} = 0.02 RT$

given $D_{AB} = 1.32 \times 10^{-5} \frac{m^2}{s}$

$\therefore \boxed{N_A = 2.64 \times 10^{-4} \frac{m^2}{s}}$

Q.4 $l = 1 mm$

$D_{AB} = 0.95 \times 10^{-9} \frac{m^2}{s}$

at $z = 0$ | at $z = 1mm$

$\omega\% = 0.09$ | $\omega\% = 0.03$ (fracn)

$\omega_{A_1} = 9g$ | $\omega_{A_2} = 3g$

$\Rightarrow n_{A_1} = \frac{9}{60}$, | $\therefore n_{A_2} = 3/60$

taking 100g basis $n_{B_1} = \frac{91}{18}$ | $\Rightarrow n_{B_2} = 97/18$

$\Rightarrow \boxed{y_{A_1} = 0.0288}$ | $\boxed{y_{A_2} = 0.0092}$

assume dilute soln, so $\rho \simeq 1000$

$M_1 = 0.09 \times 60 + 0.91 \times 18 = 21.78 g$

$$M_2 = 0.03 \times 60 + 0.97 \times 18$$
$$= 19.26 g$$

$$M_{avg} = \frac{M_1 + M_2}{2} = 20.52 g$$

$$\frac{\rho}{M_{avg}} = C = \frac{1000}{20.52 \times 10^{-3}} = \frac{10^6}{20.52}$$

$$N_A = \frac{D_{AB} \cdot C}{l} \ln\left(\frac{C - C_{A_1}}{C - C_{A_2}}\right)$$

$$= \frac{0.095 \times 10^{-9} \times 10^6}{10^{-3} \times 20.52} \ln\left(\frac{1 - 0.0092}{1 - 0.0288}\right)$$

$$\Rightarrow \boxed{N_A = 9.25 \times 10^{-7} \frac{kg\,mol}{m^2 \cdot s}}$$

Q.5 (a) $N_A = -N_B$

given: $l = 0.2 m$ $D = 0.01 m$

$D_{AB} = 2.75 \times 10^{-5} \frac{m^2}{s}$

$P_{A_1} = 1.5 atm$, $P_{A_2} = 0.5 atm$

for equimolar C.D

$$N_A = \frac{D_{AB}}{RTl} (P_{A_1} - P_{A_2})$$

$$\Rightarrow \boxed{N_A = 6.14 \times 10^{-3} \frac{kg\,mol}{m^2 \cdot s}}$$

$$\Rightarrow \omega = N_A \cdot \frac{\pi D^2}{4} = 4.823 \times 10^{-7} \frac{kg\,mol}{s}$$

(b) non-equimolar C.D.

$$N_B = -\frac{3}{4} N_A$$

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

$$\Rightarrow N_A = \frac{N_A}{4}\cdot\frac{C_A}{C} + J_A$$

$$\Rightarrow N_A = \frac{J_A}{1 - \frac{C_A}{4C}} \quad J_A \rightarrow -D_{AB}\frac{dC_A}{dz}$$

$$\therefore N_A = \frac{4 D_{AB} \cdot C}{l} \ln\left(\frac{1 - \frac{y_{A_2}}{4}}{1 - \frac{y_{A_1}}{4}}\right)$$

$$y_{A_1} = \frac{1.5}{2}, \quad y_{A_2} = \frac{0.5}{2}$$

$$\Rightarrow \boxed{N_A = 6.9 \times 10^{-6} \frac{\text{Kgmol}}{m^2 \cdot S}}$$

$$\therefore \omega = N_A \cdot \frac{\pi D^2}{4} = \frac{6.9 \times 10^{-6} \times \pi \times (0.01)^2}{4}$$

$$\therefore \boxed{\omega = 5.46 \times 10^{-10} \frac{\text{Km}}{S}}$$

(c) Non diffusing B

$$\Rightarrow N_B = 0.$$

$$\therefore N_A = \frac{D_{AB} \cdot P}{RT \cdot l}\left(\frac{1 - y_{A_2}}{1 - y_{A_1}}\right)$$

$$= 1.32 \times 10^{-5} \ \frac{\text{kg mol}}{m^2 s}$$

$$\therefore \ W_A = N_A \cdot \frac{\pi D^2}{4} = 1.036 \times 10^{-9} \ \frac{\text{kg mol}}{s}$$