King Saud University
Department of Chemical Engineering
TEST-1: Part-1 (Closed Book) **Mass Transfer (CHE 318)** **Time: 15 min**

Roll No:	Gp:

Following are Sherwood number, Schmidt number, and Reynolds number definitions:

$$N_{Sh} = k'_c \frac{L}{D_{AB}}; N_{Sc} = \frac{(\mu/\rho)}{D_{AB}}; N_{Re} = \frac{Lv\rho}{\mu}$$

(1) A high value of the Sherwood number indicates

(a) convective mass transfer is more important as compared to diffusive mass transport	(b) convective mass transfer is less important as compared to diffusive mass transport
(c) diffusive mass transfer is high as compared to convective mass transport	(d) Nothing can be said about mass transport

(2) The Schmidt number is much higher for liquids as compared to gases **mainly** because

(a) higher momentum diffusivity of liquids as compared to gases	(b) lower momentum diffusivity of liquids as compared to gases
(c) higher mass diffusivity of liquids as compared to gases	(d) lower mass diffusivity of liquids as compared to gases

(3) For the diffusion of gases A and B in a binary mixture of A and B, the flux of A is given by $N_A = -cD_{AB}\frac{d(x_A)}{dz} + \frac{c_A}{c}(N_A + N_B)$. For the diffusion of gas B through the stagnant non-diffusing gas C, the flux of B (N_B) is given by,

$(a)\quad -cD_{BC}\frac{d(x_B)}{dz} + \frac{c_B}{c}(N_B)$	$(b)\quad -cD_{BC}\frac{d(x_B)}{dz} + \frac{c_B}{c}(N_C)$
$(c)\quad -cD_{BC}\frac{d(x_C)}{dz} + \frac{c_B}{c}(N_C)$	$(d)\quad -cD_{BC}\frac{d(x_C)}{dz} + \frac{c_B}{c}(N_B)$

(4) For the diffusion of gas B through the stagnant non-diffusing gas C a binary mixture of B and C, the flux of B (N_B) is given by,

$(a)\quad cD_{BC}\frac{d(x_C)}{dz} + \frac{c_B}{c}(N_B)$	$(b)\quad -cD_{BC}\frac{d(x_B)}{dz} + \frac{c_B}{c}(N_C)$
$(c)\quad cD_{BC}\frac{d(x_B)}{dz} + \frac{c_B}{c}(N_B)$	$(d)\quad cD_{CB}\frac{d(x_B)}{dz} + \frac{c_B}{c}(N_B)$

(5) The permeability of polymer A is more than ten times higher than the polymer B for the oxygen gas. For packaging a high value pharmaceutical product (medicine), it required to keep the diffusion flux of atmospheric oxygen to the medicine as low as possible to avoid its oxidation to increase the shelf life (product expiry). Based on your mass transfer knowledge, which of the following options will you choose

(a) 0.5 mm film of polymer A	(b) 0.5 mm film of polymer B
(c) (i) 0.2 mm film of polymer A (ii) 0.3 mm film of polymer B	(d) (i)0.3 mm film of polymer B (ii) 0.2 mm film of polymer A

6) At P = 1 atm and T = 298 K, a mixture of Hydrogen and Ammonia contains 10 mole% Hydrogen. The diffusivity of Hydrogen in this mixture is $0.783 \times 10^{-4}\, m^2/s$. What will be the molecular diffusivity of Hydrogen in the mixture containing 20 mole% Hydrogen at P = 1 atm and T = 350 K.

(a) greater than $0.783 \times 10^{-4}\, m^2/s$	(b) equal to $0.783 \times 10^{-4}\, m^2/s$
(c) less than $0.783 \times 10^{-4}\, m^2/s$	(d) cannot be predicted with given information

(7) Write appropriate SI units for k_c' used in molar flux of solute A in equi-molar counter-diffusion, $N_A = k_c'(c_{A1} - c_{A2})$

(8) Write down appropriate SI units for k_G used in molar flux of solute A diffusing through stagnant, non-diffusing B, $N_A = k_G(p_{A1} - p_{A2})$

(9+10) Write the relationship between k_c' and k_G

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TEST-1 **Mass Transfer (CHE 318)** **Time: 75 min**

Question 1: **Predict** the diffusivity of ethyl alcohol (C_2H_5OH; MW=46) solute in solvent water using Wilke-Chang correlation at atmospheric conditions for T = 25 degree C.
Compare your results with experimental value by computing the % error.

Data: At 25 degree C, the viscosity of water at is 0.9×10^{-3} Pa.s.

	Marks
$D_{AB} = 1.173 \times 10^{-16} (\varphi M_B)^{1/2} \left(\frac{T}{\mu_B V_A^{0.6}}\right)$	
$V_A = 2(0.0148) + 6(0.0037) + 1(0.0074) = 0.0592 \frac{m^3}{kg\ mol}$	
$D_{AB} = 1.173 \times 10^{-16} \times (2.6 \times 18)^{1/2} \left(\frac{298}{0.9 \times 10^{-3} \times 0.0592^{0.6}}\right) = 1.45 \times 10^{-9} \frac{m^2}{s}$	
$D_{AB}(Exptl) = 1.25 \times 10^{-9} \frac{m^2}{s}$	
$\%\ Error = \frac{\lvert 1.45 \times 10^{-9} - 1.25 \times 10^{-9} \rvert}{1.26 \times 10^{-9}} \times 100 = 16.9$	

Question 2: Hydrogen gas at 2.0 atm and 298 K C is flowing in a two-layered tube of 2.0 mm inside diameter and 4.0 mm outside diameter. Calculate the leakage of hydrogen through a tube 5 m long in kg mol H_2/s at steady state. These layers are arranged as follows:

- Layer-1: vulcanized rubber (inside diameter 2.0-mm and outside diameter 3.0-mm)
- Layer-2: polyethylene (inside diameter 3.0-mm and outside diameter 4.0-mm)

Calculate the leakage of hydrogen through the tube in kg mol H_2/s at steady state.
A related useful formula is given below:

$$\overline{N_A} = \frac{(p_{A1} - p_{A2})}{22.4} \frac{2\pi L}{\left[\frac{\ln(r_2/r_1)}{P_M}\right]}$$

$$\overline{N_A} = \frac{(p_{A1} - p_{A2})}{22.4} \frac{2\pi L}{\left[\frac{\ln(r_2/r_1)}{P_M}\right]} = \frac{(p_{A1} - p_{A2})}{22.4} \frac{2\pi L}{\left[\left\{\frac{\ln(r_2/r_1)}{P_M}\right\}_{rubber} + \left\{\frac{\ln(r_2/r_1)}{P_M}\right\}_{PE}\right]}$$

$$\overline{N_A} = \frac{(2.0 - 0)}{22.4} \frac{2\pi \times 5}{\left[\left\{\frac{\ln(3/2)}{34.2 \times 10^{-12}}\right\}_{rubber} + \left\{\frac{\ln(4/3)}{6.53 \times 10^{-12}}\right\}_{PE}\right]} = \frac{1}{22.4} \frac{2\pi \times 5}{[1.2 \times 10^{10} + 4.4 \times 10^{10}]}$$

$$\overline{N_A} = 2.5 \times 10^{-11} \frac{kgmol}{s}$$

Question 3 (Based on Example in Book):

A tube is coated on the inside with naphthalene and has an inside diameter of 20 mm and a length of 1.1-m. Air at 318 K and an average pressure of 101.3 kPa flows through this pipe at a velocity of 0.80 m/s. The surface temperature of the naphthalene can be assumed to be at 318 K and its vapor pressure at 318 K is 74 Pa = 2.8 $\times 10^{-5}$ $(kg\ mol/m^3)$. The exit concentration is found to be $1.5 \times 10^{-5}\ kg\ mol/m^3$. Assume that the D_{AB} of naphthalene in air at 318 K is 6.92×10^{-6} m^2/s. For air, $\mu = 1.932 \times10^{-5}$ Pa·s, $\rho = 1.114\ (kg/m^3)$.

Using the overall material balance, determine the mass transfer coefficient.

Question 3:

Cross-sectional area of the packed bed,

$$A_C = \frac{\pi}{4}(D_C)^2 = \frac{\pi}{4}(0.02)^2 = 3.14 \times 10^{-4}\ m^2$$

Mass transfer area of tube: $A = \pi D_c L = \pi \times 20 \times 10^{-3} \times 1.1 = 0.0691\ m^2$

Volumetric flow rate in m^3/s: $V = v \times \frac{\pi}{4} D_c^2 = 0.8 \times \frac{\pi}{4}(20 \times 10^{-3})^2 = 2.51 \times 10^{-4}\ \frac{m^3}{s}$

Compute concentrations, $kg\ mol/m^3$

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

$$C_{Ai} = \frac{P_A^0}{RT} = \frac{74}{8314 \times 318} = 2.8 \times 10^{-5}\ kg\ mol/m^3$$

$$C_{A2} = 1.5 \times 10^{-5}\ kg\ mol/m^3$$

Compute molar flow from the mass transfer, N_A, in $kg\ mol/s$

$$N_A A = A k_C (C_{Ai} - C_A)_{LM} = A k_C \frac{C_{A2} - C_{A1}}{ln \frac{(C_{Ai} - C_{A2})}{(C_{Ai} - C_{A1})}} = k_C \times 0.0691\ \times \frac{(1.5 \times 10^{-5} - 0.0)}{ln \frac{(2.8 \times 10^{-5} - 0.0)}{(2.8 \times 10^{-5} - 1.5 \times 10^{-5})}}$$

$$N_A A = k_C \times 0.0691\ \times 1.975 \times 10^{-5}$$

Compute mass transfer rate, N_A, in $kg\ mol/s$ using the material balance,

$$N_A A = V(C_{A2} - C_{A1}) = 2.51 \times 10^{-4}(1.5 \times 10^{-5} - 0) = 3.765 \times 10^{-9}$$

Equating,

$$k_C \times 0.0691\ \times 1.975 \times 10^{-5} = 3.765 \times 10^{-9}$$

$$\boldsymbol{k_C = 2.76 \times 10^{-5}\ m/s}$$

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$$\overline{N_A} = 4.0 \times 10^{-11} \frac{kgmol}{s}$$

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$$N_A A = k_C \times 0.0691\ \times 1.12 \times 10^{-5}$$

Compute mass transfer rate, N_A, in $kg\ mol/s$ using the material balance,

$$N_A A = V(C_{A2} - C_{A1}) = 2.51 \times 10^{-4}(2.5 \times 10^{-5} - 0) = 6.275 \times 10^{-9}$$

Equating,

$$k_C \times 0.0691\ \times 1.12 \times 10^{-5} = 6.275 \times 10^{-9}$$

$$\boldsymbol{k_C = 8.1 \times 10^{-3}\ m/s}$$