TRANSPORT PHENOMENA
(CHEN 4101)

Time Allotted : 3 hrs **Full Marks : 70**

Figures out of the right margin indicate full marks.

Candidates are required to answer Group A and <u>any 5 (five)</u> from Group B to E, taking <u>at least one</u> from each group.

Candidates are required to give answer in their own words as far as practicable.

Group – A
(Multiple Choice Type Questions)

1. Choose the correct alternative for the following: **10 × 1 = 10**

(i) For an unit vector δ_1 along x-direction and δ_2 along y-direction the definition for unit dyad $\delta_1\delta_2$ yields ______________

(a) $\begin{bmatrix} 0 & 1 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{bmatrix}$ (b) $\begin{bmatrix} 0 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 0 \end{bmatrix}$

(c) $\begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 0 \end{bmatrix}$ (d) $\begin{bmatrix} 0 & 1 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 0 \end{bmatrix}$

(ii) Using Von-Karman integral method the thickness of momentum boundary layer is equal to ______

(a) $\frac{4.64}{\sqrt{Re_x}}$ (b) $\frac{2.32}{\sqrt{Re_x}}$ (c) $\frac{1}{\sqrt{Re_x}}$ (d) $\frac{9.28}{\sqrt{Re_x}}$.

(iii) $\vec{\nabla} \times (c\vec{U}) =$ __________, where 'c' is the constant

(a) $c\vec{\nabla} \times \vec{U}$ (b) $c\vec{\nabla} \bullet \vec{U}$

(c) $c \times (\vec{\nabla} \times \vec{U})$ (d) $c \times (\vec{\nabla} \bullet \vec{U})$

(iv) In the modified Reynolds analogy the 'j' factor for mass transfer is equal to

(a) $St_m Sc^{1/3}$ (b) $St_H Sc^{1/3}$

(c) $St_m Sc^{2/3}$ (d) $St_H Sc^{2/3}$.

(v) For fluctuating properties ϕ_1 and ϕ_2, the time averaging of the product of these properties yields __________

(a) $\phi_1^{mean}\phi_2^{mean} + \overline{\phi_1'\phi_2'}$ (b) $\phi_1^{mean}\phi_2^{mean}$

(c) $\overline{\phi_1'\phi_2'}$ (d) $\phi_1^{mean}\phi_2^{mean} + \phi_1'\phi_2'$

(vi) Turbulent energy dissipation function is dependent on ______
(a) gradient of the temperature fluctuation
(b) gradient of the velocity fluctuation
(c) product of gradient of velocity fluctuation
(d) none of above.

(vii) The radius of a capillary tube (length: 0.5 m) is equal to ______ for a Newtonian liquid (density: 955.2 kg/m^3; kinematic viscosity: 4.03 × 10^{-5} m^2/s) flow with mass flow rate of 0.003 kg/s. Pressure drop in the tube: 4.829 x 10^5 Pa.
(a) 7.51 ×10^{-4} m (b) 8.51 × 10^{-4} m
(c) 9.51 ×10^{-4} m (d) 10.51 × 10^{-4} m.

(viii) When vapor condenses on a cooled wall the thickness of the resulting liquid film is ______
(a) directly proportional to the latent heat of condensation of the vapour
(b) inversely proportional to the latent heat of condensation of the vapor
(c) has no relation to latent heat of condensation of the vapour
(d) directly proportional to the square of latent heat of condensation of the vapour.

(ix) The Lennard-Jones potential function is given by ____________, where r is the actual distance between a pair of molecules, σ is the collision diameter and ε is the characteristic energy of the molecules.
(a) $4\varepsilon\left[\left(\frac{\sigma}{r}\right)^6-\left(\frac{\sigma}{r}\right)^{12}\right]$ (b) $4\varepsilon\left[\left(\frac{\sigma}{r}\right)^{12}-\left(\frac{\sigma}{r}\right)^{6}\right]$
(c) $4\varepsilon\left[\left(\frac{\sigma}{r}\right)^3-\left(\frac{\sigma}{r}\right)^{12}\right]$ (d) $4\varepsilon\left[\left(\frac{\sigma}{r}\right)^{12}-\left(\frac{\sigma}{r}\right)^{3}\right]$

(x) For fluids with Pr >1, the temperature boundary layer ______
(a) overlaps with velocity boundary layer
(b) lies outside the velocity boundary layer
(c) lies inside the velocity boundary layer
(d) overlaps with the velocity boundary layer.

Group – B

2. (a) For an irrotational two dimensional flow of a fluid (density ρ) show that the value of the exponent m is equal to either 0 or 1, when $u_x(x,y)=Cx^m$, $u_y(x,0)=0$ and $P(0,0)=P_0$. u_x is the x direction component of velocity u, u_y is the y direction component of velocity u and P is the applied pressure to generate flow.

(b) "No-slip assumption's validity during the formulation of any transport model for a fluid flow inside a conduit depends on the geometry of the conduit." – Justify the appropriateness of the statement.

9 + 3 = 12

3. (a) "In a cartesian coordinate system a scalar, vector and tensor can be represented with 3^0, 3^1 and 3^2 respectively." – Justify the correctness of the statement.

(b) The following data are available for the viscosities of mixtures of hydrogen and Freon-12 (dichlorodifluoromethane) (MW 120.92) at 25°C and 1 atm:

Mole fraction of H_2	0	1
$\mu x 10^6$ (poise)	124	88.4

Find out the viscosity of the mixture, when 50% of hydrogen is mixed with 50% of Freon-12.

3 + 9 = 12

Group – C

4. (a) Applying shell momentum balance, derive Hagen-Poiseuille equation in case of a laminar flow of an incompressible Newtonian fluid in a circular tube.

(b) "The logic behind Reynold's analogy is the similarity between nondimensional form of the convection-diffusion equation for any transport process, when both Pr=1 and Sc=1." – Prove the correctness of the statement.

7 + 5 = 12

5. (a) For the turbulent flow in smooth circular tubes, the function $\frac{\bar{v}_z}{\bar{v}_{z,max}} = \left(1 - \frac{r}{R}\right)^{1/n}$ is sometimes useful for curve-fitting purposes: near Re=4 × 10^3, n=6; near Re=1.1 × 10^5, n=7; and near Re=3 × 10^6, n=10. Show that the ratio of average to maximum velocity is $\frac{\langle \bar{v}_z \rangle}{\bar{v}_{z,max}} = \frac{2n^2}{(n+1)(2n+1)}$.

(b) Show that the time averaging of the product of two properties ϕ_1 and ϕ_2 is given by $\overline{\phi_1\phi_2} = \Phi_1\Phi_2 + \overline{\phi_1'\phi_2'}$, where Φ is the mean component and ϕ' is the fluctuating component of ϕ.

7 + 5 = 12

Group – D

6. (a) Fig. 1 given below shows heat conduction in a finite slab of given dimensions. The thermal conductivity and density of the slab are 0.96 cal/(cm s ^oC) and 8 gm/cc. The slab is initially kept at 20 ^oC.

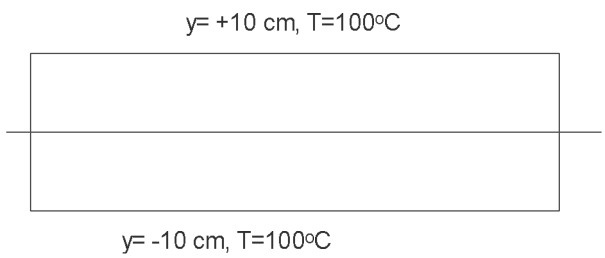

Fig. 1

State the governing equation together with all boundary and initial conditions. Derive the dimensionless form of all equations. Show detailed steps.

(b) Derive the equation for temperature profile as a function of time and space. You are required to determine the temperature profile along the slab at 10s.

4 + 8 = 12

7. Calculate the thermal conductivity of a mixture containing 10 mole % CO_2 and 50 mole % H_2 and the rest Ar at 1 atm and 300K. The following data is given:

Gas	C_p J/(kg K)	μ (Pa s)	κ (W/m K)
H_2	14280	0.8944×10^{-5}	0.1789
CO_2	848	1.506×10^{-5}	0.0166
Ar	520	2.278×10^{-5}	0.01784

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Group – E

8. Cl_2 (A)-air mixture is fed to a chamber filled with cyclohexene (C_6H_{10}) dissolved in CCl_4. It was found that the reaction of Cl_2 with C_6H_{10} is second order with respect to Cl_2 and zero order with respect to C_6H_{10}. Hence the rate of disappearance of Cl_2 per unit volume is $k_2C_A^2$. B is a C_6H_{10} - CCl_4, mixture, assuming that the diffusion can be treated as pseudobinary. Assume that the air is essentially insoluble in the C_6H_{10} - CCl_4, mixture. Let the liquid phase be sufficiently deep that L can be taken to be infinite. Show that the concentration profile is given by $\frac{C_{A0}}{C_A} = \left(1 + \sqrt{\frac{k_2C_{A0}}{6D_{AB}}}z\right)^2$

Explain the significance of Reynolds analogy in transportation of a quantity during fluid flow?

9 + 3 = 12

9. (a) A droplet of liquid A, of radius r_1 is suspended in a stream of gas B. We postulate that there is a spherical stagnant gas film of radius r_2 surrounding the droplet. The concentration of A in the gas phase is x_{A1} at $r = r_1$ and X_{A2} at the outer edge of the film, $r = r_2$. By a shell balance, show that for steady-state diffusion r^2N_{Ar} is a constant within the gas film, and set the constant equal to $r_1^2N_{Ar1}$ at the droplet surface also show that the result leads to the following equation for x_A.

$$r_1^2N_{Ar1} = -\frac{cD_{AB}}{1-x_A}r^2\frac{dx_A}{dr}$$

(b) What is the purpose of calculating mass transfer average velocity in two different ways – one is the mass average velocity and the other one is the molar average velocity?

9 + 3 = 12

Department & Section	Submission Link
CHE	https://classroom.google.com/c/MTIyMDU0NDEwOTE0/a/MjY0MjUxMjQ3Njgw/details