Problems:

1. Consider the one-dimensional mass transfer for a mixture of oxygen (A) and carbon dioxide (B) at 294K and a total pressure of 1.519×10^5 Pa. If $x_A = 0.40$, $v_A = +0.08$ m/s and $v_B = -0.02$ m/s, calculate:

   i. x_B

   ii. $\overline{M}$

   iii. ρ_A, ρ_B, ρ

   iv. c_A, c_B, c

   v. w_A, w_B

   vi. $\vec{u}_A, \vec{u}_B$ 1

   vii. $\vec{U}_A, \vec{U}_B$ 2

   viii. $\vec{\Phi}_A, \vec{\Phi}_B, \vec{\Phi}_A + \vec{\Phi}_B$

   ix. $\vec{\phi}_A, \vec{\phi}_B, \vec{\phi}_A + \vec{\phi}_B$

   x. $\vec{j}_A, \vec{j}_B$

   xi. $\vec{J}_A, \vec{J}_B$

2. A gaseous mixture at 265K and 1.0 atm contains 25% O_2, 60% N_2 and 15% CO_2 (mole basis). The velocities of the components are -0.084 cm/s (O_2), +0.120 cm/s (N_2) and +0.052 cm/s (CO_2). Find the N_2 diffusion velocity relative to the mole-average velocity and the molar diffusional flux of N_2.

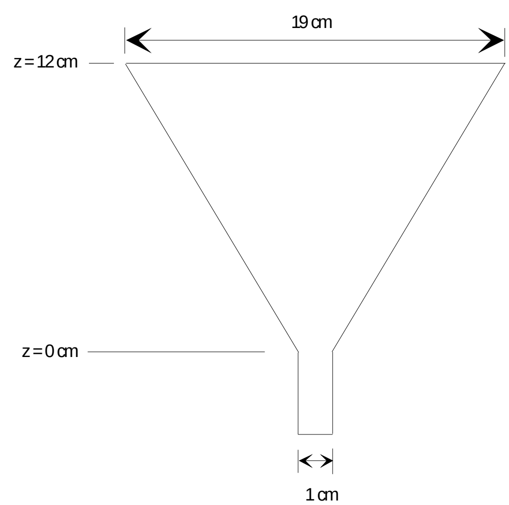
3. At a particular instant in time, the mole fraction of chlorine (C) in air at 1.0 atm and 298 K varies with position z (from 0 to 1 cm) by the following equation:

$$y_C = z^2 - 2z + 1$$

The diffusion coefficient of chlorine in air is 0.10 cm^2/s. If the mole average velocity is equal to zero, determine

i. The concentration of the gas mixture.
ii. The concentration of chlorine at z = 0.4 cm.
iii. The molar diffusional flux of chlorine at z = 0.4 cm. What does the sign indicate?
iv. The velocity of chlorine at z = 0.4 cm.
v. The velocity of air at z = 0.4 cm.
vi. Draw a graph containing chlorine mole fraction as a function of z position. On the same set of axes (but using different scale!) plot the molar diffusional flux as a function of z position. What will the concentration profile of chlorine look like (i.e., sketch) a short time period in the future?

4. Consider a funnel connected by a hose to an external reservoir as shown in the following diagram:



The height (H) of this funnel is 12 cm. At the lower outlet the funnel radius is 1 cm while at the open upper end the radius is 19 cm. The reservoir and funnel contain acetone at 298K so that the level of acetone in the funnel remains 2 cm above the lower end of the funnel (above the neck).

i. Write an expression relating the cross-sectional area of the funnel to the vertical location in the funnel.
ii. Find the steady-state flux of acetone through the top of the funnel, and the concentration profile of acetone in the gas inside the funnel. Plot the gas phase concentration versus height in the funnel. Assume a steady stream of gas B (Air)

flows gently across the open end of the funnel so that the concentration of acetone is essentially zero at the upper opening. The diffusion coefficient of acetone in air at 298K is 0.124 cm^2/s while the molar concentration of acetone is 13.62 mol/l. The gas in equilibrium with pure acetone has an acetone mole fraction of 0.303.

5. A 125 μm polymeric film having an area of 0.2 m^2 separates air from pure O_2, with both gases at 1 atm and 285K. If oxygen has a diffusion coefficient in tis polymeric material of 9.2×10^{-6} cm^2/s, calculate the mass flowrate (mg/min) of oxygen through the surface.

6. A bottle of methanol is spilled in the 25°C lab, and it pools to form a 6 cm diameter circle. Assume that methanol evaporation occurs through a stagnant air layer of 3.5 mm. The diffusion coefficient of methanol in air is 0.164 cm^2/s. What is the mass flowrate (mg/min) of methanol evaporating?

7. Consider the steady-state diffusion of a biological compound (A) into a cylindrical tube containing a flowing liquid. Compound A must diffuse through the tube composed of B. The tube has an inside radius of r_1 and an outside radius of r_2. At $r = r_1$ the mole fraction of A in the fluid is x_{A1}, while at $r = r_2$ this mole fraction is x_{A2}. Assume that Fick's Law applies and the diffusion of A in B is a constant D_{AB}. The particular section of tube to be considered has a length of L. Assume that A does not interact in any way with solid B.

   i. Draw a diagram of the system.
   ii. Use a shell balance to derive a differential equation for the flux of A.
   iii. Use Fick's Law and the equation derived in part b) to derive a second order differential equation for the flux. Use the appropriate boundary conditions to result in an equation for the concentration profile of A in the tube as a function of radius.
   iv. Derive an equation for the total molar flow of A (mol/s) through the section of tubing at $r = r_2$.
   v. You are interested in having ethanol (A) diffuse through an artificial film (B) having OD 8.3 mm and ID 6.1 mm. The lab informs you that ethanol has a diffusivity through B of 4.2 x 10^{-5} cm^2/s. You wish to have a steady-state concentration of ethanol at the outside film no greater than 21 ppm. What is the minimum length of tubing you will need to have a molar flow of ethanol of at least 24 mg/h? Under these conditions plot the concentration profile of ethanol in the film. What is the concentration of ethanol midway through the film?

8. Police detectives enter the residence of a suspect and therein note that the suspect prepared a mug of tea prior to departing. One officer (who successfully completed this course) notes that the 10 cm tall mug is still half filled with tea and that a ring 2 cm below the rim indicates where the liquid level was when evaporation began. When did the suspect last drink from his mug? Compare calculation for assumption of 0% relative humidity in room to assumption of 50% relative humidity in room. (The diffusion coefficient of water in air at 25°C is 2.5×10^{-5} m^2/s)

9. An $L \times L$ square horizontal slab of uniform width H has its lower surface placed in direct contact with the top surface of another slab also of width H. The concentration of solute A at the extreme bottom surface is zero, while the concentration of A at the extreme top surface is C_{AS}. The diffusion coefficient of A in the upper slab is D_{AU} while in the lower slab it is D_{AL}. Assume negligible end effects, and that A remains dilute in the slabs. Find a) an expression for the concentration of A at the contact surface between the slabs (C_A^*) and b) an expression for the flux of A across this surface. c) If D_{AU} is twice the value of D_{AL}, what is the relationship between C_A^* and C_{AS}?

10. There are N films in series with thickness $L_1, L_2, \ldots L_N$ and diffusion coefficients for solute A of $D_1, D_2, \ldots D_N$. Derive the expression for the flux of solute A through these solid films if the concentration difference across the entire series of films is $C_{A0} - C_{AN}$. What is the flux of A if $D_1 = 10^{-5}cm^2/s$, $D_2 = 10^{-6}cm^2/s$, $D_3 = 10^{-7}cm^2/s$, $C_{A0} = 5$ mol/L, $C_{AN} = 0$ mol/L and each of the three films is 1 mm in thickness? Which film imparts the greatest resistance to solute flux?

11. Cellophane is used to keep food moist at 5°C. Calculate the loss of water for a wrapping of 0.10 mm thickness with an area of 0.2 m^2. The water vapor pressure inside the wrapping is 10 mm Hg while the room the food is kept in has a water vapor pressure of 5 mm Hg. Assume a water permeability for cellophane of 1.0×10^{-10} [m^3 water/s·m^2atm/m].