ENGG 201 – Kinetic Theory Flux Examples

Chapter 5 –Example #1 - Mass

A cubical container (1 m wide, 2 m deep, 3 m high) is filled with nitrogen gas at 300K and 1 atm. One wall of the container (2 m by 3 m) is made of a thin semi-permeable plastic sheet, which allows oxygen to pass through. The concentration of oxygen just inside the plastic is 0.01 kmol/m^3, and the diffusivity of oxygen in nitrogen is 1.521x10^{-5}m^2/s.

(a) Use this information to estimate the collision diameter of oxygen ( ).
(b) Calculate the diffusivity of oxygen in nitrogen at 400K and 2 atm (m^2/s).
(c) Calculate the diffusion flux of oxygen through the container (i.e. from the plastic wall to the opposite wall) at 300K and 1 atm (kmol/m^{2}s).
(d) Determine the amount of oxygen that would be transported in 2 h through the plastic at 300K and 1 atm (kg), assuming that the flux remains the same as calculated in c).

Ans. *(a) 3.67* *(b) 1.17x10^{-5}m^2/s* *(c) 1.52x10^{-7}kmol/m^{2}s* *(d) 0.210kg*

$$D_{AA} = \frac{RT}{PN_A \pi \sigma^2}\sqrt{\frac{RT}{\pi M}}$$

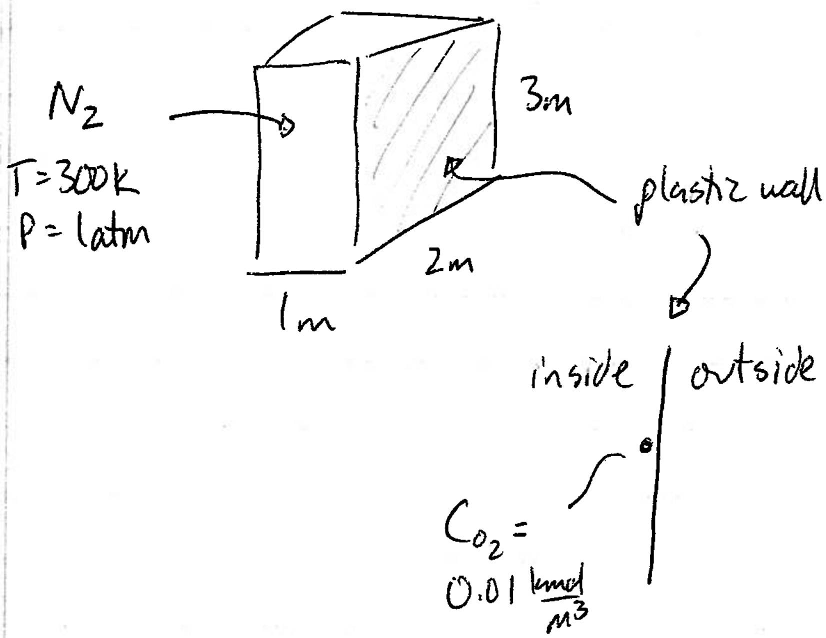
Chapter 5 –Example #2 – Heat

Two infinite slabs are separated by a distance of 10 cm and argon gas (M=39.95 kg/kmol) at low pressure is held between them. One slab is maintained at a constant temperature of 350 K while the other slab is held at 330K. The molecular diameter of the Argon molecule is 3.5 angstroms. Calculate:

(a) The constant volume heat capacity of Argon (in J/mole K).
(b) The thermal conductivity of the Argon (in W/m K) at an average temperature of 340K.
(c) The heat flux (Q/A) occurring between the two slabs using Fourier's Law and an average thermal conductivity as calculated in part (b) above. Report the heat flux in W/m^2.

Ans. *(a) 12.47 J/mol.K* *(b) 8x10^{-3} W/m.K* *(c) 1.6 W/m^2.*

Chapter 5 - Example #1 - Mass Flux



$D_{O_2/N_2} = 1.521 \times 10^{-5}\ m^2/s$

a) $$D = \frac{RT}{P N_A \pi \sigma^2}\sqrt{\frac{RT}{\pi M}}$$

$$1.521\times10^{-5}\,\frac{m^2}{s} = \frac{8.314\,\frac{kPa\,m^3}{kmol\,K}\times 300K}{101.325\,kPa \times 6.023\times10^{26}/kmol \times \pi\,\sigma^2}\sqrt{\frac{(8.314\,\frac{kPa\,m^3}{kmol\,K})(300K)\,1000}{\pi \times 32\,kg/kmol}}$$

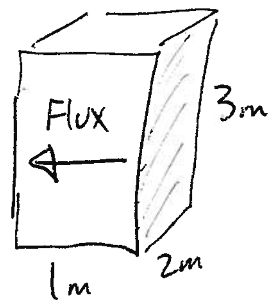
$$\sigma = 3.67\times10^{-10}\,m = \boxed{3.67\,\mathring{A}}$$

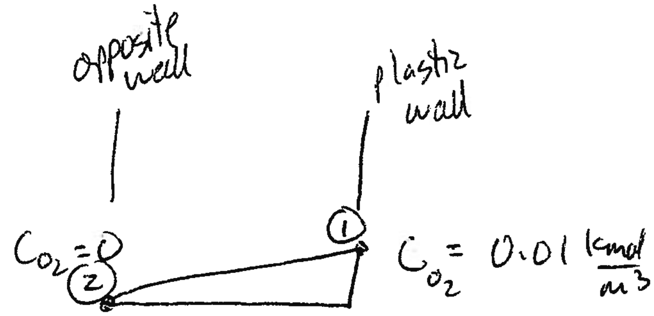
b) $$D \propto \frac{T^{3/2}}{P} \qquad D_1 \propto \frac{T_1^{3/2}}{P_1}$$

$$\frac{D_2}{D_1} = \frac{T_2^{3/2}\,P_1}{T_1^{3/2}\,P_2} = \frac{(400K)^{3/2}}{(300K)^{3/2}}\cdot\frac{101.325\,kPa}{202.65\,kPa} = 0.7698$$

$$D_2 = 1.521\times10^{-5}\,\frac{m^2}{s}\times 0.7698 = \boxed{1.17\times10^{-5}\,m^2/s}$$

c)





$$j_{O_2} = -D_{O_2}\frac{dC}{dx} = -D_{O_2}\frac{\Delta C}{\Delta x} = -D_{O_2}\frac{C_2 - C_1}{X_2 - X_1}$$

$$j_{O_2} = -1.521\times10^{-5}\ \frac{m^2}{s} \times \frac{0 - 0.01\ kmol/m^3}{1\ m}$$

$$\boxed{j_{O_2} = 1.521\times10^{-7}\ kmol/m^2 s}$$

d) $j_{O_2} = \dfrac{n}{At} \longrightarrow n = j_{O_2} A t$

$$n = \left(1.521\times10^{-7}\ \frac{kmol}{m^2 s}\right)(6\ m^2)\left(24\times3600\ \frac{s}{h}\right)$$

Flux area $= 2\times3m$
$= 6m^2$

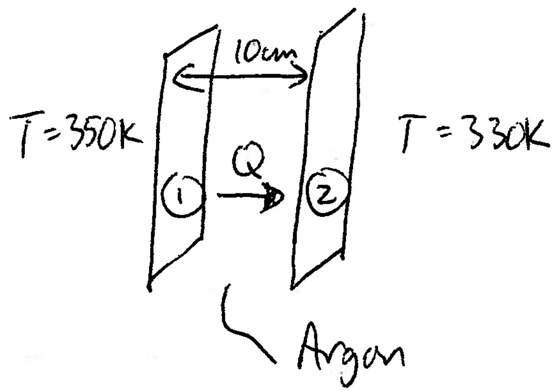
$$n = 6.57\times10^{-3}\ kmol$$

$$m = nM$$

$$m = 6.57\times10^{-3}\ kmol \times 32\ \frac{kg}{kmol}$$

$$\boxed{m = 0.210\ kg}$$

Chapter 5 - Example #2 - Heat Flux



$\sigma = 3.5 \times 10^{-10} m$

$M = 39.95$

a) $C_v = \frac{3}{2} R$ for ideal gas

$$C_v = \frac{3}{2}\, 8.314\ kJ/kmol\,K = \boxed{12.471\ kJ/kmol\,K}$$

b) $$k = \frac{C_v}{N_A \pi \sigma^2}\sqrt{\frac{RT}{\pi M}}$$

$$k = \frac{12.471\ kJ/kmol\,K}{6.023 \times 10^{26}/kmol \times \pi \times (3.5 \times 10^{-10} m)^2}\sqrt{\frac{8.314 \frac{kPa\, m^3}{kmol\, K} \times 340K \times 1000}{\pi \times 39.95\ kg/kmol}}$$

$$k = 8.07 \times 10^{-6}\ kJ/mKs = \boxed{8.07 \times 10^{-3}\ W/mK}$$

c) $$\frac{Q}{A} = -k\frac{dT}{dx} = -8.07 \times 10^{-3} \frac{W}{mK}\ \frac{330K - 350K}{10 \times 10^{-2} m}$$

$$\boxed{\frac{Q}{A} = 1.61\ \frac{W}{m^2}}$$