ENGG 201 W2016 – Ch 5 Example Problems – Kinetic Theory

W2003 Midterm - Question Number V *(25 Marks ~ 20 minutes)*

At low pressures and high temperatures, nitrogen (M_{N2}=28 kg/kmol) can be assumed to behave like an ideal gas.

a) What is the velocity that the highest number of nitrogen molecules would be expected to be traveling at if the conditions are 250°C and 2 bars? *(/4)*
b) What is the root mean square velocity of nitrogen molecules at 250°C and 2 bars? *(/4)*
c) What is the mean separation distance between nitrogen molecules at 250°C and 2 bars? *(/4)*
d) If the viscosity of nitrogen is $5x10^{-5}$ Pa.s at 250°C and 2 bars, what would the viscosity be at 500°C and 4 bars? *(/4)*
e) Using the information in (d), what is the collision diameter of a nitrogen molecule? *(/4)*
f) What would be the force pushing on the inside surface of a spherical 1 m diameter balloon filled with nitrogen at 500°C and 4 bars? *(/5)*

W2015 Midterm Question Number II *(25 Marks ~ 30 minutes)*

Part A (/12)
A rigid container of 50 m^3 volume contains CO_2 gas (MW = 44 kg/kmol) at a temperature of 0^oC and pressure of 101 kPa. Assume the CO_2 collision diameter is 3 Å and CO_2 behaves as an ideal gas.

a) What is the density of CO_2 gas? (/4)
b) What is the constant pressure specific heat capacity (C_P) of the CO_2 gas at these conditions? (/2)
c) What is the thermal conductivity (k) of the CO_2 at these conditions? (/3)
d) What is the ratio of the viscosity (μ) of CO_2 at these conditions (0^oC and pressure of 101 kPa) to the viscosity at the same pressure but an elevated temperature (20^oC)? (/3)

Part B (/13)
A closed standard house room (dimension H,W and L: 3m x 3m x 3m) initially holds fresh air at 23^oC. You can assume that air is a single ideal gas component. One of the internal walls is coated with a substance that releases phosphine gas, PH_3 (Molar mass M= 34 kg/kmol). The initial concentration of the gas source at the wall surface is measured to be 100 ppm (mg phosphine/L). The wall opposite the phosphine source has a window with a small crack such that the rate of phosphine leaking out of the room does not result in a buildup in the room.

a) The diffusivity of phosphine gas in the air at room conditions is equal to D = 0.381 cm^2/s. Calculate the initial flux of phosphine gas (away from the wall releasing the gas) (kmol/m^2.s). (/6)
b) If the leak in the window is blocked, assuming the initial rate remains constant, find the time in hours at which the concentration of the phosphine gas will become 0.3 ppm in the above mentioned room (3m x3m x 3m). This concentration is the safe limit for domestic use of the room. (/7)

FORMULA SHEET

Constants / Conversions

$R = 8.314\frac{kPa.m^3}{kmol.K} = 8.314\frac{J}{mol.K}$ $N_A = 6.023x10^{26}\frac{molecules}{kmol}$ $g = 9.81 m/s^2$

$101.325\ kPa = 1\ atm$ $1\ bar = 100\ kPa$ $1\ L = 1000\ cm^3$

Geometric Shapes

$V_{sphere} = \frac{4}{3}\pi r^3$ $SA_{sphere} = 4\pi r^2$ $V_{cylinder} = \pi r^2 h$

Ideal Gas

$Pv = nRT$

Kinetic Theory of Gases

$c_{mp} = \sqrt{\frac{2RT}{M}}$ $\sqrt{\overline{c^2}} = \sqrt{\frac{3RT}{M}}$ $\bar{c} = \sqrt{\frac{8RT}{\pi M}}$

$P = \frac{N_A m\overline{c^2}}{3V_m}$ $E_k = \frac{1}{2}m\overline{c^2}$ $k = \frac{R}{N_A}$

$\lambda = \frac{1}{\sqrt{2}\pi\sigma^2\rho_N}$ $\delta = \left[\frac{kT}{P}\right]^{1/3}$ $\rho_N = \frac{N_A}{V_m} = \frac{P}{kT}$

Kinetic Theory of Gases - Transport Properties

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

$\mu = \frac{\rho_N\bar{c}\lambda m}{2}$ $\kappa = \frac{\lambda\rho_N\bar{c}}{2}\frac{C_v}{N_A}$

$F/A = -\mu\frac{du}{dz}$ $Q/A = -\kappa\frac{dT}{dz}$ $j_A = -D\frac{dC}{dz}$

$C_v = \frac{3}{2}R$ $C_p = \frac{5}{2}R$ $C_p = C_v + R$