CHM 3400 – Problem Set 1
Due date: Wednesday, January 15th.

Do all of the following problems. Show your work. Note the following constants and conversion factors.

1 L = 1 dm^3 = 1000 cm^3 = 1000 mL (exact)	R = 0.082057 L•atm/mol•K
1 m^3 = 1000 L (exact)	R = 8.3145 J/mol•K
1 atm = 1.01325 bar = 1.01325 x 10^5 Pa = 760 torr (exact)	k = 1.3806 x 10^{-23} J/K
1 bar = 10^5 Pa = 10^5 Nt/m^2 (exact)	N_A = 6.0221 x 10^{23} molecule/mol

"Jumpin' Jack Flash, it's a gas gas gas" – Mick Jagger, Keith Richards

1) For Mars, the pressure and temperature of the atmosphere at surface level is p = 610. Nt/m^2 = 610. Pa, and T = 215. K. Under these conditions we can assume the ideal gas law applies.

a) What is the molar density of the Martian atmosphere at the surface of Mars? Give your final answer in units of mol/m^3.

b) The number density of molecules in a gas (ρ_N) is defined as

$$\rho_N = \frac{N}{V} = \frac{\text{number of molecules}}{\text{volume}} \qquad (1.1)$$

ρ_N represents the number of gas molecules per unit volume of the gas. ρ_N is usually given in units of molecules/cm^3, although other units can be used.

Based on your answer to part a, find ρ_N for the atmosphere of Mars at the surface of the planet. Give your final answer in units of molecules/cm^3.

c) The atmosphere of Mars is to a first approximation a mixture of carbon dioxide, nitrogen, and argon, with trace amounts of other gases. If we ignore the trace gases, the mole fractions of CO_2, N_2, and Ar in the atmosphere of Mars are (along with the molecular masses)

X_{CO2} = 0.955	X_{N2} = 0.026	X_{Ar} = 0.019
M_{CO2} = 44.01 g/mol	M_{N2} = 28.01 g/mol	M_{Ar} = 39.95 g/mol

Based on your answer to part a and the information above (and assuming Dalton's Law is correct), find the density by mass of the Martian atmosphere at surface level. Give your final answer in units of g/m^3. (Note that density by mass for a gas is often given in units of kg/m^3. We use units of g/m^3 here because of the low value for density compared to that for the sea level density of the Earth's atmosphere.)

2) The element chlorine has two naturally occurring isotopes, ^{35}Cl (m = 34.969 amu) and ^{37}Cl (m = 36.965 amu). The density of a sample of chlorine gas (Cl_2), measured at p = 1.0000 torr, T = 273.15 K, is D = 4.168 x 10^{-3} g/L. Assuming that chlorine gas obeys the ideal gas law, find the percent by number (related to the mole fraction) of chlorine atoms that are the ^{35}Cl isotope, and the percent that are the ^{37}Cl isotope.

3) A 1.640 L gas cylinder contains 158.3 g of carbon monoxide (CO, MW = 28.01 g/mol) at a temperature T = 22.0 °C. Find the following

a) The value for pressure for the gas, using the ideal gas law. Give your final answer in units of atm.

b) The value for pressure for the gas, using the van der Waals equation, For CO, a = 1.453 L^2•atm/mol^2, b = 0.0395 L/mol. Give your final answer in units of atm.

c) Which value for pressure do you expect to be closer to the actual pressure of carbon monoxide in the gas cylinder? Why?

4) The values for the critical pressure (p_c), critical molar volume ($V_{m,c}$) and critical temperature (T_c) for a gas can be estimated from the van der Waals a and b coefficients using the relationships

$$p_c = \frac{a}{27b^2} \qquad V_{m,c} = 3b \qquad T_c = \frac{8a}{27bR} \qquad (4.1)$$

a) What is the physical significance of T_c, the critical temperature, for a real gas?

b) Using the relationships in equn 4.1, find the values for p_c, $V_{m,c}$, and T_c for carbon monoxide (Note that values for the van der Waals coefficients for carbon monoxide are given in problem 3). Give your final answers in units of atm (for p_c), cm^3/mol (for $V_{m,c}$) and K (for T_c).

c) The experimental values for the critical constants for carbon monoxide are p_c = 34.6 atm, $V_{m,c}$ = 93.0 cm^3/mol, and T_c = 134.4 K. How well do the values found using equn 4.1 agree with the experimental values for the critical constants.

5) The collision cross section for an air molecule is σ = 0.42 nm^2. Use MW = 29.0 g/mol for the molecular mass of an air molecule. Find the following for a sample of air at p = 1.00 atm and T = 288. K.

a) d, the diameter of an air molecule (which corresponds to the size of an air molecule). Use the relationship $\sigma = \pi d^2$. Give your final answer in units of nm.

b) v_{rms}, the root mean square average speed of a molecule of air in the sample, given by the equation

$$v_{rms} = (3RT/M)^{1/2} \qquad (5.1)$$

Give your final answer in units of m/s.

c) λ, the mean free path of an air molecule, which represents the average distance the molecule travels between collisions. λ is given by the relationship

$$\lambda = \frac{kT}{2^{1/2}\sigma p} \qquad (5.2)$$

Give your final answer in units of nm.

d) z, the average number of collisions for a molecule of air, given by the relationship

$$z = \frac{2\sigma p}{kT} (8RT/\pi M)^{1/2} \qquad (5.3)$$

Give your final answer in units of collisions/s.