CH353 – Physical Chemistry I
Spring 2013, Unique 52575

Exam 1 – January 25, 2013

Name: Key

Always assume ideal gas unless directed otherwise.

You may use any material that does not have a heartbeat and does not connect to the internet or cellular network.

Honor Code:

"The core values of the University of Texas at Austin are learning, discovery, freedom, leadership, individual opportunity, and responsibility. Each member of the University is expected to uphold these values through integrity, honesty, trust, fairness, and respect toward peers and community."

I certify that the work on this exam is entirely my own.

Signature Date

1. (20 points) Determine if the following statements are true or false.

a. True **(False)** All gasses are ideal in the limit of high pressure.

b. True **(False)** Induced-dipole intermolecular forces are most important when two species are far apart (i.e. at large values of r).

c. True **(False)** If two molecules carrying a permanent dipole moment approach each other in the gas phase, they will spontaneously align so that their dipole moments are pointed in the same direction.

d. True **(False)** A van der Waals gas that is dominated by attractive intermolecular forces at low pressure will be dominated by attractive intermolecular forces at all pressures.

e. True **(False)** 10 g of hydrogen gas contains more hydrogen atoms than 100 g of water.

f. **(True)** False Attractive intermolecular forces will reduce the pressure of a gas compared to the value predicted from the ideal gas law.

2. (15 points) Atmospheric air is approximately 80% $N_2(g)$ and 20% $O_2(g)$.

a) Determine the density (in units of g mL^{-1}) of dry air at sea level and room temperature (1.0 atm and 25°C).

Assume $V = 1 mL$

$P = 1.0 atm$

$T = 298 K$

$n = \frac{PV}{RT} = \frac{(1.0 atm)(0.001 L)}{(0.082 L\,atm/mol\,K)(298 K)}$

$n = 4.09 \times 10^{-5} mol$

$FW = 0.8(28 g/mol) + 0.2(32 g/mol) = 28.8 g/mol$

$m = n(FW)$

$= (4.09 \times 10^{-5} mol)(28.8 g/mol)$

$m = 0.0012 g$

$\boxed{\rho = 0.0012 g/mL}$

b) Determine the density (in the same units and under the same conditions) of air that is 20% water vapor (i.e. atmosphere of 20% humidity). Be explicit about what assumptions you are making.

Assume H_2O displaces $N_2 + O_2$ in the same ratio:

N_2: $80\% - 0.2(80\%) = 64\%$

O_2: $20\% - 0.2(20\%) = 16\%$

H_2O: 20%

100%

$FW = (0.64)(28 g/mol) + (0.16)(32 g/mol) + (0.2)(18 g/mol)$

$FW(\text{humid air}) = 26.6 g/mol$

→

Everything else is the same: $P = 1.0\,atm$

$T = 298\,K$

$V = 1\,mL$

$\Rightarrow n = 4.09 \times 10^{-5}\,mol$

$\Rightarrow m = (4.09 \times 10^{-5}\,mol)(26.6\,g/mol)$

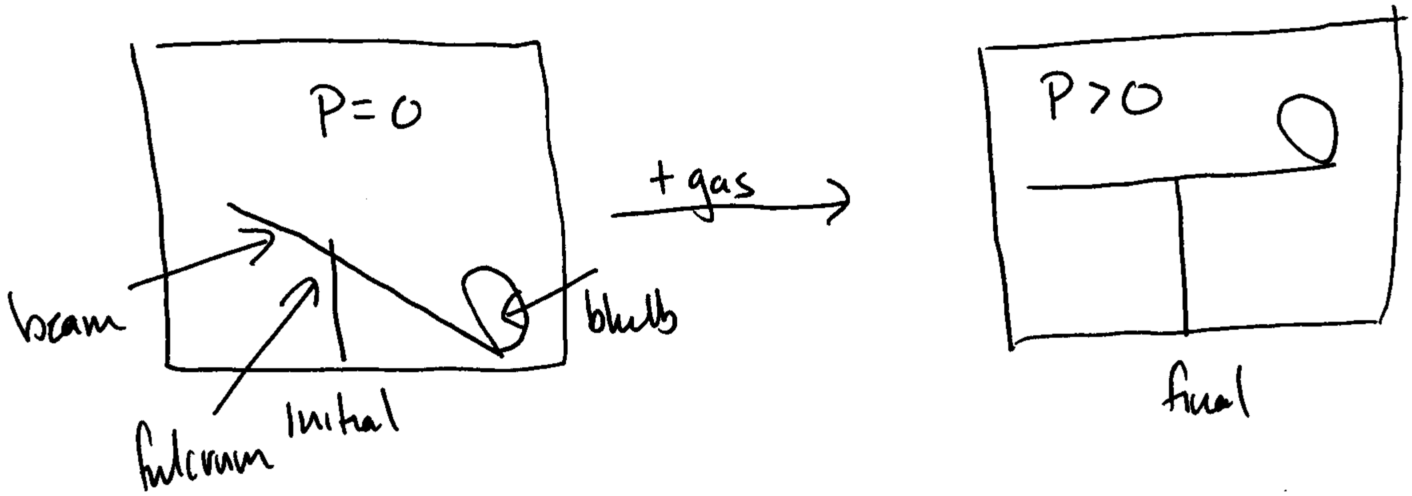
$m = 0.0011\,g$

$$\rho = \frac{m}{V} = 0.0011\,g$$

Humid air is <u>less</u> dense than dry air because H_2O is lighter than either the N_2 or O_2 that it displaces.

3. (30 points) A gas microbalance is a device for measuring the molecular weight of gasses. In a gas microbalance, a glass bulb containing a standard gas sits on one end of a beam, which itself sits on a fulcrum. The beam is enclosed in a vessel with rigid walls, and when the vessel is evacuated the end of the beam containing the glass bulb rests on the bottom of the vessel. As the gas being measured is slowly introduced into the vessel, the buoyancy of the glass bulb increases, and the beam pivots on the fulcrum until it reaches a level balance point.

a) Draw the initial and final states of the gas microbalance described above.



b) To calibrate the balance, CHF_3 gas was pumped into the vessel until the balance point was reached at 0.557 atm. An unknown fluorocarbon gas ($C_xH_yF_z$) gas was then pumped into the vessel, and the balance point of the beam was reached at a pressure of 0.430 atm. What is the molar mass of the unknown fluorocarbon gas and what is a possible molecular formula?

$FW(CHF_3) = 70\,g/mol$

$P(CHF_3) = 0.557\,atm$

$P(unknown) = 0.430\,atm$

$FW(unknown) = ?$

mass of displaced bulb $= \rho V$

V = volume of bulb

ρ = density of gas

Same for any gas

$\rho(CHF_3) = \rho(unknown)$; $\rho = \frac{P(FW)}{RT}$

$$\frac{P(CHF_3)\,FW(CHF_3)}{RT} = \frac{P(unknown)\,FW(unknown)}{RT}$$

$$FW(unknown) = \frac{P(CHF_3)\,FW(CHF_3)}{P(unknown)} = \frac{(0.557\,atm)(70\,g/mol)}{0.430\,atm}$$

FW(unknown) = 90.7 g/mol **C_3HF_3 is possible**

4. (15 points) Calculate the pressure of $CO_2(g)$ behaving as a van der Waals gas at a pressure of 300 atm and 900 K. Is CO_2 behaving as an ideal gas under these conditions, and if not, what are the dominant intermolecular forces? (Be specific – not just attractive or repulsive, but what is the physical mechanism at work?)

Ideal:

$P_{ideal} = 300\,atm$

$T = 900K$

$a = 3.640\ L^2 atm/mol^2$

$b = 0.042674\ L/mol$

Assume 1 mol

$PV_m = RT$

$V_m = \frac{(0.0821\ L\,atm/mol\,K)(900K)}{(300\ atm)}$

$V_m = 0.2463\ L/mol$

vdW:

$P_{vdw} = \frac{RT}{V_m - b} - \frac{a}{V_m^2}$

$P_{vdw} = \frac{(0.0821\ L\,atm/mol\,K)(900K)}{(0.2463\ L/mol - 0.042674\ L/mol)} - \frac{3.640\ L^2 atm/mol^2}{(0.2463\ L/mol)^2}$

$P_{vdw} = 302\ atm$

$P_{ideal} \neq P_{vdw} \Rightarrow CO_2 \neq$ ideal

$P_{vdw} > P_{ideal} \Rightarrow CO_2$ dominated by repulsive forces

CO_2 has no permanent dipole and no coulombic interactions, so only intermolecular forces at play are:

induced dipole $\propto -1/r^6$

repulsive $\propto 1/r^{12}$ → dominating force

5. (20 points) A mixture of 12.0 moles of an unknown gas and 15.5 moles of $O_2(g)$ is held in a rigid container at 3.0 atm. A thermostat is used to maintain the temperature of the system at 300 K. The unknown gas begins to decompose to form 2 moles of gaseous product. When 4.8 moles of the unknown gas remain, what is the partial pressure of $O_2(g)$?

The partial pressure of O_2 doesn't change because its total # of moles and volume don't change.