1. (20 points)

In the synthesis of carbon black, gaseous methane (diluted in argon) reacts with a hot surface at a temperature $T_s$ leaving behind pure solid carbon (C) and releasing two hydrogen molecules ($H_2$). If the number density of the $CH_4$ adjacent the heated surface is $n_{CH_4}^0$, and if the methane reacts with unity probability, estimate the deposition rate (Kg/m$^2$/s) of carbon.

Useful process data: $n_{CH_4}^0 = 10^{22}$ m$^{-3}$  
$T_s = 1200$K  
$m_{CH_4} = 2.66 \times 10^{-26}$ Kg  
$m_{H_2} = 3.34 \times 10^{-27}$ Kg

2. (40 points)

Consider the reactions between molecular hydrogen and oxygen used to power the space shuttle main rocket engine:

$$2H_2 + O_2 \leftrightarrow 2H_2O$$

Thermochemical data for the three species involved are given below.

(i) How much heat (calories) is released per mole of molecular oxygen consumed if this reaction proceeds at $T = 2000$K and a constant pressure $P = 1$ atm?

(ii) In which direction does this reaction shift with increasing pressure?

(iii) In which direction does this reaction shift with increasing temperature?

(iv) Assuming initial number of moles as follows: $\hat{N}^o_{O_2} = 1$, $\hat{N}^o_{H_2} = 2$, $\hat{N}^o_{H_2O} = 0$, express the Law of Mass Action in terms of the degree of advancement in equilibrium, $\xi^*$.

Useful Thermochemical data: (T=2000K)

$$\Delta \hat{H}_{f_{O_2}} = -122,037 \text{ cal/mole}, \quad \log_{10} Kp_{f_{O_2}} = 6.355$$

$$\Delta \hat{H}_{f_{H_2}} = -108,449 \text{ cal/mole}, \quad \log_{10} Kp_{f_{H_2}} = 5.581$$

$$\Delta \hat{H}_{f_{H_2O}} = -229,596 \text{ cal/mole}, \quad \log_{10} Kp_{f_{O_2}} = 12.299$$
Each question is worth 10 points.

1. Molecules of mass \( m = 10^{-25} \) Kg are created in a chamber (by means of some chemical reaction) with a speed (independent of direction) of \( c_0 = 1000 \) m/s. Determine the temperature of the molecules after equilibrium is reached by means of molecular collisions.

\[
T = \text{______________K}
\]

2. A cell contains a mixture of argon and helium, initially of equal concentrations. A small hole is made in the side of the cell (Kn >>1) allowing some gas to escape.

(a) After some time, the cell contains: _____ more helium than argon

_____ less helium than argon

(b) Initially, what species contributes more to the energy flux through the hole?:

___ helium

___ argon

(c) Initially, the momentum flux carried by the helium is _____ greater than for argon

_____ less than for argon

_____ the same as argon

3. Consider the hydrazine decomposition reaction:

\[
M + H_2N_2 \leftrightarrow M + H_2 + N_2
\]

(a) Write the Law of Mass Action for this equilibrium in terms of the species mole fractions, and total pressure \( P \).

(b) Express the equilibrium constant, \( K_p \), in terms of the equilibrium constants for the formation reactions for the species involved in the above reaction.

\[
K_p =
\]

4. (a) Write down an expression for the sensible enthalpy (mole basis) of species \( j \)

\[
\hat{h}_{sens,j} =
\]

(b) What is \( \Delta \hat{H}_T \) (in words)?

(c) Write down the relationship between the chemical potential at reference pressure, the sensible enthalpy, the heat of formation, and the entropy.

\[
\hat{\mu}_j =
\]