Problem 1(20%)

(a) A small adiabatic air compressor is used to pump air into a 10 m^3 insulated tank. The tank initially contains air at 25 ˚C and 101.33 kPa, exactly the conditions at which air enters the compressor. The pumping process continues until the pressure in the tank reaches 1000 kPa. If the process is adiabatic and if compression is insentropic, what is the shaft work of the compressor? Assume air to be an ideal gas for which C_p=(7/2)R and C_v=(5/2)R. (10%)

(b)Suppose that an internal combustion engine runs on octane, for which the enthalpy of combustion is -3328 $kJmol^{-1}$. What is the maximum height, neglecting all forms of friction, to which a car of mass 1000 kg can be driven on 1.00 litter of octane. Given that the engine cylinder temperature is 2000 ˚C and the exit temperature is 1000 ˚C. (density of octane:0.703 g/mL) (10%)

Problem 2(20%)

(a) (4%) Derive the Gibbs-Duhem equation for two-component mixtures. State clearly any assumptions made. What is the physical meaning of the Gibbs-Duhem equation?
(b) (3%) On the basis of (a), derive the Gibbs-Duhem-Margules equation that $(\partial \ln f_A/\partial \ln x_A)_{p,T} = (\partial \ln f_B/\partial \ln x_B)_{p,T}$ where f denotes the fugacity and x the mole fraction whereas subscripts A and B denote the two components, respectively.
(c) (3%) On the basis of (b), show that if Raoult's law applies to one of the two components in the mixture, it must also apply to the other component.
(d) (3%) What is your physical interpretation of the statement in (c)?
(e) (4%) Derive the well-known Phase Rule of Gibbs that $F = C - P + 2$ where F denotes the degree of freedom and C the number of components. State clearly any assumptions made.
(f) (3%) Could there be cases where the Phase Rule needs to be modified? Explain.

Problem3(20%)

(a) One mole of gas A will dissociate into 1 mole of gas B and and 1 mole of gas C. Pure A was put into a closed vessel kept isothermal at 298 K. The initial pressure is 1 atm. After a long time to ensure that equilibrium had been reached, analysis of the content in the vessel showed that the concentration of A was 25mol%. Calculate

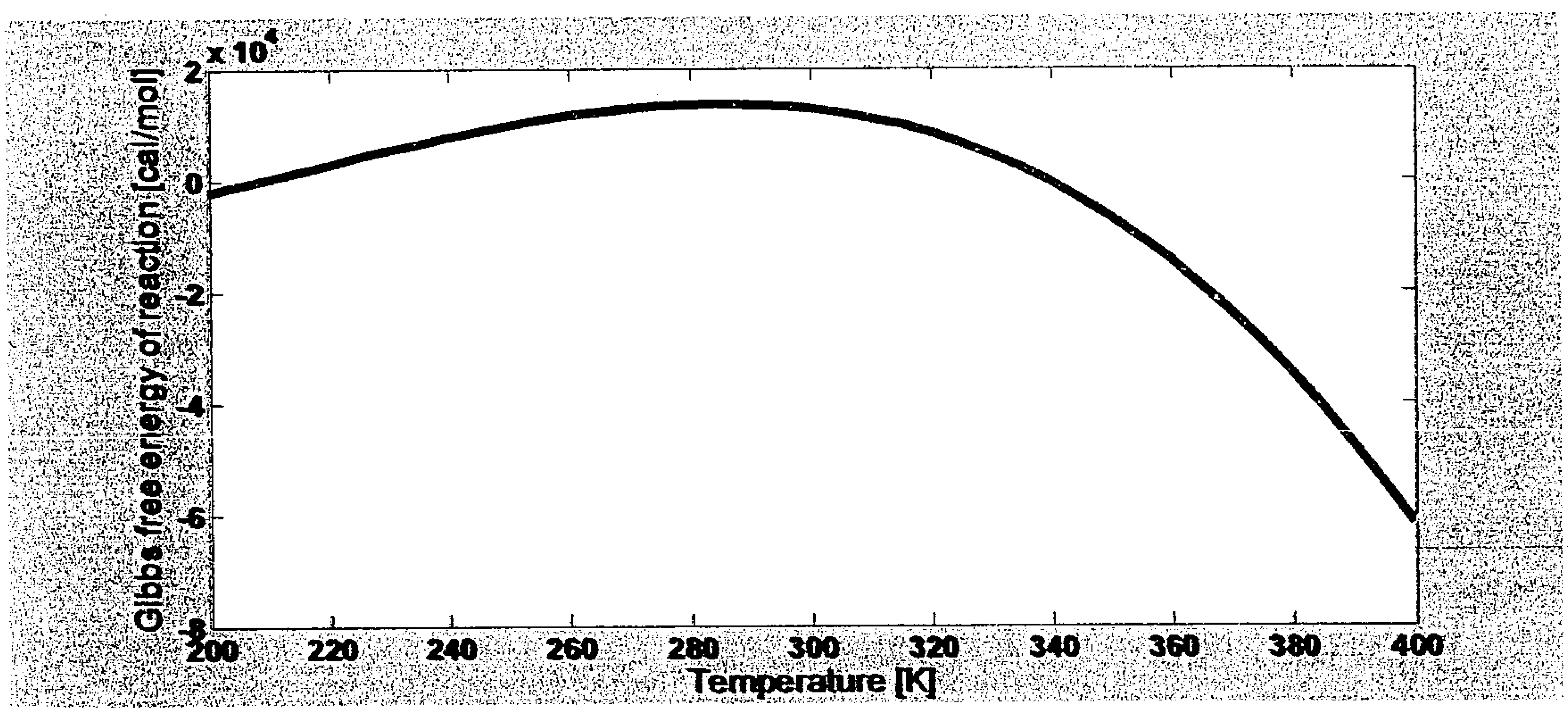
- (2%) the fraction of A that has dissociated at equilibrium,
- (2%) the extent of reaction,
- (2%) the equilibrium pressure of the vessel,
- (2%) the equilibrium constant of the reaction at 298 K, and
- (2%) the standard Gibbs free energy of reaction.

(b) The denature of protein P in water can be described by the reaction: $P_N \leftrightarrow P_D$. P_N denote the natural state, and P_D is denatured state. The free energy of the reaction is given by the following equation

$$\Delta G^{o}_{rxn}=127100-2248*T+11.57*T^2-0.01783*T^3 \ \frac{cal}{mol}$$

The plot of ΔG^{o}_{rxn} versus T is given in the following figure.

- Will the protein denature at
  - (2%) 250 K,
  - (2%) 300 K, and
  - (2%) 350 K?
- (4%) Will the heat of reaction at 300 K be much greater than zero, close to zero, or much less than zero



Problem4(20%)

(a) In continuous-flow reactors under steady state,

- (5%) what are the definition and physical meaning of Da (Damköhler number)?
- (5%) How to use this parameter to estimate the conversion for a first-order irreversible reaction in a CSTR? (5%)

(b) There is a series reaction, $A \xrightarrow{k_1} R \xrightarrow{k_2} S$, in two equal-sized CSTRs in series, which are operated isothermally under steady state. If $k_1 = k_2 = 1$ meanwhile τ and $C_{A,0}$ indicate the space time and initial concentration of A,

- (5%) please show how to find the maximal concentration of R, and
- (5%) what is the maximal concentration of R?

Problem5(20%)

(a) (12%) The elementary liquid-phase reaction

$$A + 2B \underset{k_2}{\overset{k_1}{\rightleftharpoons}} R$$

with rate equation

$$-r_A = -\frac{1}{2} r_B = 12.5 \frac{liter^2}{mol^2 min} C_A C_B^2 - 1.5 \frac{1}{min} C_R \qquad \left[\frac{mol}{liter \cdot min}\right]$$

is to take place in a *6*-liter steady state mixed-flow reactor. Two feed streams, one containing *1.2 mol/liter* of A and another containing *2.8 mol/liter* of B are to be introduced into the reactor, and 50% conversion of the limiting reactant is desired. What should be the flow rates going into the reactor? Assume a constant density through

(b) (8%) The reactor setup in the following figure consists of three plug-flow reactors in two parallel branches. Branch D has a reactor of 50 liters followed by a reactor of 30 liters. Branch E has a reactor of 40 liters. What fraction of the feed should go into branch D.