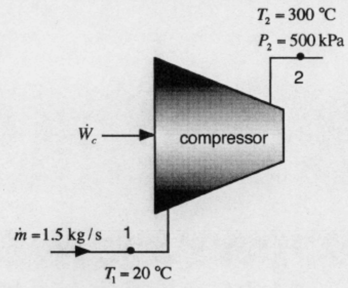
Midterm II



1. Air flows at a steady rate of 1.5 kg/s through a compressor. The inlet temperature at 1 is 20 °C. At the exit location 2, the temperature is 300 °C and the pressure is 500 kPa. The pressure at 1 is unknown, due to an instrumentation failure. The compressor operates adiabatically and has an efficiency of 0.8. In analyzing this system, treat air as an ideal gas with constant specific heats: $c_p = 1.005$ kJ/kgK, $c_v = 0.780$ kJ/kgK.

(a) What is the input power to the compressor?
(b) What would the temperature at 2 be if the compressor were reversible and adiabatic?
(c) What is the inlet pressure at 1?

(a) SSSF: $\overset{0}{\dot{W}_c} = \dot{m}(h_1 - h_2) = \dot{m}\, c_p (T_1 - T_2) = 1.5(1.005)(20-300)$

$\dot{W}_c = -422.1$ kW

(b) $\eta = \dfrac{\dot{W}_{c,i}}{\dot{W}_c} = \dfrac{\dot{m} c_p (T_1 - T_{2,i})}{\dot{m} c_p (T_1 - T_2)} \rightarrow \eta(T_1 - T_2) = T_1 - T_{2,i}$

$\rightarrow T_{2,i} = T_1 - \eta(T_1 - T_2) = 20 - .8(20-300) = 244$°C

(c) $P_1 = P_2 \left(\dfrac{T_1}{T_{2,i}}\right)^{k/(k-1)} = 500\left(\dfrac{293}{244+273}\right)^{1.29/.29} = 39.4$ kPa.

2. The corresponding standard free energy change is indicated to the right of the two reactions below

glucose 6-phosphate → fructose 6-phosphate $\Delta G'^\circ = 1.7$ kJ/mol
glucose 6-phosphate → glucose 1-phosphate $\Delta G'^\circ = 7.3$ kJ/mol

Use this information to calculate the equilibrium constant K'_{eq} for the reaction

fructose 6-phosphate → glucose 1-phosphate

↳ equivalent to the reverse of (1) followed by (2)

$\Rightarrow \Delta G'^\circ = -1.7 + 7.3 = 5.6$ kJ/mol $= 5600$ J/mol

$K'_{eq} = e^{-\Delta G'^\circ/\bar{R}T} = \exp\{-5600/(8.315 \cdot 298)\} = 0.104$

3. Consider the chemical reaction

$$2A + B \rightleftarrows C$$

which occurs at biochemical standard conditions. The change in free energy for the reaction is $\Delta G'^{\circ} = -20.2$ kJ/mol. In this reaction, the reactants form the activated complex A_2B^* at the transition state.

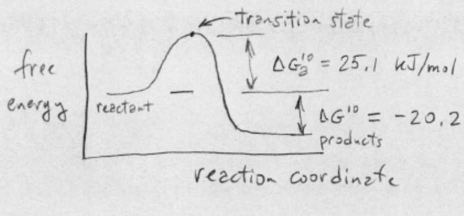
$$2A + B \rightleftarrows A_2B^*$$

When the reactants form the transition state complex, the entropy decreases by 0.033 kJ/(mol K) and the enthalpy increases by 15.3 kJ/mol.

(a) Determine the free energy change associated with the formation of the transition state. Draw the free energy vs. reaction coordinate diagram for this reaction and indicate the changes in free energy associated with formation of the transition state and the products.

(b) Assuming that the Arrhenius model for the rate constant applies, determine the factor by which the reaction rate will increase if the concentration of A triples and the temperature is increased by 30 °C.

(a) $\Delta G_a'^{\circ} = \Delta H_a'^{\circ} - T\Delta S_a'^{\circ} = 15.3 - 298(-.033) = 25.1$ kJ/mol



(b) $J = k' e^{-\Delta G_a'^{\circ}/RT} [A]^2[B]$

$$\frac{J_{new}}{J_{old}} = \frac{e^{-25{,}100/(8.315 \cdot 328)}}{e^{-25{,}100/(8.315 \cdot 298)}} \cdot \frac{(3[A]_{old})^2}{[A]_{old}^2} = 22.7$$

4. Consider the chemical reactions below that occur in a system at biochemical standard conditions (note the indicated standard free energy change for each):

(i)	$2A + B \rightarrow C$	$\Delta G'^{\circ} = 9.7$ kJ/mol
(ii)	$C + D \rightarrow E$	$\Delta G'^{\circ} = -12.7$ kJ/mol
(iii)	$E + F \rightarrow I$	$\Delta G'^{\circ} = 4.7$ kJ/mol

(a) Only species A, B and D are initially present in the system. Will species E be produced in significant amounts? Justify your answer quantitatively.

(b) Only species A, B, D and F are initially present in the system. Will species I be produced in significant amounts? Justify your answer quantitatively.

(c) Initially the system contains only species A, B, D and F and an enzyme that reduces the activation energy f reaction (iii) by 5.2 kJ/mol. Will species I be produced in significant amounts? Justify your answer.

<u>Note:</u> Justification for answers must be indicated to receive full credit.

(a) equations (i) and (ii) are coupled

$\Delta G'^{\circ}_{overall} = 9.7 - 12.7 = -3.0$ kJ/mol

Since $\Delta G'^{\circ}_{overall} < 0 \Rightarrow$ reactants A, B, C & D will be converted to E in significant amounts

(b) coupled equation are equivalent to $2A + B + D + F \rightarrow I$ with an overall $\Delta G'^{\circ}_{overall} = 9.7 - 12.7 + 4.7 = 1.7$ kJ/mol. Since $\Delta G'^{\circ}_{overall}$ is positive, significant amounts of I will not be produced

(c) changes in activation energy do not affect the ultimate equilibrium concentrations so, as in part (b), significant amounts of I will not be produced.