Instructions:
1. You may not consult with any other student about the problems in this exam.
2. You may use any notes or books as you wish.
3. You must show your work to get full credit.

1. Mixture of Two Volatile Liquids (60 points)

Toluene and benzene form nearly ideal solutions. At 20°C, the vapor pressure of pure toluene (T) is 18.5 kPa and that of pure benzene (B) is 51.3 kPa.

Questions:
(a) Make a sketch of the pressure-composition diagram for a toluene-benzene mixture.
(b) Compute the total pressure of a vapor that is in equilibrium with a solution containing 0.6 mole fraction toluene and 0.4 mole fraction benzene at 20°C.
(c) What is the mole fraction of toluene in the vapor in part (a)?

A closed system contains 1 mole of toluene and 1 mole of benzene. The remainder of this problem concerns this mixture.

Questions:
(d) If the pressure above the mixture is 1 bar, is the mixture a liquid, a vapor, or a liquid-vapor mixture?
(e) If the pressure over the mixture at 20°C is reduced, at what pressure does the first vapor form?
(f) What is the composition of the first trace of vapor formed?
(g) If the pressure is reduced further, at what pressures does the last trace of liquid disappear?
(h) What is the composition of the last trace of liquid?

2. Equilibrium in Electrolyte Solutions (60 points)

This problem concerns the following three electrolyte solutions: 0.01 molal Ca(NO$_3$)$_2$, 0.01 molal NaNO$_3$ and 0.01 molal MgSO$_4$.

Questions:
(a) Calculate the mean ionic molality $m_\pm$ of each of the three solutions above.
(b) Calculate the ionic strength of each solution.
(c) Calculate the thickness of the screening layer in each solution.
(d) Calculate the mean ionic activity of each solution.
(e) Silver chloride, AgCl, is a weakly soluble salt. In which one of the three solutions above should AgCl have the highest solubility? Explain your prediction.
(f) The equilibrium constant for the dissolution of AgCl:

$$\text{AgCl(s)} \rightarrow \text{Ag}^{+}(\text{aq}) + \text{Cl}^{-}(\text{aq})$$

is $K_{sp} = 1.56 \times 10^{-10}$ at 25°C, where concentrations are expressed in molality. Calculate the solubility, in moles/kg, of AgCl in each of the three solutions above.
3. Chemical Kinetics (30 points)

The decomposition of a molecule A occurs through the following mechanism:

\[ A + A \rightleftharpoons A^* + A \]

\[ A^* \rightarrow \text{products} \]

Questions:

(a) Use the steady-state approximation to derive the rate law of this reaction.

(b) Interestingly, the reaction is sometimes observed to be first order in A and sometimes to be second order in A. Explain why based on your answer in (a).

(c) Would the reaction be most likely to be first-order at high pressure of A or at low pressure of A? Explain.