1. (30 pts) The excess Gibbs energy for a binary mixture of substances \(a\) and \(b\) at temperature \(T\) and pressure \(P\) is given by

\[
g^E = x_a x_b \left( \frac{1}{C x_a + D x_b} + E \right)
\]

Where \(C\), \(D\) and \(E\) are constant parameters. Obtain the formula for activity coefficients \(\gamma_a\) and \(\gamma_b\) as functions of \(T\), \(x_a\) and \(x_b\).

2. (35 pts) A binary system at \(T = 60^\circ C\) obeys the Margules 3-suffix rule, where the activity coefficients are given by

\[
RT \ln \gamma_1 = x_2^2 (A_{12} + 2(A_{21} - A_{12})x_1)
\]

\[
RT \ln \gamma_2 = x_1^2 (A_{21} + 2(A_{12} - A_{21})x_2)
\]

where \(A_{12} = 1000 \frac{J}{mol}\) and \(A_{21} = 500 \frac{J}{mol}\). Assume that the liquid fugacities of pure substance 1 and 2 at this temperature are \(f_1 = P_{sat,1} = 90\ kPa\) and \(f_2 = P_{sat,2} = 50\ kPa\), respectively. Assume that the fugacity coefficients of each substance are given by \(\hat{\phi}_1 = 0.8\) and \(\hat{\phi}_2 = 0.92\) in the vapor phase. Determine the vapor composition corresponding to \(x_1 = 0.35\).

3. (35 pts) The heat of mixing for a binary mixture of \(a\) and \(b\) is given by

\[
\Delta h_{mix} = x_a x_b \left( A_1 + A_2(x_b - x_a) \right) \left( \frac{J}{mol} \right)
\]

Where \(A_1\) and \(A_2\) are dependent on temperature \(T\) (in K) as follows:

\(A_1 = -450 + 0.1(T - 300)\) \quad ; \quad \(A_2 = 3000 - 0.2(T - 300)\)

Let \(x_a = 0.3\), we have \(\gamma_a = 1.10\) at \(T = 330\ K\), what is \(\gamma_a\) at \(T = 400\ K\) ?

(Hint: recall that

\[
\left( \frac{\partial (\ln \gamma_a)}{\partial T} \right)_{P,n_a,n_b} = -\frac{(\Delta H_{mix})_a}{RT^2}
\]

and note that \((\Delta H_{mix})_a\) is a function of \(T\).)