1. (20) Give short, concise answers to each of the following.

a. A small amount of solid naphthalene is added to benzene. Do you expect the freezing and boiling points of benzene to get further apart or closer together?
   Further apart

b. Many substances have several different solid phases. Can a one-component system have four phases in equilibrium? Give your reasoning.
   No 4 phases would give variance = -1

c. Calculate the ionic strength of a 0.10 m Na₂SO₄ solution.
   \[ I = \frac{1}{6} (0.20 \times 10^2 + 0.10 \times 10^2) = 0.30 \]

d. How many components are there in a water solution of H₃PO₄?
   2

e. The vapor pressure of water at 25°C is 23.77 Torr. How much does the vapor pressure decrease if we add enough sugar to make xₜ₉₉ = 0.90?
   \[ \Delta P = P^* - P = x_P^* \times (1 - x_P^*) = P^* (1 - x_P^*) = 23.77 \times (0.10) = 2.37 \text{ Torr} \]

f. How is the variance defined mathematically?
   \[ N = \text{variables} - \text{equations} \]

g. What is \( E^0 \) for the standard hydrogen electrode?
   \[ E^0 = 0 \]

h. The cell reaction for the cell, Zn | ... | ... | Cu is spontaneous as written. Which electrode is positive if the cell is allowed to run free?
   Cu

i. An isotonic saline solution, which has the same osmotic pressure as blood plasma, is 0.15 M NaCl. What is its osmotic pressure at 37°C?
   \[ \Pi = 2 M \frac{R \times 370.15}{T} = 2 \times 0.15 \text{ mol/L} \times \frac{R \times 370.15}{T} \]
   \[ = 7.6 \text{ atm} \]

2. (10) Calculate the equilibrium constant for the reaction, 2 NO(g) + O₂ → 2 NO₂, at 25°C.
   \[ \Delta G° = 2 \times 251.71 - 2 (266.57) = -70.52 \text{ kJ} \]
   \[ K = e^{-\frac{\Delta G°}{RT}} = e^{-\frac{70.52}{8.31 \times 298}} = 2.6 \times 10^{-11} \]
3. (15) Consider the electrochemical cell: Ag(s) | AgI(s) | HI(aq) | HCl(aq) | AgCl(s) | Ag(s).
   a. Write the half-reactions and the overall cell reaction.

   $2$ \hspace{1cm} R \hspace{1cm} \begin{align*}
   \text{Ag}^+ \text{Ce}^{-} + 2 \rightarrow \text{Ag} + \text{Ce}^- \\
   E^0_R = 0.22
   \end{align*}$

   $2$ \hspace{1cm} L \hspace{1cm} \begin{align*}
   \text{Ag} + \text{I}^- \rightarrow \text{AgI} + 2 \hspace{1cm} (E^0_L = -0.15) + 0.26
   \end{align*}$

   $2$ \hspace{1cm} \begin{align*}
   \text{Ag}^+ \text{Ce}^{-} + \text{I}^- \rightarrow \text{AgI} + \text{Ce}^-
   \end{align*}$

   b. Calculate $E^0$ for the cell.

   $\begin{align*}
   E^0 &= E^0_R - E^0_L = 0.22 - (-0.15) = +0.37 \text{ V}
   \end{align*}$

   c. Calculate $\Delta G^0$ for the cell reaction.

   $\begin{align*}
   \Delta G^0 &= -nF(0.37) = -1 \times 96487 \equiv -96 \text{ kJ}
   \end{align*}$

   d. Does the cell reaction proceed spontaneously as written? Explain.

   $\eta^0 > 0$, $E^0 > 0$ and $\Delta G^0 < 0$

4. (10) Derive an expression for $a_{\text{salt}}$ (the activity of a salt in water solution) for the salt, CeCl₄, in terms of the molality, $m$, of the salt and a suitably defined $\gamma_\pm$.

   $\text{CeCl}_4 (aq) \rightarrow \text{Ce}^{4+} + 4 \text{Cl}^-$

   $\gamma_4 = \text{ln} a_{\text{Ce}^{4+}} + 4 \text{ln} a_{\text{Cl}^-}$

   $m_+ = m$

   $m_- = 4m$

   $a_{\text{salt}} = \frac{m_+ Y_+ (m_- Y_-)^4}{m Y_+ (4m Y_-)^4} = 256 \times m^5 \gamma_+^5 \gamma_-^5$

   with $\gamma_\pm = \sqrt{Y_+ Y_-^{4}}$
5. (10) The $E^\circ$ for the cell, $\text{Zn(s)}|\text{ZnSO}_4(\text{aq})||\text{CuSO}_4(\text{aq})|\text{Cu(s)}$, is well described by $E^\circ = 1.10 - 1.087 \times 10^{-4} (T - 298.15)$ near 298.15 K. Calculate $\Delta S^\circ$ at 298.15 K.

\[
\Delta S^\circ = -\left(\frac{\partial E^\circ}{\partial T}\right)_p = -\left(\frac{\partial [\text{Zn}]}{\partial \ln a}\right)_p = n\frac{\Delta S^e}{\Delta T}\rho
\]

\[
= 2 \text{ Faraday} (-1.047 \times 10^{-4})
\]

\[
= -20.98 \frac{\text{ J}}{\text{ K}}
\]

6. (10) Using standard cell notation write the cell that would have the cell reaction:

\[
2 \text{ H}_2\text{SO}_4(\text{aq}) + \text{ PbO}_2(\text{s}) + \text{ Pb(s)} \rightarrow 2 \text{ PbSO}_4(\text{aq}) + 2 \text{ H}_2\text{O}(\text{l}).
\]

Reduction: \[\text{ PbO}_2 + 2e^- + 2 \text{ H}_2\text{SO}_4 \rightarrow \text{ PbSO}_4 + 2\text{H}_2\text{O} + \text{ SO}_4^{2-}\]

Oxidation: \[\text{ Pb(s)} | \text{ PbSO}_4(\text{aq})| \text{ H}_2\text{SO}_4(\text{aq}) | \text{ PbO}_2(\text{s}) | \text{ Pt( s)}\]

or other non-reactive metal electrode.
7. (15) On the diagram below:

1 is the melting point of substance A.
2 is the melting point of some other compound.
3 is the melting point of substance B.
4 is a eutectic melting point.
5 is a eutectic melting point.
6 is the maximum solubility (solid-solid solution) of A in B.

Sketch and label the phase diagram and find the formula of any compounds formed between A and B.

8. (10) The equilibrium constant for the reaction, \( \frac{3}{2} \text{H}_2(\text{g}) + \frac{1}{2} \text{N}_2(\text{g}) \rightarrow \text{NH}_3(\text{g}) \), is 762 at 298.15 K. Calculate the equilibrium constant at 125°C.

\[
\ln k_2 - \ln k_1 = -\frac{\Delta H^o}{R} \left( \frac{1}{T_2} - \frac{1}{T_1} \right)
\]

\[
k_2 = k_1 e^{-\frac{\Delta H^o}{R} \left( \frac{1}{T_2} - \frac{1}{T_1} \right)} = 762 e^{-\frac{4.672}{125 - 298.15}} = 7.13
\]