1. Explain (define in words) each of the symbols in the following expressions
   (a) $\Delta_r G = \Delta_r G^\circ + RT \ln Q$
   (b) $dG = V dp - SdT + \mu_A n_A + \mu_B n_B + \ldots$
   (c) $S = -k \sum p_i \ln p_i$

2. (a) Starting from $dU = dq + dw$, show that $dU = TdS - pdV$; then derive a similar formula for $dH$.
   (b) Using the results of problem 2a, derive expressions for $(\partial H / \partial S)_p$ and $(\partial U / \partial V)_S$.

3. Write an equation describing how the reaction enthalpy depends on temperature. Define in words each of the symbols that you use.

4. The isothermal compressibility is defined as $\kappa = -(1/V)(\partial V / \partial p)_T$. What is $\kappa$ for an ideal gas?

5. Draw a sketch of an osmometer, identifying all the parts. What does this measure?

6. For each of the following expressions, is the value (a) always positive; (b) always zero; (c) always negative; (d) none of the above? Justify your answers.
   (a) $\left( \frac{\partial G}{\partial T} \right)_{p, \text{composition}}$
   (b) $\left( \frac{\partial G}{\partial n_1} \right)_{T, p, n_2, n_3, \ldots}$ (ideal solution)
   (c) $\Delta_r G$ (at equilibrium)
   (d) $\Delta_r G^\circ$ (at equilibrium)
   (e) $\Delta_{\text{vap}} H(T_{\text{vap}})$
   (f) $\Delta_{\text{vap}} G(T_{\text{vap}})$

7. For a binary mixture of components “A” and “B”: write an equation for the mole fraction $x_A$ and for the molality $b_A$. Derive an equation giving $x_A$ in terms of $b_A$, assuming $x_A \ll 1$. Show your work, and define any symbols you are using.

8. At 25 C, the vapor pressure of pure water is 0.031 atmospheres. What is $\Delta_{\text{vap}} G^\circ$ at this temperature? Note that $R = 8.31$ J K$^{-1}$mol$^{-1}$, and that $\Delta_{\text{vap}} G^\circ \equiv \mu^\circ(\text{gas}) - \mu^\circ(\text{liquid})$. Show your work.

9. Phenol, $C_6H_5OH$, is a very weak acid, with a $pK_a$ of 9.89. What is the pH of a 1 M solution of phenol in water?

10. The Clausius-Clapeyron equation states that, for a liquid–vapor phase boundary, $d \ln p / dT = \Delta_{\text{vap}} H / (RT^2)$. Assuming that the heat of vaporization is constant over some range of temperature and pressure, show that:
    $\ln p_2 = \ln p_1 + \frac{\Delta_{\text{vap}} H}{R} \left( \frac{1}{T_1} - \frac{1}{T_2} \right)$
    where $p_1$ is the vapor pressure at temperature $T_1$, same for $p_2, T_2$. 