Terms in bold:

- phase transitions
- phase boundaries
- dynamic equilibrium
- normal boiling point
- supercritical fluid
- normal freezing (melting) point
- number of degrees of freedom, \( F \)
- superfluid
- molality
- partial molar volume
- standard chemical potential
- Henry's law
- elevation of boiling point
- ebullioscopic constant
- osmotic pressure
- osmotic virial coefficient
- transition temperature
- vapor pressure
- boiling
- critical pressure
- melting temperature
- triple point
- number of components, \( C \)
- (non) electrolyte solutions
- partial molar property
- partial molar Gibbs energy
- partial vapor pressure
- ideal-dilute solutions
- depression of freezing point
- semipermeable membrane
- osmometry
- tie line
- phase diagram
- thermal analysis
- boiling temperature
- critical point
- freezing temperature
- phase rule
- number of phases, \( P \)
- molar concentration
- chemical potential
- Raoult's Law
- ideal solutions
- colligative property
- cryoscopic constant
- osmosis
- van't Hoff Equation
- azeotrope
I. Terms, Equations, and Short Answer (6 pts)

1) The van't Hoff equation describes osmotic pressure. (1 pt)

Write this equation: \( \Pi V = n_B RT \) or \( \Pi = [B]RT \)

2) In the equation \( \Delta T = K_b b_B \), \( K_b \) is called: ebullioscopic constant (1 pt)

3) Two colligative properties are given. What are the other two? (1 pt if both correct)

   (i) boiling point elevation
   (ii) freezing point depression
   (iii) vapor pressure lowering
   (iv) osmosis

   (iii) vapor pressure lowering not precisely described in text, credit given.

4) Another name for the partial molar Gibbs energy is chemical potential (1 pt)

5) On the liquid-vapor equilibrium line (L-V) in a phase diagram, which of the following is true? (Graded right-wrong, 2 pts maximum; more than one response may be correct.) (The gas can be considered ideal.) (2 pts)

   (i) \( \mu^\circ (\text{liq}) = \mu^\circ (\text{vapor}) \)
   (ii) \( \mu (\text{liq}) = \mu^\circ (\text{vapor}) + RT \ln(p_v/p_v^\circ) \)
   (iii) \( \mu_L (\text{liq}) = \mu (\text{vapor}) \)
II. (14 pts total)

6. The phase diagram for CO\(_2\) is shown. 20.0 g of CO\(_2\), initially in the form of dry ice, are sealed in a 1.00 L high pressure container. The CO\(_2\) and the vessel warm up at constant volume to a final temperature of 298 K. Which best describes what is in the vessel at 298 K?

The density of dry ice is 2.0 g/cm\(^3\).

(i) gas only  
(b) liquid only  
(c) solid only  
(d) gas + liquid  
(e) gas + solid  
(f) solid + liquid  
(g) critical fluid

If only gas is present, the pressure is
\[ p = \frac{20.0}{44.0} \times 0.082059 \times \frac{298}{1.0} \]
\[ = 11.11 \text{ atm} = 11.3 \text{ bar} \]

Liquid does not form at p<67 bar at 298 K, so only gas is present.

7. For the system in the sealed container below, give: (3 pts)

(a) the number of components, \( C = 3 \) (water, CHCl\(_3\), naphthalene)

(2) the number of phases, \( P = 5 \) (1 vapor, 2 solid, 2 liquid)

(3) the number of degrees of freedom, \( F = 0 \) (from the phase rule)
8. For cyclohexane, the normal melting point is 6.7°C, the normal boiling point is 84.2°C, and the triple point is 6.5°C, 23 torr.

On the graph paper below, graph the phase diagram for cyclohexane as accurately as you can showing the locations of these 3 points. Label the axes and apply linear numerical scales to each. Then draw the 2-phase lines.

(3 pts)
9. The osmosis cell shown below consists of two compartments separated by a semi-permeable membrane, which is permeant toward the solvent (water) but not the solute. The solute in the left-hand compartment (L) is the polyalcohol shown below, with \( n=1 \). The solute in the right-hand compartment (R) is the analogous polyalcohol with \( n=2 \). In each compartment, the solution consists initially of 10.0 g of solute dissolved in 100.0 g of water. (5 pts total)

\[
\text{Solute: } \quad \begin{array}{c}
\text{CH}_3\text{-CH-} \left( \text{CH}_2\text{-CH} \right)_n \text{-CH}_2\text{-CH}_2 \\
\text{OH} & \text{OH} & \text{OH}
\end{array}
\]

(a) Does the level in the open tube in the left-hand compartment \( \text{rise, stay the same, fall} \) as the system approaches equilibrium (circle one)? \text{Molecular weight is lower for } n=1, \text{ thus molality is larger. Water flows leftward tending to equalize concentrations.}

(b) Which of the following conditions is true at equilibrium?

\[\text{True} \quad \text{False}\]

\[\begin{array}{ll}
\text{i) } & \mu_L(\text{water}) = \mu_R(\text{water}) \quad \text{(water is permeant and at equilibrium)} \\
\text{ii) } & \mu_L(\text{pa}) = \mu_R(\text{pa}) \quad \text{(pa is impermeant, not at equilibrium)} \\
\text{iii) } & \mu_L(\text{water}) = \mu_L(\text{water}) + RT \ln x_{\text{pa}} \quad \mu_L(\text{water}) \text{ depends on pressure and } x_{\text{water}}, \text{ not } x_{\text{pa}} \\
\text{iv) } & \mu_L(\text{water}) = \mu_R(\text{water}) \quad \text{and} \quad \mu_L(\text{pa}) = \mu_R(\text{pa})
\end{array}\]

(pa=polyalcohol, \( x_{\text{pa}} = \text{mole fraction of pa} \))

(This question is graded right-wrong, 5 pts maximum, 0 pts minimum. In part (b), more than one response could be correct.)