Intermolecular Forces

1. From *Lange's Handbook of Chemistry*, 13TH Ed. (McGraw Hill), we find ΔH_{vap} for H_2O to be 40.7 kJ mol^{-1}. We also know the vapor pressure of water at 100°C. Calculate the vapor pressure of water at 25.0°C in a closed container.

$$\ln\frac{P_{25}}{760\text{ torr}} = \frac{40,700\ ^{J}\!/\!_{mol}}{8.314\ ^{J}\!/\!_{mol\cdot K}}\left(\frac{1}{373.2\text{ K}} - \frac{1}{298.2\text{ K}}\right)$$

$$\frac{P_{25}}{760\text{ torr}} = 0.03692$$

$$P_{25} = 28.1\text{ torr}$$

2. The vapor pressures and associated temperatures for ethanol were found in the CRC *Handbook of Chemistry and Physics*. Determine ΔH_{vap} for ethanol. Is it different from water? Why?

***v.p.* (mm Hg)**	**Temp (°C)**
40.0	19.0
400.0	63.5
760.0	78.4

$$\ln\frac{40\text{ mm Hg}}{400\text{ mm Hg}} = \frac{\Delta H_{vap}}{8.314\ ^{J}\!/\!_{mol\cdot K}}\left(\frac{1}{373.2\text{ K}} - \frac{1}{298.2\text{ K}}\right)$$

$$-2.3026 = \frac{\Delta H_{vap}}{8.314\ ^{J}\!/\!_{mol\cdot K}}\left(-4.5231\times10^{-4}\text{ K}^{-1}\right)$$

$$\Delta H_{vap} = 42,300\ ^{J}\!/\!_{mol} = 42.3\ ^{kJ}\!/\!_{mol}$$

3. The vapor pressures measured at several temperatures for benzene are shown in the table. Calculate the normal boiling point for benzene. (The literature value is 80.1°C.)

Temp (°C)	***v.p.* (kPa)**
0.0	4.11
10.0	6.77
20.0	10.78
40.0	25.00

First, get ΔH_{vap} :

$$\ln\frac{4.11\text{ kPa}}{6.77\text{ kPa}} = \frac{\Delta H_{vap}}{8.314\ ^{J}\!/\!_{mol\cdot K}}\left(\frac{1}{283.2\text{ K}} - \frac{1}{273.2\text{ K}}\right)$$

$$\Delta H_{vap} = 32,103\ ^{J}\!/\!_{mol}$$

Now, get n.b.p.:

$$\ln\frac{25.00\text{ kPa}}{101.325\text{ kPa}} = \frac{32,103\ ^{J}\!/\!_{mol}}{8.314\ ^{J}\!/\!_{mol\cdot K}}\left(\frac{1}{T_{n.b.p}} - \frac{1}{313.2\text{ K}}\right)$$

$$-1.3995 = 3861.3\text{ K}\left(\frac{1}{T_{n.b.p}} - 0.0031928\text{ K}^{-1}\right)$$

$$T_{n.b.p} = 353.3\text{ K} = 80.11°\text{C}$$

4. How much energy is needed to melt an ice cube (at constant temperature) that has a mass of 28.0 g? (ΔH_{fusion} = 6.02 kJ mol^{-1})

$$q = n \cdot \Delta H_{\text{fusion}} = \left(28.0\text{ g} \big/ 18.015\,{}^{\text{g}}\!/\!_{\text{mol}}\right) 6.02\,{}^{\text{kJ}}\!/\!_{\text{mol}} = 9.36\text{ kJ}$$

5. How much energy is required to convert 28.0 g of ice at -12.0°C to steam at 100.0°C in a closed vessel? (Hint: What information not listed will be needed?)

$$c_{\text{ice}} = 2.01 \tfrac{\text{J}}{\text{g}\cdot°\text{C}}$$

$$c_{\text{liquid}} = 4.184 \tfrac{\text{J}}{\text{g}\cdot°\text{C}}$$

$$\Delta H_{\text{fusion}} = 6.01\text{ kJ mol}^{-1}$$

$$\Delta H_{\text{vap}} = 40.7\text{ kJ mol}^{-1}\text{ (at 100°C; 44.0 kJ mol}^{-1}\text{ at 25°C)}$$

$$q_{\text{solid-solid}} = mc_{\text{ice}}\Delta T = (28.0\text{ g})(2.01\tfrac{\text{J}}{\text{g}\cdot°\text{C}})(0°\text{C} - [\text{-}12.0°\text{C}]) = 675.4\text{ J}$$

$$q_{\text{fusion}} = n \cdot \Delta H_{\text{fusion}} = \left(28.0\text{ g} \big/ 18.015\,{}^{\text{g}}\!/\!_{\text{mol}}\right)\left(6.01\text{ kJ mol}^{-1}\right)\left(1000\tfrac{\text{J}}{\text{kJ}}\right) = 9341.1\text{ J}$$

$$q_{\text{liq-liq}} = mc_{\text{liq}}\Delta T = (28.0\text{ g})(4.184\tfrac{\text{J}}{\text{g}\cdot°\text{C}})(100.0°\text{C} - 0.0°\text{C}) = 11,715.2\text{ J}$$

$$q_{\text{vap}} = n \cdot \Delta H_{\text{fusion}} = \left(28.0\text{ g} \big/ 18.015\,{}^{\text{g}}\!/\!_{\text{mol}}\right)\left(40.7\text{ kJ mol}^{-1}\right)\left(1000\tfrac{\text{J}}{\text{kJ}}\right) = 63,258.4\text{ J}$$

Total Energy:

$$q_{\text{total}} = 675.4\text{ J} + 9341.1\text{ J} + 11,715.2\text{ J} + 63,258.4\text{ J} = 84990\text{ J}$$