Problem 13-14 Boiling point elevation and vapour pressure reduction above solution

The boiling temperature of a solution containing 4.4 g of organic substance and 1 kg of ethanol ($M_{ethanol}$ = 46 g mol^{-1}) is by 0.135 °C higher than the normal boiling point of ethanol (78.3 °C). The vaporization enthalpy of ethanol at normal boiling point is 38.5 kJ mol^{-1}. The organic substance in ethanol solution does not dissociate.

(a) Determine the molar mass of the substance under study.

(b) How much lower will be the vapour pressure above the solution than the vapour pressure above pure ethanol? Saturated vapour pressure of ethanol is expressed by Antoine equation:

$\log(p^s/\text{kPa}) = A - \frac{B}{C+(t/°\text{C})}$	A	B	C
	7.2335	1591	226

[(a) M_2 = 40 g mol^{-1}; (b) Δp_1 = 81.09 Pa]

Solution:

$$K_b = \frac{\boldsymbol{R}T_{b1}^2 \cdot M_1}{\Delta_{vap}H_1} = \frac{8.314 \cdot 351.45^2 \cdot 46 \cdot 10^{-3}}{38500} = 1.227 \text{ K kg mol}^{-1}$$

$$\left[\frac{(\text{J K}^{-1}\text{ mol}^{-1}) \cdot \text{K}^2 \cdot (\text{kg mol}^{-1})}{\text{J mol}^{-1}} = \text{K kg mol}^{-1}\right]$$

$$\Delta T_b = K_b \cdot \underline{m}_2$$

$$\underline{m}_2 = \frac{m_2}{M_2 \cdot m_1} = \frac{\Delta T_b}{K_b} = \frac{0.135}{1.227} = 0.11 \text{ mol kg}^{-1}$$

$n_2 = 0.11$, $m_1 = 1000$ g , $M_1 = 46$ g mol^{-1}

(a) $n_2 = \frac{m_2}{M_2}$, $m_2 = 4.4$ g , $n_2 = 0.11$

$$M_2 = \frac{m_2}{n_2} = \frac{4.4}{0.11} = 40 \text{ g mol}^{-1}$$

(b) $x_2 = \frac{0.11}{0.11 + 1000/46} = 0.0050345$

t = 38°C

From Antoine equation:

$$\log(p^s/\text{kPa}) = A - \frac{B}{C+(t/^o\text{C})} = 7.2335 - \frac{1591}{226+38} = 1.207$$

p^s = 16.106$_5$ kPa

$$\Delta p_1 = p_1^s - p_1 = x_2 \cdot p_1^s = 0.0050345 \cdot 16.106_5 = 0.08109 \text{ kPa} = 81.09 \text{ Pa}$$