Question 1 (10 points)

A pure 14.85 g sample of the weak base ethylamine, C₂H₅NH₂, is dissolved in enough distilled water to make 500. mL of solution.

(a) Calculate the molar concentration of the C₂H₅NH₂ in the solution.

\[
n_{\text{C}_2\text{H}_5\text{NH}_2} = \frac{14.85 \text{ g C}_2\text{H}_5\text{NH}_2}{45.09 \text{ g C}_2\text{H}_5\text{NH}_2} = 0.3293 \text{ mol C}_2\text{H}_5\text{NH}_2
\]

\[
M_{\text{C}_2\text{H}_5\text{NH}_2} = \frac{0.3293 \text{ mol C}_2\text{H}_5\text{NH}_2}{0.500 \text{ L}} = 0.659 \text{ M}
\]

The aqueous ethylamine reacts with water according to the equation below.

\[
\text{C}_2\text{H}_5\text{NH}_2(\text{aq}) + \text{H}_2\text{O}(l) \rightleftharpoons \text{C}_2\text{H}_5\text{NH}_3^+(\text{aq}) + \text{OH}^-(\text{aq})
\]

(b) Write the equilibrium-constant expression for the reaction between C₂H₅NH₂(\text{aq}) and water.

\[
K_b = \frac{[\text{C}_2\text{H}_5\text{NH}_3^+][\text{OH}^-]}{[\text{C}_2\text{H}_5\text{NH}_2]} \quad \text{(One point is earned for the correct expression.)}
\]

(c) Of C₂H₅NH₂(\text{aq}) and C₂H₅NH₃⁺(\text{aq}), which is present in the solution at the higher concentration at equilibrium? Justify your answer.

C₂H₅NH₂ is present in the solution at the higher concentration at equilibrium. Ethylamine is a weak base, and thus it has a small \(K_b\) value. Therefore only partial dissociation of C₂H₅NH₂ occurs in water, and \([\text{C}_2\text{H}_5\text{NH}_3^+]\) is thus less than \([\text{C}_2\text{H}_5\text{NH}_2]\).
(d) A different solution is made by mixing 500. mL of 0.500 \( M \) \( \text{C}_2\text{H}_5\text{NH}_2 \) with 500. mL of 0.200 \( M \) \( \text{HCl} \). Assume that volumes are additive. The pH of the resulting solution is found to be 10.93.

(i) Calculate the concentration of \( \text{OH}^- \) in the solution.

\[
\text{pH} = -\log[H^+] \\
[H^+] = 10^{-10.93} = 1.17 \times 10^{-11} \\
[\text{OH}^-] = \frac{K_w}{[H^+]} = \frac{1.00 \times 10^{-14}}{1.17 \times 10^{-11}} = 8.5 \times 10^{-4} \text{ M} \\
\text{OR} \\
\text{pOH} = 14 - \text{pH} = 14 - 10.93 = 3.07 \\
\text{pOH} = -\log[\text{OH}^-] \\
[\text{OH}^-] = 10^{-3.07} = 8.5 \times 10^{-4} \text{ M}
\]

One point is earned for the correct concentration.

(ii) Write the net-ionic equation that represents the reaction that occurs when the \( \text{C}_2\text{H}_5\text{NH}_2 \) solution is mixed with the HCl solution.

\[
\text{C}_2\text{H}_5\text{NH}_2 + \text{H}_3\text{O}^+ \rightarrow \text{C}_2\text{H}_5\text{NH}_3^+ + \text{H}_2\text{O}
\]

One point is earned for the correct equation.

(iii) Calculate the molar concentration of the \( \text{C}_2\text{H}_5\text{NH}_3^+ \) that is formed in the reaction.

\[
\text{moles of } \text{C}_2\text{H}_5\text{NH}_2 = 0.500 \text{ L} \times \frac{0.500 \text{ mol}}{1.00 \text{ L}} = 0.250 \text{ mol} \\
\text{moles of } \text{H}_3\text{O}^+ = 0.500 \text{ L} \times \frac{0.200 \text{ mol}}{1.00 \text{ L}} = 0.100 \text{ mol} \\
\]

<table>
<thead>
<tr>
<th>[\text{C}_2\text{H}_5\text{NH}_2]</th>
<th>[\text{H}_3\text{O}^+]</th>
<th>[\text{C}_2\text{H}_5\text{NH}_3^+]</th>
</tr>
</thead>
<tbody>
<tr>
<td>initial value</td>
<td>0.250</td>
<td>0.100</td>
</tr>
<tr>
<td>change</td>
<td>-0.100</td>
<td>-0.100</td>
</tr>
<tr>
<td>final value</td>
<td>0.150</td>
<td>~ 0</td>
</tr>
</tbody>
</table>

\[
[\text{C}_2\text{H}_5\text{NH}_3^+] = \frac{0.100 \text{ mol } \text{C}_2\text{H}_5\text{NH}_3^+}{1.00 \text{ L}} = 0.100 \text{ M}
\]

One point is earned for the correct number of moles of \( \text{C}_2\text{H}_5\text{NH}_2 \) and \( \text{H}_3\text{O}^+ \).

One point is earned for the correct concentration.
(iv) Calculate the value of $K_b$ for $\text{C}_2\text{H}_5\text{NH}_2$.

\[
[C_2H_5NH_2] = \frac{0.150 \text{ mol C}_2\text{H}_5\text{NH}_2}{1.00 \text{ L}} = 0.150 \text{ M}
\]

\[
K_b = \frac{[C_2H_5NH_3^+][OH^-]}{[C_2H_5NH_2]} = \frac{(0.100)(8.5 \times 10^{-4})}{0.150} = 5.67 \times 10^{-4}
\]

One point is earned for the correct calculation of the molarity of $\text{C}_2\text{H}_5\text{NH}_2$ after neutralization.

One point is earned for the correct value.
1. (a) \[ n = \frac{m}{M} = \frac{14.85}{106.15 \text{ g/mol}} = 0.14027 \text{ mol} \]

\[
[C_2H_5NH_3^+] = \frac{n}{V} = \frac{0.14027}{0.500} = 0.28054 \text{ M}
\]

(b) \[
K_{eq} = \frac{[OH^-][C_2H_5NH_3^+]}{[C_2H_5NH_2]}
\]

(c) Ethylamine (C₂H₅NH₂) is a weak base. Therefore, it does not fully dissociate in water and the equilibrium lies at the left side because \( K_{eq} \ll 1 \). Thus, C₂H₅NH₂(aq) is present in the solution at a higher concentration than C₂H₅NH₃⁺(aq) at equilibrium.

(d) (i) \( pH = 10.93 \)

\[
[OH^-] = 10^{-10.93} = 8.51 \times 10^{-4} \text{ M}
\]

(ii) \( C_2H_5NH_2(aq) + H^+(aq) \rightarrow C_2H_5NH_3^+(aq) \)

(iii) \[ n_{C_2H_5NH_2} = VM = (0.500)(0.500) = 0.250 \text{ mol} \]

\[ n_{HCl} = VM = (0.500)(0.200) = 0.100 \text{ mol} \]

\[ C_2H_5NH_2(aq) + H^+(aq) \rightarrow C_2H_5NH_3^+(aq) \]

\[
\begin{align*}
0.250 \text{ mol} & - 0.100 \text{ mol} & 0.100 \text{ mol} \\
0.150 \text{ mol} & 0 & 0.100 \text{ mol}
\end{align*}
\]

\[
[C_2H_5NH_3^+] = \frac{n}{V} = \frac{0.100}{1.00} = 0.100 \text{ M}
\]
(iv) \[ C_{2}H_{5}NH_{2}^{+}(aq) + H_{2}O(l) \rightleftharpoons C_{2}H_{5}NH_{3}^{+}(aq) + OH^{-} \]

\[ K_b = \frac{C_{2}H_{5}NH_{3}^{+} \cdot OH^{-}}{C_{2}H_{5}NH_{2}^{+}} \]

\[ K_b = \frac{(0.100)(8.51 \times 10^{-4})}{(0.150)} = 5.67 \times 10^{-4} \]
CHEMISTRY
Section II
(Total time—95 minutes)

Part A
Time—55 minutes
YOU MAY USE YOUR CALCULATOR FOR PART A.

CLEARLY SHOW THE METHOD USED AND THE STEPS INVOLVED IN ARRIVING AT YOUR ANSWERS. It is to your advantage to do this, since you may obtain partial credit if you do and you will receive little or no credit if you do not. Attention should be paid to significant figures.

Be sure to write all your answers to the questions on the lined pages following each question in this booklet. Do NOT write your answers on the lavender insert.

Answer Questions 1, 2, and 3. The Section II score weighting for each question is 20 percent.

1. A pure 14.85 g sample of the weak base ethylamine, C₂H₅NH₂, is dissolved in enough distilled water to make 500. mL of solution.

   (a) Calculate the molar concentration of the C₂H₅NH₂ in the solution.

   The aqueous ethylamine reacts with water according to the equation below.
   \[
   \text{C₂H₅NH₂(aq) + H₂O(l) } \rightleftharpoons \text{ C₂H₅NH₃⁺(aq) + OH⁻(aq)}
   \]

   (b) Write the equilibrium-constant expression for the reaction between C₂H₅NH₂(aq) and water.

   (c) Of C₂H₅NH₂(aq) and C₂H₅NH₃⁺(aq), which is present in the solution at the higher concentration at equilibrium? Justify your answer.

   (d) A different solution is made by mixing 500. mL of 0.500 M C₂H₅NH₂ with 500. mL of 0.200 M HCl. Assume that volumes are additive. The pH of the resulting solution is found to be 10.93.

   (i) Calculate the concentration of OH⁻(aq) in the solution.

   (ii) Write the net-ionic equation that represents the reaction that occurs when the C₂H₅NH₂ solution is mixed with the HCl solution.

   (iii) Calculate the molar concentration of the C₂H₅NH₃⁺(aq) that is formed in the reaction.

   (iv) Calculate the value of \( K_b \) for C₂H₅NH₂.

\[
K_b = \frac{[C₂H₅NH₃⁺][OH⁻]}{[C₂H₅NH₂]} = \frac{[C₂H₅NH₃⁺] \times [OH⁻]}{[C₂H₅NH₂]} = \frac{(10^{-10}) \times (10^{-3})}{10^{-14}} = 10^{-2}
\]

Number of moles: \( 14.85 \text{ g C₂H₅NH₂} \times \frac{1\text{ mol C₂H₅NH₂}}{53.08 \text{ g C₂H₅NH₂}} = 0.4 \text{ mol C₂H₅NH₂} \)

Moles of \( \text{C₂H₅NH₃⁺} = \frac{2 \text{ mol C₂H₅NH₂}}{3 \text{ mol C₂H₅NH₂}} = 6/3 = 2/3 \text{ mol} \)

\[
\text{Molar concentration} = \frac{n}{V} = \frac{2/3 \text{ mol}}{0.5 \text{ L}} = 6\text{ M}
\]

GO ON TO THE NEXT PAGE.
b) equilibrium constant: 
\[ K_{eq} = \frac{[\text{CsH}_2\text{NH}_3][\text{OH}^-]}{[\text{CsH}_2\text{NH}_2^+]} \]

c) \([\text{CsH}_2\text{NH}_2]\) < \([\text{CsH}_2\text{NH}_2^+]\) because \(\text{CsH}_2\text{NH}_2^+\) is weak acid and does not give up \(\text{H}^+\) much like strong acid.

d) \[ p\text{H} + p\text{OH} = 14 \]
\[ 10.93 + p\text{OH} = 14 \]
\[ p\text{OH} = 3.07 \]
\[ -\log[\text{OH}^-] = 3.07 \]
\[ [\text{OH}^-] = 10^{-3.07} = 8.51 \times 10^{-4} \]

ii) \(\text{CsH}_2\text{NH}_2(aq) + \text{HCl}(aq) \leftrightarrow \text{CsH}_2\text{NH}_2^+(aq) + \text{Cl}^-(aq)\)

iii) moles of \(\text{CsH}_2\text{NH}_2\) = \(M \times V = 0.9 M \times 0.5 L = 0.45 \text{ mole}\)

moles of \(\text{HCl}\) = \(0.5 L \times 0.2 M = 0.1 \text{ mole}\)

Since \(\text{CsH}_2\text{NH}_2\) and \(\text{HCl}\) have same rate of mole consumption, \(\text{HCl}\) is limiting agent.

\(\text{CsH}_2\text{NH}_2^+\) has 0.1 mole through reaction.

Molarity = \(\frac{\text{mole}}{V} = \frac{0.1 \text{ mole}}{0.5 L} = 0.2 M\)

iV) \(K_{b2} = \frac{K_w}{K_{a}}\)
\[ K_a = \frac{[\text{CsH}_2\text{NH}_3][\text{OH}^-]}{[\text{CsH}_2\text{NH}_2^+]} = \frac{(0.1)^2}{0.5 \times 0.2} = 0.1 = 10^{-1} \]

\[ K_{b2} = \frac{1 \times 10^{-10}}{10^{-1}} = 10^{-9} \]
ADDITIONAL PAGE FOR ANSWERING QUESTION 1

a) \[ \text{14.85} = 0.32 \text{ mol} \]
   \[ \text{45.03} \]

\[ 0.32 \times \frac{800}{1580} = 0.16 \text{ m} \]

b) \[ k_e = \frac{[C_2H_5NH_3]^+ [OH^-]}{[C_2H_5NH_2]^+ [H_2O]} \]

c) \[ C_2H_5NH_2 \text{ has higher concentration because it is a weak alkaline} \]

D): (i) \[ \text{pH} = 10.93 \]
   \[ = 14 - 10.93 \]
   \[ = 3.07 \]
   \[ [\text{OH}^-] = 3.07 \times 10^{-5} \]

GO ON TO THE NEXT PAGE.
(iii) \[ C_{2}H_{5}NH_{2} + H^{+} \rightarrow C_{2}H_{5}NH_{3}^{+} \]

(iii) \[ C_{2}H_{5}NH_{2} \]

\[ \frac{0.500 \times 5.00}{100} = 0.25 \text{ M} \]

HCl

\[ \frac{0.200 \times 5.00}{100} = 0.10 \text{ M} \]

\[ C_{2}H_{5}NH_{3}^{+} = 0.40 \]

(iii)

\[ K_{b} = \frac{[C_{2}H_{5}NH_{3}][OH^{-}]}{[C_{2}H_{5}NH_{2}]} \]

\[ [OH^{-}] = K_{b} \frac{[C_{2}H_{5}NH_{3}]}{[C_{2}H_{5}NH_{2}]} \]
AP® CHEMISTRY
2009 SCORING COMMENTARY (Form B)

Question 1

Sample: 1A
Score: 10

This response earned all 10 points: 2 for part (a), 1 for part (b), 1 for part (c), 1 for part (d)(i), 1 for part (d)(ii), 2 for part (d)(iii), and 2 for part (d)(iv).

Sample: 1B
Score: 5

This response earned 5 of the possible 10 points. In part (a) only 1 of the 2 points was earned because of a math error (the answer is incorrect by a factor of 10). In part (b) 1 point was earned for the correct equilibrium expression. In part (c) the point was not earned because the justification is incorrect. In part (d)(i) 1 point was earned for the correct concentration of hydroxide ion (correct significant figures and units were not required on this question). The point was not earned for the equation in part (d)(ii) because the equation is not in net ionic form. In part (d)(iii) both points were earned—the first for the correct initial number of moles of C₂H₅NH₂ and H⁺ and the second for the correct final concentration of C₂H₅NH³⁺. In part (d)(iv) neither point was earned for the substitution of incorrect concentrations into the wrong expression.

Sample: 1C
Score: 3

This response earned 3 of the possible 10 points. In part (a) 1 point was earned for the calculation of the correct number of moles. In part (b) the point was not earned because “H₂O” is included in the equilibrium expression. In part (c) 1 point was earned for stating that ethylamine would be present in a higher concentration “because it is a weak alkali.” In part (d)(i) the point was not earned because a math error resulted in an incorrect value. In part (d)(ii) 1 point was earned for the correct net-ionic equation. In part (d)(iii) neither point was earned because both the initial concentration of H⁺ and the final concentration of C₂H₅NH³⁺ are incorrect. In part (d)(iv) neither point was earned because there is no substitution of concentrations into a proper expression.