AP® CHEMISTRY
2006 SCORING GUIDELINES (Form B)

Question 1

$$C_6H_5COOH(s) \rightleftarrows C_6H_5COO^-(aq) + H^+(aq) \qquad K_a = 6.46 \times 10^{-5}$$

1. Benzoic acid, C_6H_5COOH, dissociates in water as shown in the equation above. A 25.0 mL sample of an aqueous solution of pure benzoic acid is titrated using standardized 0.150 *M* NaOH.

(a) After addition of 15.0 mL of the 0.150 *M* NaOH, the pH of the resulting solution is 4.37. Calculate each of the following.

(i) $[H^+]$ in the solution

$[H^+] = 10^{-4.37}\ M = 4.3 \times 10^{-5}\ M$	One point is earned for the correct answer.

(ii) $[OH^-]$ in the solution

$[OH^-] = \dfrac{K_w}{[H^+]} = \dfrac{1.0 \times 10^{-14}\ M^2}{4.3 \times 10^{-5}\ M} = 2.3 \times 10^{-10}\ M$	One point is earned for the correct answer.

(iii) The number of moles of NaOH added

mol $OH^- = 0.0150\ L \times 0.150\ mol\ L^{-1} = 2.25 \times 10^{-3}$ mol	One point is earned for the correct answer.

(iv) The number of moles of $C_6H_5COO^-(aq)$ in the solution

mol OH^- added = mol $C_6H_5COO^-(aq)$ generated, thus mol $C_6H_5COO^-(aq)$ in solution $= 2.25 \times 10^{-3}$ mol	One point is earned for the correct answer.

(v) The number of moles of C_6H_5COOH in the solution

$K_a = \dfrac{[H^+][C_6H_5COO^-]}{[C_6H_5COOH]} \Rightarrow [C_6H_5COOH] = \dfrac{[H^+][C_6H_5COO^-]}{K_a}$ $[C_6H_5COOH] = \dfrac{(4.3 \times 10^{-5} M) \times \dfrac{2.25 \times 10^{-3}\ mol}{0.040\ L}}{6.46 \times 10^{-5}} = 3.7 \times 10^{-2}\ M$ thus, mol $C_6H_5COOH = (0.040\ L)(3.7 \times 10^{-2}\ M) = 1.5 \times 10^{-3}$ mol	One point is earned for the correct molarity. One point is earned for the correct answer.

Question 1 (continued)

Alternative solution for part (a)(v):

$\text{pH} = \text{p}K_a + \log \dfrac{[\text{C}_6\text{H}_5\text{COO}^-]}{[\text{C}_6\text{H}_5\text{COOH}]}$ $\Rightarrow \text{pH} - \text{p}K_a = \log [\text{C}_6\text{H}_5\text{COO}^-] - \log [\text{C}_6\text{H}_5\text{COOH}]$ $\Rightarrow \log [\text{C}_6\text{H}_5\text{COOH}] = \log [\text{C}_6\text{H}_5\text{COO}^-] - (\text{pH} - \text{p}K_a)$ $= \log \left(\dfrac{2.25 \times 10^{-3} \text{ mol}}{0.040 \text{ L}} \right) - (4.37 - 4.190)$ $= -1.25 - 0.18 = -1.43$ $\Rightarrow [\text{C}_6\text{H}_5\text{COOH}] = 10^{-1.43} = 3.7 \times 10^{-2} M$ thus, mol $\text{C}_6\text{H}_5\text{COOH} = (0.040 \text{ L})(3.7 \times 10^{-2} M) = 1.5 \times 10^{-3}$ mol	

(b) State whether the solution at the equivalence point of the titration is acidic, basic, or neutral. Explain your reasoning.

At the equivalence point the solution is <u>basic</u> due to the presence of $\text{C}_6\text{H}_5\text{COO}^-$ (the conjugate base of the weak acid) that hydrolyzes to produce a basic solution as represented below. $\text{C}_6\text{H}_5\text{COO}^- + \text{H}_2\text{O} \rightleftarrows \text{C}_6\text{H}_5\text{COOH} + \text{OH}^-$	One point is earned for the prediction <u>and</u> the explanation.

In a different titration, a 0.7529 g sample of a mixture of solid $\text{C}_6\text{H}_5\text{COOH}$ and solid NaCl is dissolved in water and titrated with 0.150 M NaOH. The equivalence point is reached when 24.78 mL of the base solution is added.

(c) Calculate each of the following.

(i) The mass, in grams, of benzoic acid in the solid sample

$\text{mol } \text{C}_6\text{H}_5\text{COOH} = (0.02478 \text{ L}) \times (0.150 \text{ mol OH}^- \text{ L}^{-1}) \times \dfrac{1 \text{ mol } \text{C}_6\text{H}_5\text{COOH}}{1 \text{ mol OH}^-}$ $= 3.72 \times 10^{-3} \text{ mol } \text{C}_6\text{H}_5\text{COOH}$ $\text{mass } \text{C}_6\text{H}_5\text{COOH} = 3.72 \times 10^{-3} \text{ mol } \text{C}_6\text{H}_5\text{COOH} \times \dfrac{122 \text{ g } \text{C}_6\text{H}_5\text{COOH}}{1 \text{ mol } \text{C}_6\text{H}_5\text{COOH}}$ $= 0.453 \text{ g } \text{C}_6\text{H}_5\text{COOH}$	One point is earned for the correct answer.

Question 1 (continued)

(ii) The mass percentage of benzoic acid in the solid sample

$\text{mass \% } C_6H_5COOH = \frac{0.453\text{ g } C_6H_5COOH}{0.7529\text{ g}} \times 100$ $= 60.2\%$	One point is earned for the correct answer.