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.

Alternative solution for part (a)(v):

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

$\text{mol } \text{C}_6\text{H}_5\text{COOH} = (0.02478 \text{ L}) \times (0.150 \text{ mol OH}^- \text{ L}^{-1}) \times \frac{1 \text{ mol } \text{C}_6\text{H}_5\text{COOH}}{1 \text{ mol OH}^-}$ $= 3.72 \times 10^{-3} \text{ mol } \text{C}_6\text{H}_5\text{COOH}$ $\text{mass } \text{C}_6\text{H}_5\text{COOH} = 3.72 \times 10^{-3} \text{ mol } \text{C}_6\text{H}_5\text{COOH} \times \frac{122 \text{ g } \text{C}_6\text{H}_5\text{COOH}}{1 \text{ mol } \text{C}_6\text{H}_5\text{COOH}}$ $= 0.453 \text{ g } \text{C}_6\text{H}_5\text{COOH}$	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.

1A,

CHEMISTRY

Section II

(Total time—90 minutes)

Part A

Time—40 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 Question 1 below. The Section II score weighting for this question is 20 percent.

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

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

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

   (iii) The number of moles of NaOH added

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

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

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

   In a different titration, a 0.7529 g sample of a mixture of solid C_6H_5COOH 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

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

a) i) $pH = -\log[H^+]$ $4.37 = -\log[H^+]$ $[H^+] = 4.27\times10^{-5}$ M

ii) $[H^+][OH^-] = K_w \rightarrow (4.27\times10^{-5})[OH^-] = 1\times10^{-14}$ $[OH^-] = 2.34\times10^{-10}$ M

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iii) $n = CV = 0.150(15.0/1000) = 2.25\times10^{-3}$ mol

iv) number of moles of NaOH initially = number of moles of $C_6H_5COO^-$ after the reaction

$n = 2.25\times10^{-3}$ mol

v) $pH = pK + \log \frac{[C_6H_5COO^-]}{[C_6H_5COOH]}$ $\Rightarrow$ $4.37 = -\log 6.46\times10^{-5} + \log \frac{n_{salt}/V}{n_{acid}/V}$

$0.19 = \log \frac{2.25\times10^{-3}}{n_{acid}}$ $\frac{2.25\times10^{-3}}{n_{acid}} = 1.51$ $n_{acid} = 1.49\times10^{-3}$ mol

b) basic; when you add equal number of moles of acid to the base then the ion of the weak acid will be produced. This ion will react with water to give you the acid and OH^- thus increasing the pH of the solution.

c) i) at equivalence point number of moles of acid initially would be equal to number of moles of base in this reaction. $n_{NaOH} = CV = 3.72\times10^{-3}$ mol $\Rightarrow$ $n_{acid} = 3.72\times10^{-3}$ mol

$M_{acid} = 110$ mass of acid = $nM = 0.409$ g

ii) mass percentage = $\frac{\text{mass of acid}}{\text{mass total}} \cdot 100\% = 54.3\%$

1B

ai) pH = 4.37 $[H^+] = 10^{-pH} = 10^{-4.37}$

$[H^+] = 4.27 \times 10^{-5}\ M$

aii) pOH = 14 − 4.37 = 9.63 $[OH^-] = 10^{-pOH} = 10^{-9.63}$

$[OH^-] = 2.34 \times 10^{-10}\ M$

iii) $.150\ M\ NaOH \times .015\ L = 2.25 \times 10^{-3}\ mol$

iv) $[H^+] = [C_6H_5COO^-]$ $4.27 \times 10^{-5}\ M\ C_6H_5COO^- \times .025\ L =$

1.07×10^{-6}

v) $K_a = \frac{[H^+][A^-]}{HA} = \frac{[4.27 \times 10^{-5}][4.27 \times 10^{-5}]}{[C_6H_5COOH]} = 6.46 \times 10^{-5}$

$\frac{1.823 \times 10^{-9}}{[C_6H_5COOH]} = 6.46 \times 10^{-5}$

$[C_6H_5COOH] = 1.18 \times 10^{-13}\ M$

b) The solution @ equivalence point is basic because a strong base is being added to a weak acid, and the strong base dissociates more readily, so the solution at the equivalence point contains more OH^- so it is basic.

c) i) $0.150\ M\ NaOH \times .02478\ L = 0.003717$ mols NaOH = mols C_6H_5COOH @ equivalence point

molar mass of benzoic acid = 122.1244 g

$0.003717\ mols \times \frac{122.1244\ g}{1\ mol} = .454\ g\ C_6H_5COOH$ (benzoic acid)

ii) $\frac{0.454\ g\ benzoic\ acid}{.07529\ g\ total} \times 100 =$ 60.3% benzoic acid

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1C,

CHEMISTRY
Section II
(Total time—90 minutes)

Part A
Time—40 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.

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   (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

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

   (iii) The number of moles of NaOH added

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

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

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

   In a different titration, a 0.7529 g sample of a mixture of solid C_6H_5COOH 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

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

(1) a) i) $pH = 4.37$
$pH = -\log[H^+]$
$4.37 = -\log[H^+]$
$[H^+] = 1 \times 10^{-4.37}$
$= 4.27 \times 10^{-5} M$

ii) $[OH^-] = [H^+]$
$= 4.27 \times 10^{-5}$
M

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1C2

iii) $15mL = 0.015L$ $0.015\cancel{L} \times \frac{0.150 mol}{\cancel{L}} = 2.25 \times 10^{-3} mol\ NaOH$

iv) $[H^+] = [C_6H_5COO^-]$

$[C_6H_5COO^-] = 4.27 \times 10^{-5} M$

$0.04\cancel{L} \times \frac{4.27 \times 10^{-5} mol}{\cancel{L}} = 1.71 \times 10^{-6} mol\ C_6H_5COO^-$

total volume $= 15.0 + 25.0$
$= 40.0mL = 0.04L$

v) $K_a = \frac{x^2}{[HA]}$

$6.46 \times 10^{-5} = \frac{(4.27 \times 10^{-5})^2}{[HA]}$ $[HA] = \frac{(4.27 \times 10^{-5})^2}{6.46 \times 10^{-5}} = 2.82 \times 10^{-5} M$

$0.04\cancel{L} \times \frac{2.82 \times 10^{-5} mol}{\cancel{L}} = 1.13 \times 10^{-6} mol\ C_6H_5COOH$

b) At the equivalence point of the titration, the solution is acidic because at the equivalence point for a buffered solution [$pH = K_a$].

c) $0.7529\cancel{g\ sample} \times \frac{6(12.01) + 5(1.01) + 16.00\ g\ C_6H_5COOH}{94.12 + (22.99 + 35.45)\cancel{g\ sample}}$

$= 0.7529 \times \frac{94.12}{152.56}$

AP® CHEMISTRY
2006 SCORING COMMENTARY (Form B)

Question 1

Sample: 1A
Score: 8

This excellent response earned 8 out of 9 possible points: 1 point for part (a)(i), 1 point for part (a)(ii), 1 point for part (a)(iii), 1 point for part (a)(iv), 2 points for part (a)(v), 1 point for part (b), and 1 point for part (c)(ii). The point was not earned in part (c)(i) because the molar mass of benzoic acid used is incorrect. This incorrect mass is used correctly in part (c)(ii), so the point was earned in part (c)(ii).

Sample: 1B
Score: 5

The point was not earned in part (a)(iv) because the final $[C_6H_5COO^-]$ does not equal $[H^+]$ but rather $[OH^-]$. The points were not earned in part (a)(v) because the molarity of $C_6H_5COO^-$ is not adjusted for 40.0 mL of solution, and $[C_6H_5COO^-]$ is not converted to moles of $C_6H_5COO^-$. The point was not earned in part (b) because the justification is incorrect.

Sample: 1C
Score: 4

The point was not earned in part (a)(ii) because $[OH^-] \neq [H^+]$. The point was not earned in part (a)(iv) because $[C_6H_5COO^-] \neq [H^+]$. The incorrect value of $[C_6H_5COO^-]$ is used correctly in part (a)(v), so both points were earned in part (a)(v). The point was not earned in part (b) because the student misidentifies the equivalence point as the point where $pH = pK_a$. No points were earned in part (c).