AP® CHEMISTRY
2012 SCORING GUIDELINES

Question 1
(10 points)

A 1.22 g sample of a pure monoprotic acid, HA, was dissolved in distilled water. The HA solution was then titrated with 0.250 *M* NaOH. The pH was measured throughout the titration, and the equivalence point was reached when 40.0 mL of the NaOH solution had been added. The data from the titration are recorded in the table below.

Volume of 0.250 *M* NaOH Added (mL)	pH of Titrated Solution
0.00	?
10.0	3.72
20.0	4.20
30.0	?
40.0	8.62
50.0	12.40

(a) Explain how the data in the table above provide evidence that HA is a weak acid rather than a strong acid.

The pH at the equivalence point is above 7, which indicates that HA is a weak acid.	1 point is earned for the correct explanation.

(b) Write the balanced net-ionic equation for the reaction that occurs when the solution of NaOH is added to the solution of HA.

$HA(aq) + OH^-(aq) \rightarrow A^-(aq) + H_2O(l)$	1 point is earned for writing the net-ionic equation balanced for mass and charge.

(c) Calculate the number of moles of HA that were titrated.

At the equivalence point, the number of moles of base added equals the number of moles of acid initially present. $0.0400\ \text{L} \times \frac{0.250\ \text{mol NaOH}}{\text{L}} \times \frac{1\ \text{mol HA}}{1\ \text{mol NaOH}} = 0.0100\ \text{mol HA}$	1 point is earned for the correct number of moles.

Question 1 (continued)

(d) Calculate the molar mass of HA.

$\text{MM} = \frac{\text{mass of acid}}{\text{moles of acid}} = \frac{1.22\text{ g}}{0.0100\text{ mol}} = 122\text{ g/mol}$	1 point is earned for the correct molar mass.

The equation for the dissociation reaction of HA in water is shown below.

$$\text{HA}(aq) + \text{H}_2\text{O}(l) \rightleftarrows \text{H}_3\text{O}^+(aq) + \text{A}^-(aq) \qquad K_a = 6.3 \times 10^{-5}$$

(e) Assume that the initial concentration of the HA solution (before any NaOH solution was added) is 0.200 *M*. Determine the pH of the initial HA solution.

$K_a = \frac{[\text{H}_3\text{O}^+][\text{A}^-]}{[\text{HA}]}$ $6.3\times10^{-5} = \frac{(x)(x)}{(0.200-x)}$; assume that $x << 0.200\ M$. $x = [\text{H}_3\text{O}^+] = 3.5\times10^{-3}\ M$ $\text{pH} = -\log[\text{H}_3\text{O}^+] = -\log(3.5\times10^{-3}) = 2.45$	1 point is earned for the appropriate substitution into the K_a expression. 1 point is earned for the correct $[\text{H}_3\text{O}^+]$. 1 point is earned for the calculation of pH.

(f) Calculate the value of $[\text{H}_3\text{O}^+]$ in the solution after 30.0 mL of NaOH solution is added and the total volume of the solution is 80.0 mL.

$\text{HA} + \text{OH}^- \rightarrow \text{A}^- + \text{H}_2\text{O}$ mol before rxn: 0.0100 0.00750 0.00000 mol after rxn: 0.00250 0.00000 0.00750 $[\text{HA}] = \frac{0.00250\text{ mol}}{0.0800\text{ L}} = 3.13\times10^{-2}\ M$ $[\text{A}^-] = \frac{0.00750\text{ mol}}{0.0800\text{ L}} = 9.38\times10^{-2}\ M$ $K_a = \frac{[\text{H}_3\text{O}^+][\text{A}^-]}{[\text{HA}]}$ $6.3\times10^{-5} = \frac{(x)(9.38\times10^{-2}+x)}{(3.13\times10^{-2}-x)}$ Assume that $x << 9.38\times10^{-2}\ M$ and $3.13\times10^{-2}\ M$, then $6.3\times10^{-5} = \frac{(x)(9.38\times10^{-2})}{(3.13\times10^{-2})}$ $x = [\text{H}_3\text{O}^+] = 2.10\times10^{-5}\ M$.	1 point is earned for the correct calculation of moles of A^- and HA after the reaction. 1 point is earned for the appropriate substitution into the equilibrium expression. 1 point is earned for the correct calculation of $[\text{H}_3\text{O}^+]$.

ADDITIONAL PAGE FOR ANSWERING QUESTION 1

a.)

(1) the table shows that HA is a weak acid because it says that 40.0mL was the equivalence point, where the # of mols of acid = the # of mols of base. If it was a strong acid & strong base, the pH at that point would be 7. But, it is 8.62, more basic, so HA must be weak.

b.) $HA + NaOH \rightarrow H_2O + NaA$

$HA + OH^- \rightarrow H_2O + A^-$

c.) 40.0mL is equivalence point

$0.250\,M\ NaOH = \frac{\text{mols NaOH}}{0.0400\,L}$ $\quad 0.0100$ mols NaOH

1:1 ratio between HA & OH^-, so there are 0.0100 mols HA

d.) $\frac{1.22\,g \text{ in sample}}{0.0100 \text{ mols in sample}} = 122\ g/mol$ is molar mass.

e.) $HA(aq) + H_2O(\ell) \rightleftharpoons H_3O^+(aq) + A^-(aq)$

I	0.200 M	$\varnothing$	$\varnothing$
C	$-X$	$+X$	$+X$
E	$0.200-X$	X	X

≈ 0.200 → (assumption that X is negligible here)

$K_a = \frac{[H_3O^+][A^-]}{[HA]}$ $\quad 6.3\times10^{-5} = \frac{(X)(X)}{0.200}$

$X^2 = 1.26\times10^{-5}$ $\quad X = 0.0035 = [H_3O^+]$

$[H_3O^+] = [H^+]$ synonomus here, so

$pH = -\log[H^+]$ $\quad pH = -\log(0.0035)$ $\quad pH = 2.46$

f.) $0.250\ M\ NaOH = \frac{\text{mols NaOH}}{0.0300\,L}$ $\quad 0.0075$ mols NaOH added

(back →)

1A2

(#1 continued)

$HA + OH^- \rightarrow H_2O + A^-$

0.0100 mols	0.00750 mol		∅
−0.00750 mol	−0.00750 mol		+0.00750 mol
0.00250 mol HA left	∅		0.00750 mol A⁻ produced
÷ 0.0800 L			÷ 0.0800 L
0.0313 M			0.0938 M

$HA + H_2O \rightleftharpoons H_3O^+ + A^-$

I	0.0313 M	∅	0.0938 M
C	−x	+x	+x
E	≈0.0313 M (assumption)	x	≈0.0938 M (assuming x is negligible)

$K_a = \frac{[A^-][H_3O^+]}{[HA]}$ $\quad 6.3 \times 10^{-5} = \frac{(0.0938)x}{0.0313}$

$x = 2.1 \times 10^{-5} = [H_3O^+]$ in soln after reaction

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1B

(a) When a strong acid is titrated with a strong base the pH @ the equivalence point equals 7. In this case the pH of the titrated solution @ the equivalence point equals 8.62.

(b) $HA + OH^- \rightleftharpoons HOH + A^-$

(c) $40.0mL\ NaOH \cdot \frac{1.00L}{1000mL} \cdot \frac{0.250mol\ NaOH}{1.00L\ NaOH} \cdot \frac{1\ mol\ HA}{1\ mol\ NaOH} = 0.0100mol\ HA$

(d) $\frac{1.22g\ HA}{0.0100mol\ HA} = 122\ g/mol\ HA$

(e)

	HA	H_3O^+	A^-
I	0.200M	0M	0M
C	$-x$	$+x$	$+x$
E	$0.200-x$	x	x

$K_a = \frac{[H_3O^+][A^-]}{[HA]}$

$6.3\times10^{-5} = \frac{x^2}{0.200-x}$; x is negligible because $K_a \times 100 < 0.200$

$\frac{6.3\times10^{-5}}{0.200M} = x^2$

$x^2 = 3.2\times10^{-4}$ $\quad x = 0.018M$

$[H_3O^+] = 0.018M$ $\quad pH = -\log[0.018M]$

$pH = 1.751$

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1B2

(f) $0.030\text{mL NaOH} \cdot \frac{0.250\text{mol}}{\text{L}} = 0.0075\text{mol NaOH}$

$0.0100\text{mol HA} - 0.0075\text{mol NaOH} = 0.0025\text{mol HA}$

$0.00\text{ mol } A^- + 0.0075\text{mol NaOH} = 0.0075\text{mol } A^-$

$\frac{0.0025\text{mol HA}}{0.080\text{L soln}} = 0.03125\text{m HA}$

$\frac{0.0075\text{mol } A^-}{0.080\text{L soln}} = 0.09375\text{m } A^-$

$pH = pKa + \log\frac{[A^-]}{[HA]}$

$pH = -\lg(6.3\times10^{-5}) + \log\left(\frac{0.0938}{0.03125}\right)$

$pH = 4.678$

ADDITIONAL PAGE FOR ANSWERING QUESTION 1

a. The data shows that after adding 40.0mL of 0.250M NaOH, the pH of the titrated solution is 8.62, and that is the volume and pH of the equivalence point. When a weak acid is titrated with a strong base, the pH of the equivalence point is always above pH 7. 8.62 > 7.

b. $NaOH + HA \rightarrow NaA + H_2O$

$Na^+ + OH^- + HA \rightarrow Na^+ + A^- + H^+ + OH^-$

$HA \rightarrow A^- + H^+$

c. $\frac{40.0\,mL\,NaOH}{} \left| \frac{1L}{1000mL} \right| \frac{0.250\,mol\,NaOH}{1L} = 0.0100\,mol\,NaOH\ reacted.$

NaOH : HA = 1 : 1, so mol HA (reacted) = 0.0100 mol HA

d. Molar mass HA = $\frac{1.22g\ HA}{0.0100\,mol\,HA} = 122\ g/mol$

e.

	$HA + H_2O \rightleftharpoons H_3O^+ + A^-$		
I	0.200M	≈0 M	0M
C	−x	+x	+x
E	0.200−x	x	x

$6.3 \times 10^{-5} = \frac{x^2}{0.200-x}$

Assume 5% rule: $6.3 \times 10^{-5} = \frac{x^2}{0.200}$

$x^2 = 1.3 \times 10^{-5}$

$x = [H_3O^+] = 0.0036M$

$pH = -\log[H_3O^+] = -\log(0.0036M) = 2.44$

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1C2

ADDITIONAL PAGE FOR ANSWERING QUESTION 1

f. $HA + NaOH \rightarrow H_2O + A^-$

$(0.200M \times 0.05L)$	$(0.250M \times 0.03L)$	–
		–

AP® CHEMISTRY
2012 SCORING COMMENTARY

Question 1

Overview

This question assessed students' understanding of and ability to solve problems and explain concepts that pertain to a weak acid/strong base titration. Part (a) asked students to provide evidence that HA is a weak acid. Part (b) required students to write a balanced net-ionic equation for the reaction between HA and NaOH. Part (c) asked students to calculate the number of moles of HA titrated. In part (d) students were asked to calculate the molar mass of HA. In part (e) students were given the ionization equation and the K_a value for the weak acid and were asked to determine the pH of HA before addition of any NaOH. Part (f) assessed the students' understanding of the titration process by asking students to calculate $[H_3O^+]$ at a point in the titration before the equivalence point.

Sample: 1A
Score: 10

The response earned all 10 available points.

Sample: 1B
Score: 8

In part (e) the response earned the first point for the appropriate substitution into the K_a expression, but did not earn the second point because the $[H_3O^+]$ was calculated incorrectly. The third point was earned for calculating a pH consistent with the incorrect $[H_3O^+]$. In part (f) the response earned the first point for calculating the values of HA and A^- and the second point for substituting the values into the Henderson-Hasselbalch equation but did not earn the third point for the value of $[H_3O^+]$.

Sample: 1C
Score: 6

In part (b) the response did not earn the point because the equation used is not the correct net ionic equation. In part (f) the response earned no points because the student multiplies the concentration and volume for the acid and base but does not complete the calculation.