Question 1

$$HF(aq) + H_2O(l) \rightleftarrows H_3O^+(aq) + F^-(aq) \qquad K_a = 7.2 \times 10^{-4}$$

Hydrofluoric acid, $HF(aq)$, dissociates in water as represented by the equation above.

(a) Write the equilibrium-constant expression for the dissociation of $HF(aq)$ in water.

$K_a = \dfrac{[H_3O^+][F^-]}{[HF]}$	One point is earned for the correct expression.

(b) Calculate the molar concentration of H_3O^+ in a 0.40 M $HF(aq)$ solution.

$K_a = \dfrac{[H_3O^+][F^-]}{[HF]} = \dfrac{(x)(x)}{0.40 - x} = 7.2 \times 10^{-4}$	One point is earned for the correct setup (or the setup consistent with part (a)).
Assume $x << 0.40$, then $x^2 = (0.40)(7.2 \times 10^{-4})$ $x = [H_3O^+] = 0.017\ M$	One point is earned for the correct concentration.

$HF(aq)$ reacts with $NaOH(aq)$ according to the reaction represented below.

$$HF(aq) + OH^-(aq) \rightarrow H_2O(l) + F^-(aq)$$

A volume of 15 mL of 0.40 M $NaOH(aq)$ is added to 25 mL of 0.40 M $HF(aq)$ solution. Assume that volumes are additive.

(c) Calculate the number of moles of $HF(aq)$ remaining in the solution.

mol $HF(aq)$ = initial mol $HF(aq)$ − mol $NaOH(aq)$ added = $(0.025\ L)(0.40\ mol\ L^{-1}) - (0.015\ L)(0.40\ mol\ L^{-1})$ = 0.010 mol − 0.0060 mol = 0.004 mol	One point is earned for determining the initial number of moles of HF and OH^-. One point is earned for setting up and doing correct subtraction.

(d) Calculate the molar concentration of $F^-(aq)$ in the solution.

mol $F^-(aq)$ formed = mol $NaOH(aq)$ added = 0.0060 mol $F^-(aq)$ $\dfrac{0.0060\ mol\ F^-(aq)}{(0.015 + 0.025)\ L\ of\ solution} = 0.15\ M\ F^-(aq)$	One point is earned for determining the number of moles of $F^-(aq)$. One point is earned for dividing the number of moles of $F^-(aq)$ by the correct total volume.

Question 1 (continued)

(e) Calculate the pH of the solution.

$[HF] = \dfrac{0.004 \text{ mol HF}}{0.040 \text{ L}} = 0.10\ M \text{ HF}$ $K_a = \dfrac{[H_3O^+][F^-]}{[HF]} \Rightarrow \dfrac{[HF]\times K_a}{[F^-]} = [H_3O^+]$ $\Rightarrow \dfrac{0.10\ M\ (7.2\times10^{-4})}{0.15\ M} = 4.8\times10^{-4}$ $\Rightarrow \text{pH} = -\log(4.8\times10^{-4}) = 3.32$ **OR** $\text{pH} = \text{p}K_a + \log\dfrac{[F^-]}{[HF]}$ $= -\log(7.2\times10^{-4}) + \log\dfrac{0.15\ M}{0.10\ M}$ $= 3.14 + 0.18$ $= 3.32$	One point is earned for indicating that the resulting solution is a buffer (e.g., by showing a ratio of $[F^-]$ to $[HF]$ or moles of F^- to HF). One point is earned for the correct calculation of pH.

1A,

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.

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

$$HF(aq) + H_2O(l) \rightleftarrows H_3O^+(aq) + F^-(aq) \qquad K_a = 7.2 \times 10^{-4}$$

1. Hydrofluoric acid, $HF(aq)$, dissociates in water as represented by the equation above.

   (a) Write the equilibrium-constant expression for the dissociation of $HF(aq)$ in water.

   (b) Calculate the molar concentration of H_3O^+ in a 0.40 M $HF(aq)$ solution.

   $HF(aq)$ reacts with $NaOH(aq)$ according to the reaction represented below.

   $$HF(aq) + OH^-(aq) \rightarrow H_2O(l) + F^-(aq)$$

   A volume of 15 mL of 0.40 M $NaOH(aq)$ is added to 25 mL of 0.40 M $HF(aq)$ solution. Assume that volumes are additive.

   (c) Calculate the number of moles of $HF(aq)$ remaining in the solution.

   (d) Calculate the molar concentration of $F^-(aq)$ in the solution.

   (e) Calculate the pH of the solution.

a) $K_a = \dfrac{[H_3O^+][F^-]}{[HF]}$

b)

	$HF_{(aq)} + H_2O_{(l)}$	$\rightleftarrows$ $H_3O^+_{(aq)}$	$+\ F^-_{(aq)}$
Initial	.40 M	0	0
Change	$-x$	$+x$	$+x$
Equilibrium	.40 − x M	x M	x M

b) $(7.2\times10^{-4})100 < .40$, approximation is okay $\quad 7.2\times10^{-4} = \dfrac{x^2}{.4}$

$[H_3O^+] = [F^-] = \sqrt{7.2\times10^{-4}(.4M)} = .017\ M$

$[H_3O^+] = .017\ M$

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1A 2

c) $\frac{x \text{ mol NaOH}}{.015 \text{ L}} = 0.40 \text{ M NaOH}$ .006 mol NaOH

$\frac{x \text{ mol HF}}{.025 \text{ L}} = 0.40 \text{ M HF}$ .010 mol HF

monoprotic acid reacts with base 1:1 ratio

.010 mol − .006 mol = .004 mol HF remains in sol'n

d) $\frac{.004 \text{ mol HF}}{.015 \text{ L} + .025 \text{ L}} = \frac{.004 \text{ mol HF}}{.04 \text{ L}} = .1 \text{ M HF}$ $\frac{.006 \text{ mol } F^-}{.04} = .15 \text{ M } F^-$

$[F^-] = .15 \text{ M}$

e)

	$HF_{(aq)} + H_2O_{(l)}$	$\rightleftharpoons$	$H_3O^+_{(aq)}$	+	$F^-_{(aq)}$
I	.1 M		0		.15 M
C	−x		+x		+x
E	.1 − x M		x M		.15 + x M

$(7.2 \times 10^{-4})(100) < .1$, approx.

$7.2 \times 10^{-4} = \frac{(.15 \text{M})(x)}{(.1 \text{M})}$ $x = 4.8 \times 10^{-4} \text{M} = [H_3O^+]$

$-\log(4.8 \times 10^{-4} \text{M}) = 3.32 = pH$

1B, 1

CHEMISTRY
Section II
(Total time—95 minutes)

Part A
Time—55 minutes
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(a) Write the equilibrium-constant expression for the dissociation of $HF(aq)$ in water.

(b) Calculate the molar concentration of H_3O^+ in a 0.40 M $HF(aq)$ solution.

$HF(aq)$ reacts with $NaOH(aq)$ according to the reaction represented below.

$$HF(aq) + OH^-(aq) \rightarrow H_2O(l) + F^-(aq)$$

A volume of 15 mL of 0.40 M $NaOH(aq)$ is added to 25 mL of 0.40 M $HF(aq)$ solution. Assume that volumes are additive.

(c) Calculate the number of moles of $HF(aq)$ remaining in the solution.

(d) Calculate the molar concentration of $F^-(aq)$ in the solution.

(e) Calculate the pH of the solution.

a $\boxed{K = \dfrac{[H_3O^+][F^-]}{[HF][H_2O]}}$

b $K_a = \dfrac{[H_3O^+][F^-]}{[HF]} = \dfrac{x^2}{.4} = 7.2 \times 10^{-4}$

$x = 1.7 \times 10^{-2}$

$[H_3O^+] = \boxed{1.7 \times 10^{-2}\ M}$

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1B$_2$

c. $.015\,L\left(\frac{.40\,mol\,NaOH}{1\,L}\right) = .0060\,mol\ NaOH$

$.025\,L\left(\frac{.40\,mol\,HF}{1\,L}\right) = .010\,mol\ HF$

$.010\,mol - .0060\,mol = \boxed{.004\,mol\ HF\ remaining}$

d. NaOH is the limiting reactant

$.0060\,mol\ NaOH\left(\frac{1\,mol\ F^-}{1\,mol\ NaOH}\right) = .0060\,mol\ F^-$

total volume: .04 L

$\frac{.0060\,mol\,F^-}{.04\,L} = \boxed{.15\,M\ F^-}$

e. $HF + OH^- \rightarrow H_2O + F^-$

	HF	OH^-	H_2O	F^-
i	.010mol	.0060mol		0
c	−.0060	−.0060		+.0060
e	.004	0		.0060

$HF \rightarrow H^+ + F^-$

	HF	H^+	F^-
i	.004	0	.0060
c	−.004	+.004	+.004
e	0	.004	.010

$\frac{.004\,mol\,H^+}{.04\,L} = .1\,M\,H^+$

$pH = -\log(.1) = \boxed{1}$

1C, 1

CHEMISTRY

Section II

(Total time—95 minutes)

Part A

Time—55 minutes

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$$HF(aq) + H_2O(l) \rightleftarrows H_3O^+(aq) + F^-(aq) \qquad K_a = 7.2 \times 10^{-4}$$

1. Hydrofluoric acid, $HF(aq)$, dissociates in water as represented by the equation above.

   (a) Write the equilibrium-constant expression for the dissociation of $HF(aq)$ in water.

   (b) Calculate the molar concentration of H_3O^+ in a 0.40 M $HF(aq)$ solution.

   $HF(aq)$ reacts with $NaOH(aq)$ according to the reaction represented below.

   $$HF(aq) + OH^-(aq) \rightarrow H_2O(l) + F^-(aq)$$

   A volume of 15 mL of 0.40 M $NaOH(aq)$ is added to 25 mL of 0.40 M $HF(aq)$ solution. Assume that volumes are additive.

   (c) Calculate the number of moles of $HF(aq)$ remaining in the solution.

   (d) Calculate the molar concentration of $F^-(aq)$ in the solution.

   (e) Calculate the pH of the solution.

1) a) eq expression $\boxed{K_a = \frac{[F^-][H_3O^+]}{[HF]}}$ = a

b) $K_a = 7.2 \times 10^{-4}$ $\quad 7.2\times10^{-4} = \frac{[F^-][H_3O^+]}{[.40]}$

.40M HF

$2.88\times10^{-4} = [F^-][H_3O^+]$

$\boxed{[H_3O^+] = .017M}$ $\quad \sqrt{2.88\times10^{-4}} = \sqrt{s^2}$

$s = .016970563$

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 1C2

c) $HF + OH^- \rightarrow H_2O + F^-$

15ml .40M NaOH

$.40M = \frac{}{.015L} = .006mol$

25ml .40M HF

$.40M = \frac{}{.025L} = \boxed{.01mol}$

25ml HF

.40M HF

$M = \frac{mols}{L}$ $.40M = \frac{mols}{.025L}$

$\boxed{HF\ mols = .01}$

d) $\frac{[F^-]}{[HF][OH^-]}$

$HF + OH^- \rightarrow H_2O + F^-$

.01 mols

.006 mols

$\boxed{[F^-] = .46M}$

$\frac{.016\ mols}{.035\ L}$

$= .457M$

e) $pH = -\log[H^+]$

$14 = pH + pOH$

$pOH = -\log[OH^-]$

$[OH^-] = .40M$

$-\log[.40]$

$= .39794$

$14 = pH + .39794$

$\boxed{pH = 13.6}$

GO ON TO THE NEXT PAGE.

AP® CHEMISTRY
2007 SCORING COMMENTARY

Question 1

Overview

This question assessed students' understanding of aqueous equilibrium of a weak acid, stoichiometry of aqueous reactions, and buffer calculations. For parts (a) and (b) students were given a chemical equation describing the equilibrium of a weak acid in aqueous solution; they were expected to write a correct expression for the equilibrium constant and to use the equilibrium-constant expression and its value to determine $[H_3O^+]$ in a solution of known concentration. The remainder of the problem challenged students to first perform stoichiometric calculations to determine the number of moles or the concentration of species present when solutions of a weak acid and a strong base are combined. The final part of the question asked them to demonstrate mastery of the concept of buffered solutions by determining the pH of the resulting solution.

Sample: 1A
Score: 9

This response earned all 9 points: 1 for part (a), 2 for part (b), 2 part (c), 2 for part (d), and 2 for part (e).

Sample: 1B
Score: 6

The point was not earned in part (a) because the concentration of water is erroneously included in the equilibrium-constant expression. However, the concentrations are correctly substituted into the equilibrium equation and $[H_3O^+]$ is calculated correctly, so 2 points were earned in part (b). Both points were earned in part (c), and both points were earned in part (d). The student does not recognize that the resulting solution is a buffer, treating the solution as a strong acid, and therefore did not earn any points for part (e).

Sample: 1C
Score: 4

All available points were earned in parts (a) and (b). In part (c) the first point was earned for determining the number of moles of HF and NaOH initially present, but the second point was not earned because the correct reaction stoichiometry is not applied. No points were earned in part (d) because the student does not determine the correct number of moles of F^- present and does not obtain the correct volume of solution. No points were earned in part (e) because the student does not indicate that the resulting solution is a buffer, erroneously setting $[OH^-] = 0.40\ M$.