Name:_____Date:_____Block:____

Chapter 10 – Acid Base Equilibrium

Super Problem

$NH_3(aq) + H_2O(l) \leftrightarrow NH_4^+(aq) + OH^-(aq)$ $\quad Kb = 1.80 \times 10^{-5}$

Ammonia reacts with water as indicated in the reaction above.

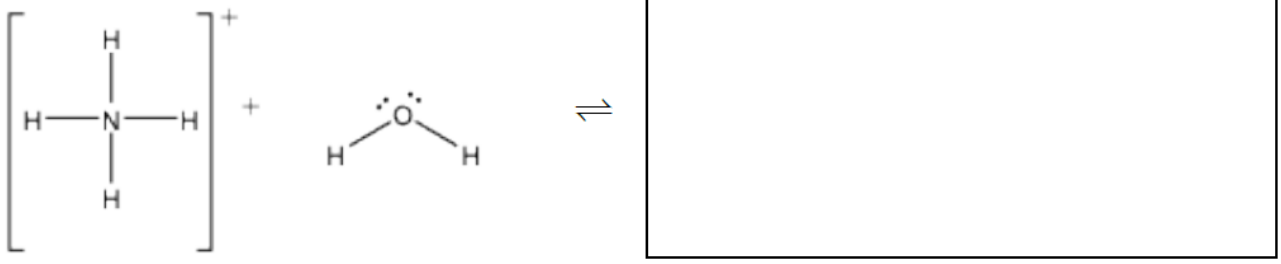
(a) Write the expression for the equilibrium constant for the reaction represented above.

(b) Calculate the pH of a 0.150 M solution of NH_3.

(c) Determine the percent ionization of the weak base NH_3.

(d) Calculate the hydronium ion, H_3O^+, concentration in the above solution. Be sure to include units with your answer.

When a specified amount of ammonium nitrate (NH_4NO_3) is dissolved in water, the ammonium ions hydrolyze the water according to the partial reaction shown below. The resulting solution has a pH of 4.827.



(e) Complete the reaction above by drawing the complete Lewis structures for both products of the hydrolysis reaction.

(f) Determine the

(i) molarity (M) of the ammonium ions in this solution

(ii) number of moles of ammonium ions in 250 mL of the above solution

NMSI SUPER PROBLEM

$NH_3(aq) + H_2O(\ell)$ ☐ $NH_4^+(aq) + OH^-(aq)$ $\quad K_b = 1.80 \times 10^{-5}$

1. Ammonia reacts with water as indicated in the reaction above.

(a) Write the equilibrium constant expression for the reaction represented above.

$K_b = \dfrac{[NH_4^+][OH^-]}{[NH_3]}$	**1 point** is earned for the correct expression

(b) Calculate the pH of a 0.150 *M* solution of NH_3

$K_b = \dfrac{x^2}{M}$ where x = $[OH^-]$ $1.80x10^{-5} = \dfrac{x^2}{0.150}$ $1.64x10^{-3} = x$ $-\log x = pOH = 2.784$ $pH = 11.216$	**1 point** is earned for the correct set up and for calculating the concentration of hydroxide ions **1 point** is earned for the correct pH

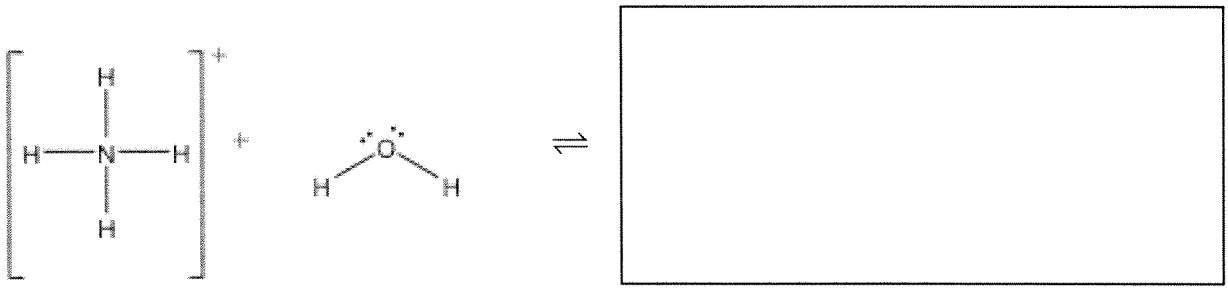
(c) Determine the percent ionization of the weak base NH_3.

$\% = \dfrac{[x]}{[M_o]} \times 100$ $\% = \dfrac{1.64 \times 10^{-3}}{[0.150]} \times 100 = 1.09\%$	**1 point** is earned for the correct percent ionization

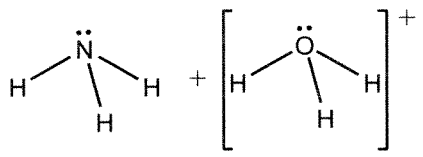
(d) Calculate the hydronium ion, H_3O^+, concentration in the above solution. Be sure to include units with your answer.

$[H_3O^+][OH^-] = 1.00 \times 10^{-14}$ $[H_3O^+] = \dfrac{1.0 \times 10^{-14}}{[OH^-]} = \dfrac{1.00 \times 10^{-14}}{1.64 \times 10^{-3}} = 6.10 \times 10^{-12} M$ OR $[H_3O^+] = 10^{-pH}$ $[H_3O^+] = 10^{-11.216} = 6.08 \times 10^{-12} M$	**1 point** is earned for the concentration of hydronium ions with units of mol L^{-1} or *M*

When a specified amount of ammonium nitrate (NH_4NO_3) is dissolved in water, the ammonium ions hydrolyze the water according to the partial reaction shown below. The resulting solution has a pH of 4.827.



(e) Complete the reaction above by drawing the *complete* Lewis structures for *both* products of the hydrolysis reaction.

	**1 point** is earned for **each** correct Lewis structure. **2 points** possible

(f) Determine the

(i) molarity (M) of the ammonium ions in this solution

$[H_3O^+] = 10^{-pH} = 10^{-4.827} = 1.49 \times 10^{-5}$ $K_a = \frac{K_w}{K_b} = \frac{1.00 \times 10^{-14}}{1.80 \times 10^{-5}} = 5.56 \times 10^{-10}$ $5.56 \times 10^{-10} = \frac{[1.49 \times 10^{-5}][1.49 \times 10^{-5}]}{[M]}$ $M = 0.400$	**1 point** is earned for calculating the K_a for ammonium ions **1 point** is earned for calculating the concentration of ions in the solution.

(ii) number of moles ammonium ions in 250 mL of the above solution.

$M = 0.400$ $0.400\,M = \frac{x \text{ mol}}{0.250 \text{ L}}$ $x = 0.100 \text{ mol}$	**1 point** is earned for calculating the molar concentration and the number of moles of ammonium ions

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.

$$K_a = \frac{[H_3O^+][OCl^-]}{[HOCl]} = 3.2 \times 10^{-8}$$

1. Hypochlorous acid, HOCl, is a weak acid in water. The K_a expression for HOCl is shown above.

   (a) Write a chemical equation showing how HOCl behaves as an acid in water.

   (b) Calculate the pH of a 0.175 *M* solution of HOCl.

   (c) Write the net ionic equation for the reaction between the weak acid HOCl(*aq*) and the strong base NaOH(*aq*).

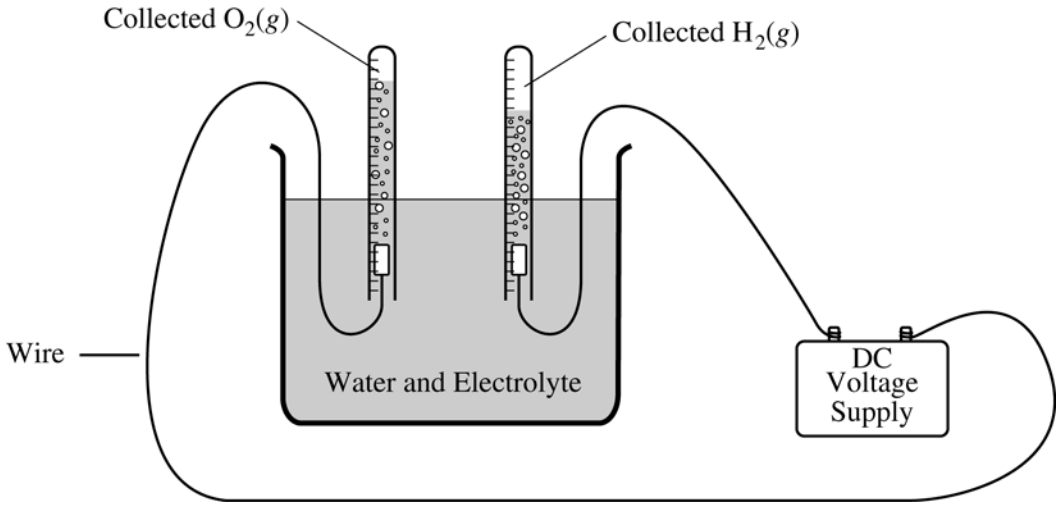
   (d) In an experiment, 20.00 mL of 0.175 *M* HOCl(*aq*) is placed in a flask and titrated with 6.55 mL of 0.435 *M* NaOH(*aq*).

      (i) Calculate the number of moles of NaOH(*aq*) added.

      (ii) Calculate $[H_3O^+]$ in the flask after the NaOH(*aq*) has been added.

      (iii) Calculate $[OH^-]$ in the flask after the NaOH(*aq*) has been added.

Answer EITHER Question 2 below OR Question 3 printed on pages 8 and 9. Only one of these two questions will be graded. If you start both questions, be sure to cross out the question you do not want graded. The Section II score weighting for the question you choose is 20 percent.



2. Water was electrolyzed, as shown in the diagram above, for 5.61 minutes using a constant current of 0.513 ampere. A small amount of nonreactive electrolyte was added to the container before the electrolysis began. The temperature was 298 K and the atmospheric pressure was 1.00 atm.

   (a) Write the balanced equation for the half reaction that took place at the anode.

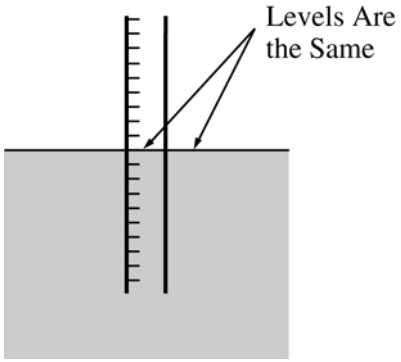
   (b) Calculate the amount of electric charge, in coulombs, that passed through the solution.

   (c) Why is the volume of $O_2(g)$ collected different from the volume of $H_2(g)$ collected, as shown in the diagram?

   (d) Calculate the number of moles of $H_2(g)$ produced during the electrolysis.

   (e) Calculate the volume, in liters, at 298 K and 1.00 atm of dry $H_2(g)$ produced during the electrolysis.

   (f) After the hydrolysis reaction was over, the vertical position of the tube containing the collected $H_2(g)$ was adjusted until the water levels inside and outside the tube were the same, as shown in the diagram below. The volume of gas in the tube was measured under these conditions of 298 K and 1.00 atm, and its volume was <u>greater</u> than the volume calculated in part (e). Explain.



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2005 SCORING GUIDELINES (Form B)

Question 1

$$K_a = \frac{[H_3O^+][OCl^-]}{[HOCl]} = 3.2 \times 10^{-8}$$

Hypochlorous acid, HOCl , is a weak acid in water. The K_a expression for HOCl is shown above.

(a) Write a chemical equation showing how HOCl behaves as an acid in water.

$HOCl(aq) + H_2O(l) \rightarrow OCl^-(aq) + H_3O^+(aq)$	One point is earned for the correct chemical equation.

(b) Calculate the pH of a 0.175 *M* solution of HOCl.

	$HOCl(aq)$ +	$H_2O(l)$ ⇄	$OCl^-(aq)$ +	$H_3O^+(aq)$
I	0.175	–	0	~ 0
C	$-x$	–	$+x$	$+x$
E	$0.175 - x$	–	$+x$	$+x$

$$K_a = \frac{[H_3O^+][OCl^-]}{[HOCl]} = \frac{(x)(x)}{(0.175 - x)}$$

Assume that $0.175 - x \approx 0.175$

$$3.2 \times 10^{-8} = \frac{x^2}{0.175}$$

$$x^2 = (3.2 \times 10^{-8})(0.175) = 5.6 \times 10^{-9}$$

$$x = [H_3O^+] = 7.5 \times 10^{-5}\ M$$

$$pH = -\log [H_3O^+] = -\log (7.5 \times 10^{-5}) = 4.13$$

One point is earned for calculating the value of $[H_3O^+]$.

One point is earned for calculating the pH.

(c) Write the net ionic equation for the reaction between the weak acid $HOCl(aq)$ and the strong base $NaOH(aq)$.

$HOCl(aq) + OH^-(aq) \rightarrow OCl^-(aq) + H_2O(l)$	One point is earned for both of the correct reactants. One point is earned for both of the correct products.

(d) In an experiment, 20.00 mL of 0.175 *M* $HOCl(aq)$ is placed in a flask and titrated with 6.55 mL of 0.435 *M* $NaOH(aq)$.

(i) Calculate the number of moles of $NaOH(aq)$ added.

$\text{mol}_{NaOH} = 6.55\ \text{mL} \times \frac{1\ \text{L}}{1{,}000\ \text{mL}} \times \frac{0.435\ \text{mol NaOH}}{1\ \text{L}}$ $\text{mol}_{NaOH} = 2.85 \times 10^{-3}\ \text{mol NaOH}$	One point is earned for the correct number of moles of NaOH.

Question 1 (continued)

(ii) Calculate $[H_3O^+]$ in the flask after the $NaOH(aq)$ has been added.

$\text{mol}_{HOCl} = 20.00\text{ mL} \times \frac{1\text{ L}}{1{,}000\text{ mL}} \times \frac{0.175\text{ mol NaOH}}{1\text{ L}} = 3.50 \times 10^{-3}\text{ mol}$ $OH^-(aq)$ is the limiting reactant, therefore all of it reacts $HOCl(aq) + OH^-(aq) \rightarrow OCl^-(aq) + H_2O(l)$ I 0.00350 0.00285 0 – C −0.00285 −0.00285 +0.00285 – E 0.00065 0 0.00285 – $M_{HOCl} = \frac{0.00065\text{ mol}}{0.02655\text{ L}} = 0.0245\ M$ $M_{OCl^-} = \frac{0.00285\text{ mol}}{0.02655\text{ L}} = 0.107\ M$ $HOCl(aq) + H_2O(l) \rightarrow H_3O^+(aq) + OCl^-(aq)$ I 0.0245 – ~0 0.107 C $-x$ – $+x$ $+x$ E $0.0245 - x$ – $+x$ $0.107 + x$ $K_a = \frac{[H_3O^+][OCl^-]}{[HOCl]} = \frac{(x)(0.107 + x)}{(0.0245 - x)}$ Assume that $0.107 + x \approx 0.107$ and that $0.0245 - x \approx 0.0245$ $3.2 \times 10^{-8} = \frac{(x)(0.107)}{(0.0245)}$ $x = [H_3O^+] = 7.3 \times 10^{-9}\ M$	One point is earned for calculating the initial number of moles of HOCl. One point is earned for the concentration or number of moles of HOCl and OCl^- after the neutralization reaction. One point is earned for the correct $[H_3O^+]$.

(iii) Calculate $[OH^-]$ in the flask after the $NaOH(aq)$ has been added.

$[H_3O^+][OH^-] = 1.0 \times 10^{-14} = K_w$ $[OH^-] = \frac{1.0 \times 10^{-14}}{[H_3O^+]} = \frac{1.0 \times 10^{-14}}{7.3 \times 10^{-9}} = 1.4 \times 10^{-6}\ M$	One point is earned for the correct concentration of OH^-.

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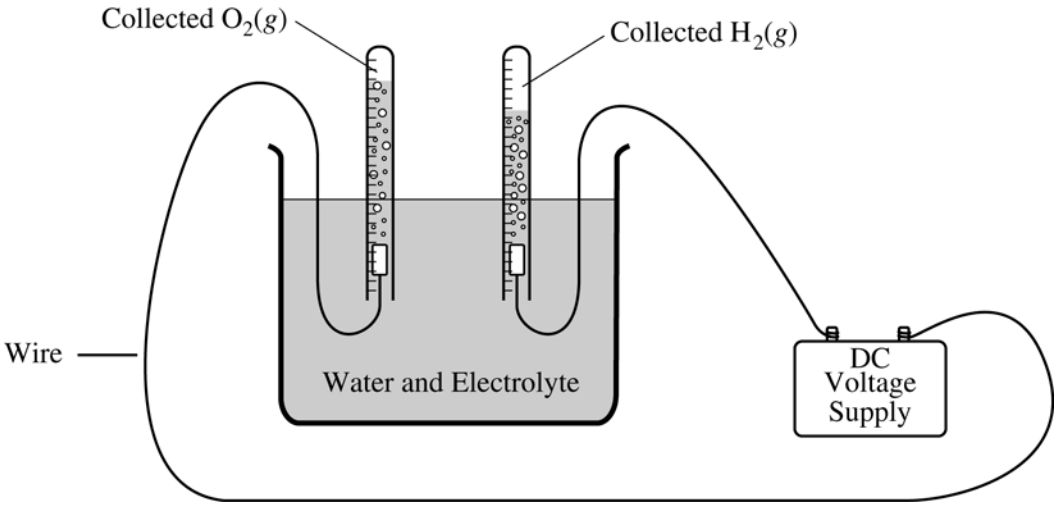
Question 2



Water was electrolyzed, as shown in the diagram above, for 5.61 minutes using a constant current of 0.513 ampere. A small amount of nonreactive electrolyte was added to the container before the electrolysis began. The temperature was 298 K and the atmospheric pressure was 1.00 atm.

(a) Write the balanced equation for the half reaction that took place at the anode.

$2\ H_2O(l) \rightarrow O_2(g) + 4\ H^+(aq) + 4\ e^-$	One point is earned for the correct half reaction.

(b) Calculate the amount of electric charge, in coulombs, that passed through the solution.

$0.513\ \text{amp} = 0.513\ \frac{\text{coul}}{\text{sec}}$ $\text{electric charge} = \left(0.513\ \frac{\text{coul}}{\text{sec}}\right) \times (5.61\ \text{min}) \times \left(\frac{60\ \text{sec}}{1\ \text{min}}\right) = 173\ \text{coulombs}$	One point is earned for the setup. One point is earned for the answer.

(c) Why is the volume of $O_2(g)$ collected different from the volume of $H_2(g)$ collected, as shown in the diagram?

When water decomposes according to the balanced chemical equation $2\ H_2O(l) \rightarrow O_2(g) + 2\ H_2(g)$, twice as many moles of hydrogen are produced than moles of oxygen.	One point is earned for the correct explanation based on the stoichiometry of the decomposition reaction.

Question 2 (continued)

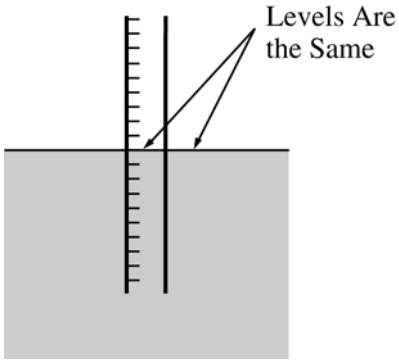
(d) Calculate the number of moles of $H_2(g)$ produced during the electrolysis.

The half-reaction that takes place at the cathode is: $2\ H_2O(l) + 2\ e^- \rightarrow H_2(g) + OH^-(aq)$ $\text{mol}_{H_2} = 173 \text{ coulombs} \times \left(\frac{1 \text{ mol } e^-}{96{,}500 \text{ coulomb}}\right) \times \left(\frac{1 \text{ mol } H_2(g)}{2 \text{ mol } e^-}\right)$ $\text{mol}_{H_2} = 8.96 \times 10^{-4} \text{ mol}$	One point is earned for the number of coulombs. One point is earned for recognizing the 1 : 2 stoichiometry.

(e) Calculate the volume, in liters, at 298 K and 1.00 atm of dry $H_2(g)$ produced during the electrolysis.

$V_{H_2} = \frac{n_{H_2} RT}{P}$ $V_{H_2} = \frac{(8.96 \times 10^{-4} \text{ mol}) \times \left(0.0821 \frac{\text{L atm}}{\text{mol K}}\right) \times (298 \text{ K})}{1 \text{ atm}} = 0.0219 \text{ L}$	One point is earned for the substitution into the gas law equation. One point is earned for the correct answer.

(f) After the hydrolysis reaction was over, the vertical position of the tube containing the collected $H_2(g)$ was adjusted until the water levels inside and outside the tube were the same, as shown in the diagram below. The volume of gas in the tube was measured under these conditions of 298 K and 1.00 atm, and its volume was <u>greater</u> than the volume calculated in part (e). Explain.



Because the electrolysis of water occurs in water, there is some water vapor in the tube of $H_2(g)$ that was collected. The volume calculated in part (e) was the volume of only the $H_2(g)$ in the tube at the given temperature and pressure. The presence of another gas (water vapor) results in a greater volume at the given temperature and pressure.	One point is earned for recognizing that there is some water vapor in the sample of hydrogen gas.

2005 AP® CHEMISTRY FREE-RESPONSE QUESTIONS

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 the booklet with the pink cover. Do NOT write your answers on the green insert.

Answer Question 1 below. The Section II score weighting for this question is 20 percent.

$$HC_3H_5O_2(aq) \rightleftarrows C_3H_5O_2^-(aq) + H^+(aq) \qquad K_a = 1.34 \times 10^{-5}$$

1. Propanoic acid, $HC_3H_5O_2$, ionizes in water according to the equation above.

   (a) Write the equilibrium-constant expression for the reaction.

   (b) Calculate the pH of a 0.265 *M* solution of propanoic acid.

   (c) A 0.496 g sample of sodium propanoate, $NaC_3H_5O_2$, is added to a 50.0 mL sample of a 0.265 *M* solution of propanoic acid. Assuming that no change in the volume of the solution occurs, calculate each of the following.

      (i) The concentration of the propanoate ion, $C_3H_5O_2^-(aq)$, in the solution

      (ii) The concentration of the $H^+(aq)$ ion in the solution

   The methanoate ion, $HCO_2^-(aq)$, reacts with water to form methanoic acid and hydroxide ion, as shown in the following equation.

$$HCO_2^-(aq) + H_2O(l) \rightleftarrows HCO_2H(aq) + OH^-(aq)$$

   (d) Given that $[OH^-]$ is 4.18×10^{-6} *M* in a 0.309 *M* solution of sodium methanoate, calculate each of the following.

      (i) The value of K_b for the methanoate ion, $HCO_2^-(aq)$

      (ii) The value of K_a for methanoic acid, HCO_2H

   (e) Which acid is stronger, propanoic acid or methanoic acid? Justify your answer.

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2005 SCORING GUIDELINES

Question 1

$$HC_3H_5O_2(aq) \rightleftarrows C_3H_5O_2^-(aq) + H^+(aq) \qquad K_a = 1.34 \times 10^{-5}$$

Propanoic acid, $HC_3H_5O_2$, ionizes in water according to the equation above.

(a) Write the equilibrium-constant expression for the reaction.

$K_a = \dfrac{[H^+][C_3H_5O_2^-]}{[HC_3H_5O_2]}$ Notes: Correct expression without K_a earns 1 point. Entering the value of K_a is acceptable. Charges must be correct to earn 1 point.	One point is earned for the correct equilibrium expression.

(b) Calculate the pH of a 0.265 M solution of propanoic acid.

$HC_3H_5O_2(aq) \rightleftarrows C_3H_5O_2^-(aq) + H^+(aq)$ I 0.265 0 ~0 C $-x$ $+x$ $+x$ E $0.265 - x$ $+x$ $+x$ $K_a = \dfrac{[H^+][C_3H_5O_2^-]}{[HC_3H_5O_2]} = \dfrac{(x)(x)}{(0.265-x)}$ Assume that $0.265 - x \approx 0.265$, then $1.34 \times 10^{-5} = \dfrac{x^2}{0.265}$ $(1.34 \times 10^{-5})(0.265) = x^2$ $3.55 \times 10^{-6} = x^2$ $x = [H^+] = 1.88 \times 10^{-3}\ M$ $pH = -\log[H^+] = -\log(1.88 \times 10^{-3})$ $pH = 2.725$	One point is earned for recognizing that $[H^+]$ and $[C_3H_5O_2^-]$ have the same value in the equilibrium expression. One point is earned for calculating $[H^+]$. One point is earned for calculating the correct pH.

Question 1 (continued)

(c) A 0.496 g sample of sodium propanoate, $NaC_3H_5O_2$, is added to a 50.0 mL sample of a 0.265 *M* solution of propanoic acid. Assuming that no change in the volume of the solution occurs, calculate each of the following.

(i) The concentration of the propanoate ion, $C_3H_5O_2^-(aq)$ in the solution

$\text{mol } NaC_3H_5O_2 = 0.496 \text{ g } NaC_3H_5O_2 \times \frac{1 \text{ mol } NaC_3H_5O_2}{96.0 \text{ g } NaC_3H_5O_2}$ $\text{mol } NaC_3H_5O_2 = 5.17 \times 10^{-3} \text{ mol } NaC_3H_5O_2 = \text{mol } C_3H_5O_2^-$ $[C_3H_5O_2^-] = \frac{\text{mol } C_3H_5O_2^-}{\text{volume of solution}} = \frac{5.17 \times 10^{-3} \text{ mol } C_3H_5O_2^-}{0.050 \text{ L}} = 0.103 \ M$	One point is earned for calculating the number of moles of $NaC_3H_5O_2$. One point is earned for the molarity of the solution.

(ii) The concentration of the $H^+(aq)$ ion in the solution

$HC_3H_5O_2(aq) \rightleftarrows C_3H_5O_2^-(aq) + H^+(aq)$ I 0.265 0.103 ~0 C $-x$ $+x$ $+x$ E $0.265 - x$ $0.103 + x$ $+x$ $K_a = \frac{[H^+][C_3H_5O_2^-]}{[HC_3H_5O_2]} = \frac{(x)(0.103 + x)}{(0.265 - x)}$ Assume that $0.103 + x \approx 0.103$ and $0.265 - x \approx 0.265$ $K_a = 1.34 \times 10^{-5} = \frac{(x)(0.103)}{0.265}$ $x = [H^+] = (1.34 \times 10^{-5}) \times \frac{0.265}{0.103} = 3.45 \times 10^{-5} \ M$	One point is earned for calculating the value of $[H^+]$.

The methanoate ion, $HCO_2^-(aq)$, reacts with water to form methanoic acid and hydroxide ion, as shown in the following equation.

$$HCO_2^-(aq) + H_2O(l) \rightleftarrows HCO_2H(aq) + OH^-(aq)$$

(d) Given that $[OH^-]$ is 4.18×10^{-6} *M* in a 0.309 *M* solution of sodium methanoate, calculate each of the following.

Question 1 (continued)

(i) The value of K_b for the methanoate ion, $HCO_2^-(aq)$

	$HCO_2^-(aq)$ +	$H_2O(l)$ ⇄	HCO_2H +	$OH^-(aq)$
I	0.309	-	0	~0
C	$-x$	-	$+x$	$+x$
E	$0.309 - x$	-	$+x$	$+x$

$x = [OH^-] = 4.18 \times 10^{-6}\ M$

$$K_b = \frac{[OH^-][HCO_2H]}{[HCO_2^-]} = \frac{(x)(x)}{(0.309-x)} = \frac{(4.18\times10^{-6})^2}{(0.309-x)}$$

x is very small ($4.18 \times 10^{-6}\ M$), therefore $0.309 - x \approx 0.309$

$$K_b = \frac{(4.18\times10^{-6})^2}{0.309} = 5.65 \times 10^{-11}$$

One point is earned for substituting 4.18×10^{-6} for both $[OH^-]$ and $[HCO_2H]$, and for calculating the value of K_b.

(ii) The value of K_a for methanoic acid, HCO_2H

$$K_w = K_a \times K_b$$

$$K_a = \frac{K_w}{K_b} = \frac{1.00\times10^{-14}}{5.65\times10^{-11}}$$

$$K_a = 1.77 \times 10^{-4}$$

One point is earned for calculating a value of K_a from the value of K_b determined in part (d)(i).

(e) Which acid is stronger, propanoic acid or methanoic acid? Justify your answer.

K_a for propanoic acid is 1.34×10^{-5}, and K_a for methanoic acid is 1.77×10^{-4}. For acids, the larger the value of K_a, the greater the strength; therefore methanoic acid is the stronger acid because $1.77 \times 10^{-4} > 1.34 \times 10^{-5}$.

One point is earned for the correct choice and explanation based on the K_a calculated for methanoic acid in part (d)(ii).

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 the booklet with the pink cover. Do NOT write your answers on the green insert.

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.

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2007 SCORING GUIDELINES

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.

$K_a = \dfrac{[H_3O^+][F^-]}{[HF]} = \dfrac{(x)(x)}{0.40 - x} = 7.2 \times 10^{-4}$ 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 setup (or the setup consistent with part (a)). 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 $F^-(aq)$ $\dfrac{0.0060 \text{ mol } F^-(aq)}{(0.015 + 0.025) \text{ L of solution}} = 0.15\ M\ F^-(aq)$	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.

$[HF] = \frac{0.004 \text{ mol HF}}{0.040 \text{ L}} = 0.10\ M$ HF $K_a = \frac{[H_3O^+][F^-]}{[HF]} \Rightarrow \frac{[HF] \times K_a}{[F^-]} = [H_3O^+]$ $\Rightarrow \frac{0.10\ M\ (7.2 \times 10^{-4})}{0.15\ M} = 4.8 \times 10^{-4}$ $\Rightarrow$ pH $= -\log(4.8 \times 10^{-4}) = 3.32$ **OR** $\text{pH} = \text{p}K_a + \log \frac{[F^-]}{[HF]}$ $= -\log(7.2 \times 10^{-4}) + \log \frac{0.15\ M}{0.10\ M}$ $= 3.14 + 0.18$ $= 3.32$	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.

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, $C_2H_5NH_2$, is dissolved in enough distilled water to make 500. mL of solution.

   (a) Calculate the molar concentration of the $C_2H_5NH_2$ in the solution.

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

   $$C_2H_5NH_2(aq) + H_2O(l) \rightleftarrows C_2H_5NH_3^+(aq) + OH^-(aq)$$

   (b) Write the equilibrium-constant expression for the reaction between $C_2H_5NH_2(aq)$ and water.

   (c) Of $C_2H_5NH_2(aq)$ and $C_2H_5NH_3^+(aq)$, 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* $C_2H_5NH_2$ 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 $C_2H_5NH_2$ solution is mixed with the HCl solution.

      (iii) Calculate the molar concentration of the $C_2H_5NH_3^+(aq)$ that is formed in the reaction.

      (iv) Calculate the value of K_b for $C_2H_5NH_2$.

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Question 1 (10 points)

A pure 14.85 g sample of the weak base ethylamine, $C_2H_5NH_2$, is dissolved in enough distilled water to make 500. mL of solution.

(a) Calculate the molar concentration of the $C_2H_5NH_2$ in the solution.

$n_{C_2H_5NH_2} = 14.85\text{ g } C_2H_5NH_2 \times \frac{1\text{ mol } C_2H_5NH_2}{45.09\text{ g } C_2H_5NH_2}$ $= 0.3293\text{ mol } C_2H_5NH_2$ $M_{C_2H_5NH_2} = \frac{0.3293\text{ mol } C_2H_5NH_2}{0.500\text{ L}} = \mathbf{0.659\ \textit{M}}$	One point is earned for the correct number of moles. One point is earned for the correct concentration.

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

$$C_2H_5NH_2(aq) + H_2O(l) \rightleftarrows C_2H_5NH_3^+(aq) + OH^-(aq)$$

(b) Write the equilibrium-constant expression for the reaction between $C_2H_5NH_2(aq)$ and water.

$K_b = \frac{[C_2H_5NH_3^+][OH^-]}{[C_2H_5NH_2]}$	One point is earned for the correct expression.

(c) Of $C_2H_5NH_2(aq)$ and $C_2H_5NH_3^+(aq)$, which is present in the solution at the higher concentration at equilibrium? Justify your answer.

$C_2H_5NH_2$ 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 $C_2H_5NH_2$ occurs in water, and $[C_2H_5NH_3^+]$ is thus less than $[C_2H_5NH_2]$.	One point is earned for the correct answer with justification.

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Question 1 (continued)

(d) A different solution is made by mixing 500. mL of 0.500 *M* $C_2H_5NH_2$ 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.

$pH = -\log[H^+]$ $[H^+] = 10^{-10.93} = 1.17 \times 10^{-11}$ $[OH^-] = \frac{K_w}{[H^+]} = \frac{1.00 \times 10^{-14}}{1.17 \times 10^{-11}} = \mathbf{8.5 \times 10^{-4}\ M}$ **OR** $pOH = 14 - pH = 14 - 10.93 = 3.07$ $pOH = -\log[OH^-]$ $[OH^-] = 10^{-3.07} = \mathbf{8.5 \times 10^{-4}\ M}$	One point is earned for the correct concentration.

(ii) Write the net-ionic equation that represents the reaction that occurs when the $C_2H_5NH_2$ solution is mixed with the HCl solution.

$C_2H_5NH_2 + H_3O^+ \rightarrow C_2H_5NH_3^+ + H_2O$	One point is earned for the correct equation.

(iii) Calculate the molar concentration of the $C_2H_5NH_3^+(aq)$ that is formed in the reaction.

moles of $C_2H_5NH_2 = 0.500\ L \times \frac{0.500\ mol}{1.00\ L} = \mathbf{0.250\ mol}$ moles of $H_3O^+ = 0.500\ L \times \frac{0.200\ mol}{1.00\ L} = \mathbf{0.100\ mol}$	One point is earned for the correct number of moles of $C_2H_5NH_2$ and H_3O^+.

	$[C_2H_5NH_2]$	$[H_3O^+]$	$[C_2H_5NH_3^+]$
initial value	0.250	0.100	~ 0
change	−0.100	−0.100	+0.100
final value	0.150	~ 0	0.100

$[C_2H_5NH_3^+] = \frac{0.100\ mol\ C_2H_5NH_3^+}{1.00\ L} = \mathbf{0.100\ M}$	One point is earned for the correct concentration.

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Question 1 (continued)

(iv) Calculate the value of K_b for $C_2H_5NH_2$.

$[C_2H_5NH_2] = \frac{0.150 \text{ mol } C_2H_5NH_2}{1.00 \text{ L}} = \mathbf{0.150\ \textit{M}}$	One point is earned for the correct calculation of the molarity of $C_2H_5NH_2$ after neutralization.
$K_b = \frac{[C_2H_5NH_3^+][OH^-]}{[C_2H_5NH_2]} = \frac{(0.100)(8.5 \times 10^{-4})}{0.150} = \mathbf{5.67 \times 10^{-4}}$	One point is earned for the correct value.