## 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.

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| $K_a = \dfrac{[H^+][C_3H_5O_2^-]}{[HC_3H_5O_2]}$ <br> Notes: Correct expression without $K_a$ earns 1 point. <br> Entering the value of $K_a$ is acceptable. <br> 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.

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

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

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

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| $HC_3H_5O_2(aq) \rightleftarrows C_3H_5O_2^-(aq) + H^+(aq)$<br>I 0.265 0.103 ~0<br>C $-x$ $+x$ $+x$<br>E $0.265 - x$ $0.103 + x$ $+x$<br>$K_a = \frac{[H^+][C_3H_5O_2^-]}{[HC_3H_5O_2]} = \frac{(x)(0.103+x)}{(0.265-x)}$<br>Assume that $0.103 + x \approx 0.103$ and $0.265 - x \approx 0.265$<br>$K_a = 1.34 \times 10^{-5} = \frac{(x)(0.103)}{0.265}$<br>$x = [H^+] = (1.34 \times 10^{-5}) \times \frac{0.265}{0.103} = 3.45 \times 10^{-5}\ M$ | 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 $4.18 \times 10^{-6}$ *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, $HCO_2^-(aq)$

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| $HCO_2^-(aq) + H_2O(l) \rightleftarrows HCO_2H + OH^-(aq)$<br>I 0.309 - 0 ~0<br>C $-x$ - $+x$ $+x$<br>E $0.309 - x$ - $+x$ $+x$<br>$x = [OH^-] = 4.18 \times 10^{-6}\ M$<br>$K_b = \frac{[OH^-][HCO_2H]}{[HCO_2^-]} = \frac{(x)(x)}{(0.309-x)} = \frac{(4.18\times10^{-6})^2}{(0.309-x)}$<br>$x$ is very small ($4.18 \times 10^{-6}\ M$), therefore $0.309 - x \approx 0.309$<br>$K_b = \frac{(4.18\times10^{-6})^2}{0.309} = 5.65 \times 10^{-11}$ | One point is earned for substituting $4.18 \times 10^{-6}$ for both $[OH^-]$ and $[HCO_2H]$, and for calculating the value of $K_b$. |

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

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| $K_w = K_a \times K_b$<br>$K_a = \frac{K_w}{K_b} = \frac{1.00\times10^{-14}}{5.65\times10^{-11}}$<br>$K_a = 1.77 \times 10^{-4}$ | 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.

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| $K_a$ for propanoic acid is $1.34 \times 10^{-5}$, and $K_a$ for methanoic acid is $1.77 \times 10^{-4}$. 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). |