Question 2
(10 points)

$$CH_3CH_2COOH(aq) + H_2O(l) \rightleftarrows CH_3CH_2COO^-(aq) + H_3O^+(aq)$$

Propanoic acid, CH_3CH_2COOH, is a carboxylic acid that reacts with water according to the equation above. At 25°C the pH of a 50.0 mL sample of 0.20 M CH_3CH_2COOH is 2.79.

(a) Identify a Brønsted-Lowry conjugate acid-base pair in the reaction. Clearly label which is the acid and which is the base.

CH_3CH_2COOH and $CH_3CH_2COO^-$ *acid* *base* OR H_3O^+ and H_2O *acid* *base*	1 point is earned for writing (or naming) either of the Brønsted-Lowry conjugate acid-base pairs with a clear indication of which is the acid and which is the base.

(b) Determine the value of K_a for propanoic acid at 25°C.

$[H_3O^+] = 10^{-pH} = 10^{-2.79} = 1.6 \times 10^{-3}\ M$	1 point is earned for correctly solving for $[H_3O^+]$.
$[CH_3CH_2COO^-] = [H_3O^+]$ AND $[CH_3CH_2COOH] = 0.20\ M - [H_3O^+]$, OR $[CH_3CH_2COOH] \approx 0.20\ M$ (state or assume that $[H_3O^+] << 0.20\ M$)	1 point is earned for the K_a expression for propanoic acid OR 1 point is earned for substituting values into the K_a expression.
$K_a = \dfrac{[CH_3CH_2COO^-][H_3O^+]}{[CH_3CH_2COOH]} = \dfrac{(1.6 \times 10^{-3}\ M)^2}{0.20\ M} = 1.3 \times 10^{-5}$	1 point is earned for correctly solving for the value of K_a.

(c) For each of the following statements, determine whether the statement is true or false. In each case, explain the reasoning that supports your answer.

(i) The pH of a solution prepared by mixing the 50.0 mL sample of 0.20 M CH_3CH_2COOH with a 50.0 mL sample of 0.20 M NaOH is 7.00.

False. The conjugate base of a weak acid undergoes hydrolysis (see equation below) at equivalence to form a solution with a pH > 7. $(CH_3CH_2COO^- + H_2O \rightleftarrows CH_3CH_2COOH + OH^-)$	1 point is earned for noting that the statement is false AND providing a supporting explanation.

Question 2 (continued)

(ii) If the pH of a hydrochloric acid solution is the same as the pH of a propanoic acid solution, then the molar concentration of the hydrochloric acid solution must be less than the molar concentration of the propanoic acid solution.

True. HCl is a strong acid that ionizes completely. Fewer moles of HCl are needed to produce the same $[H_3O^+]$ as the propanoic acid solution, which only partially ionizes.	1 point is earned for noting that the statement is true and providing a supporting explanation.

A student is given the task of determining the concentration of a propanoic acid solution of unknown concentration. A 0.173 M NaOH solution is available to use as the titrant. The student uses a 25.00 mL volumetric pipet to deliver the propanoic acid solution to a clean, dry flask. After adding an appropriate indicator to the flask, the student titrates the solution with the 0.173 M NaOH, reaching the end point after 20.52 mL of the base solution has been added.

(d) Calculate the molarity of the propanoic acid solution.

Let x = moles of propanoic acid then $x = (0.02052\text{ L NaOH}) \times \frac{0.173\text{ mol NaOH}}{1\text{ L NaOH}} \times \frac{1\text{ mol acid}}{1\text{ mol NaOH}}$ $= 3.55 \times 10^{-3}$ mol propanoic acid $\frac{3.55 \times 10^{-3}\text{ mol acid}}{0.02500\text{ L acid}} = 0.142\ M$ OR Since CH_3CH_2COOH is monoprotic and, at the equivalence point, moles H^+ = moles OH^-, then $M_A V_A = M_B V_B$ $M_A = \frac{M_B V_B}{V_A} = \frac{(0.173\ M\text{ NaOH})(20.52\text{ mL NaOH})}{25.00\text{ mL acid}} = 0.142\ M$	1 point is earned for correctly calculating the number of moles of acid that reacted at the equivalence point. 1 point is earned for the correct molarity of acid.

(e) The student is asked to redesign the experiment to determine the concentration of a butanoic acid solution instead of a propanoic acid solution. For butanoic acid the value of pK_a is 4.83. The student claims that a different indicator will be required to determine the equivalence point of the titration accurately. Based on your response to part (b), do you agree with the student's claim? Justify your answer.

Question 2 (continued)

Disagree with the student's claim From part (b) above, pK_a for propanoic acid is $\log(1.3 \times 10^{-5}) = 4.89$. Because 4.83 is so close to 4.89, the pH at the equivalence point in the titration of butanoic acid should be close enough to the pH in the titration of propanoic acid to make the original indicator appropriate for the titration of butanoic acid.	1 point is earned for disagreeing with the student's claim and making a valid justification using pK_a, K_a, or pH arguments. 1 point is earned for numerically comparing either: the two pK_a values, the two K_a values, or the two pH values at the equivalence point.