Question 3

Potassium sorbate, $KC_6H_7O_2$ (molar mass 150. g/mol) is commonly added to diet soft drinks as a preservative. A stock solution of $KC_6H_7O_2(aq)$ of known concentration must be prepared. A student titrates 45.00 mL of the stock solution with 1.25 *M* HCl(*aq*) using both an indicator and a pH meter. The value of K_a for sorbic acid, $HC_6H_7O_2$, is 1.7×10^{-5}.

(a) Write the net-ionic equation for the reaction between $KC_6H_7O_2(aq)$ and $HCl(aq)$.

$H^+ + C_6H_7O_2^- \rightleftarrows HC_6H_7O_2$	1 point is earned the net-ionic equation.

(b) A total of 29.95 mL of 1.25 *M* HCl(*aq*) is required to reach the equivalence point. Calculate $[KC_6H_7O_2]$ in the stock solution.

$\frac{1.25 \text{ mol HCl}}{1000 \text{ mL}} = \frac{x \text{ mol HCl}}{29.95 \text{ mL}}$ $x = 0.0374$ mol HCl	1 point is earned for the moles of HCl at the equivalence point.
$\frac{0.0374 \text{ mol } C_6H_7O_2^-}{45.0 \text{ mL}} = \frac{x \text{ mol } C_6H_7O_2^-}{1000 \text{ mL}} \Rightarrow 0.832\ M$	1 point is earned for the correct answer.

(c) The pH at the equivalence point of the titration is measured to be 2.54. Which of the following indicators would be the best choice for determining the end point of the titration? Justify your answer.

Indicator	pK_a
Phenolphthalein	9.3
Bromothymol blue	7.0
Methyl red	5.0
Thymol blue	2.0
Methyl violet	0.80

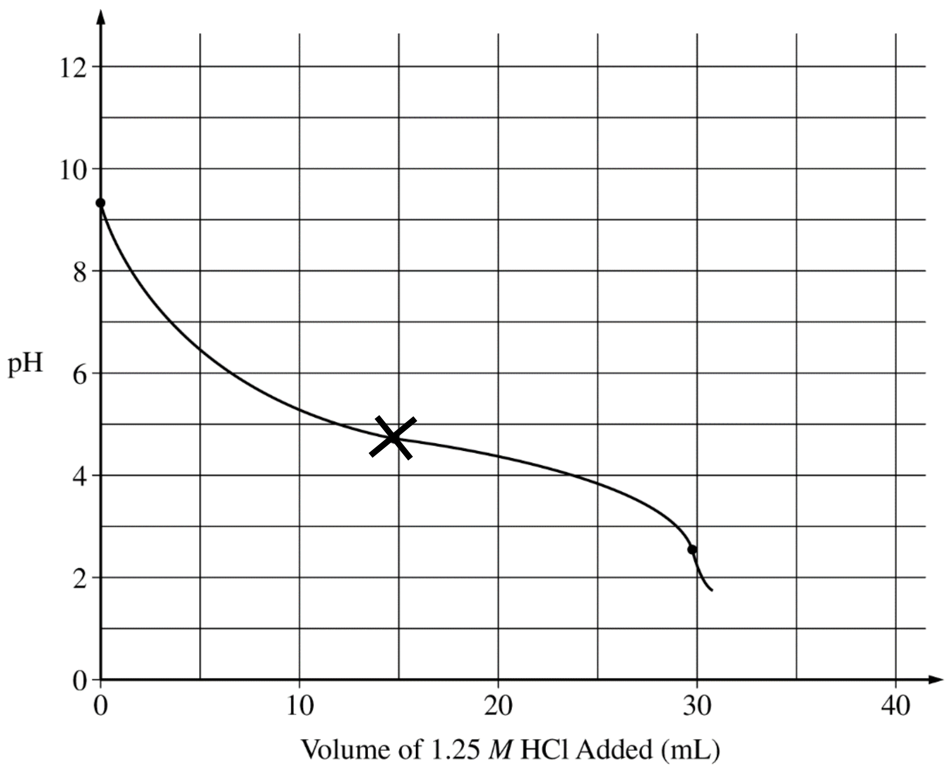
Thymol blue; it has a pK_a close to the pH at the equivalence point, so it will change color near the equivalence point.	1 point is earned for the correct indicator. 1 point is earned for correct justification.

(d) Calculate the pH at the half-equivalence point.

$pH = pK_a = -\log(1.7 \times 10^{-5}) = 4.77$	1 point is earned for the correct pH.

Question 3 (continued)

(e) The initial pH and the equivalence point are plotted on the graph below. Accurately sketch the titration curve on the graph below. Mark the position of the half-equivalence point on the curve with an X.



[The pH curve should have the correct shape.]	1 point is earned for a half-equivalence point consistent with the answer to part (d) and at the correct volume. 1 point is earned for a curve that levels off to a relatively horizontal slope through the half-equivalence point. 1 point is earned for a relatively steep negative slope through the equivalence point.

Question 3 (continued)

(f) The pH of the soft drink is 3.37 after the addition of the $KC_6H_7O_2(aq)$. Which species, $HC_6H_7O_2$ or $C_6H_7O_2^-$, has a higher concentration in the soft drink? Justify your answer.

For sorbic acid, $K_a = \dfrac{[H^+][C_6H_7O_2^-]}{[HC_6H_7O_2]}$, thus $\dfrac{[C_6H_7O_2^-]}{[HC_6H_7O_2]} = \dfrac{K_a}{[H^+]} = \dfrac{1.7 \times 10^{-5}}{10^{-3.37}} \approx 0.04$ $\Rightarrow [HC_6H_7O_2] > [C_6H_7O_2^-]$ **OR** The concentrations of $HC_6H_7O_2$ and $C_6H_7O_2^-$ are equal at the half-equivalence point. A pH of 3.37 is lower than that at the half-equivalence point, so the protonated form, $HC_6H_7O_2$, has a higher concentration in the soft drink.	1 point is earned for identifying the correct species <u>and</u> for making a comparison involving the pH (with or without calculation).

11:47

3A 1 of 3

3. Potassium sorbate, $KC_6H_7O_2$ (molar mass 150. g/mol) is commonly added to diet soft drinks as a preservative. A stock solution of $KC_6H_7O_2(aq)$ of known concentration must be prepared. A student titrates 45.00 mL of the stock solution with 1.25 M $HCl(aq)$ using both an indicator and a pH meter. The value of K_a for sorbic acid, $HC_6H_7O_2$, is 1.7×10^{-5}.

yum haha

45mL $KC_6H_7O_2$ 1.25M HCl

(a) Write the net-ionic equation for the reaction between $KC_6H_7O_2(aq)$ and $HCl(aq)$.

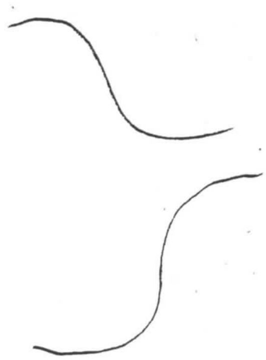
(b) A total of 29.95 mL of 1.25 M $HCl(aq)$ is required to reach the equivalence point. Calculate $[KC_6H_7O_2]$ in the stock solution.

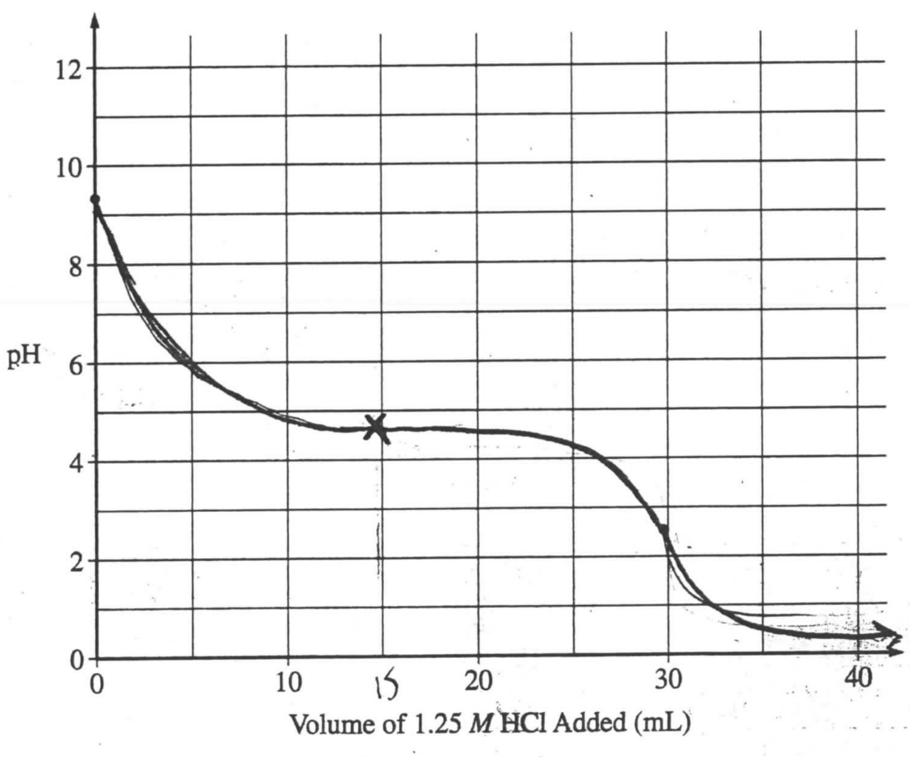
(c) The pH at the equivalence point of the titration is measured to be 2.54. Which of the following indicators would be the best choice for determining the end point of the titration? Justify your answer.

Indicator	pK_a
Phenolphthalein	9.3
Bromothymol blue	7.0
Methyl red	5.0
Thymol blue	2.0
Methyl violet	0.80

(d) Calculate the pH at the half-equivalence point.

(e) The initial pH and the equivalence point are plotted on the graph below. Accurately sketch the titration curve on the graph below. Mark the position of the half-equivalence point on the curve with an X.





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(f) The pH of the soft drink is 3.37 after the addition of the $KC_6H_7O_2(aq)$. Which species, $HC_6H_7O_2$ or $C_6H_7O_2^-$, has a higher concentration in the soft drink? Justify your answer.

(a) $C_6H_7O_2^-(aq) + H^+(aq) \rightarrow HC_6H_7O_2(aq)$

(b) 29.95 mL of 1.25 M HCl → equivalence
at equivalence all acid is gone

$1.25M = \frac{x\ mol}{.02995 L}$

x mol = 0.0374 mol H^+ → .0374 mol $C_6H_7O_2^-$

stock
$KC_6H_7O_2(aq)$ 45 mL

$xM = \frac{.0374\ mol}{.045 L}$

xM = .831111111

$[KC_6H_7O_2] = .831\ M$

(c) pH @ equivalence = 2.54
Best indicator = Thymol blue b/c it changes color at a pKa of 2.0, which is closest to the pH at equivalence of 2.54

(d) pH = pKa @ halfway to equivalence
pH = -log(Ka)
pH = -log(1.7 × 10⁻⁵)

pH = 4.77

GO ON TO THE NEXT PAGE.

(f) pH = 3.37

↑ past halfway to equivalence
- at halfway to equivalence $[C_6H_7O_2^-] = [HC_6H_7O_2]$
- since the pH is lower than the pH at equivalence, more $HC_6H_7O_2$ is present.
↳ math to support.

$pH = pKa + \log \frac{A}{HA}$

$3.37 = -\log(1.7 \times 10^{-5}) + \log(X)$

X = .039 meaning HA > A

3. Potassium sorbate, $KC_6H_7O_2$ (molar mass 150. g/mol) is commonly added to diet soft drinks as a preservative. A stock solution of $KC_6H_7O_2(aq)$ of known concentration must be prepared. A student titrates 45.00 mL of the stock solution with 1.25 *M* HCl(*aq*) using both an indicator and a pH meter. The value of K_a for sorbic acid, $HC_6H_7O_2$, is 1.7×10^{-5}.

(a) Write the net-ionic equation for the reaction between $KC_6H_7O_2(aq)$ and HCl(*aq*).

(b) A total of 29.95 mL of 1.25 *M* HCl(*aq*) is required to reach the equivalence point. Calculate $[KC_6H_7O_2]$ in the stock solution.

(c) The pH at the equivalence point of the titration is measured to be 2.54. Which of the following indicators would be the best choice for determining the end point of the titration? Justify your answer.

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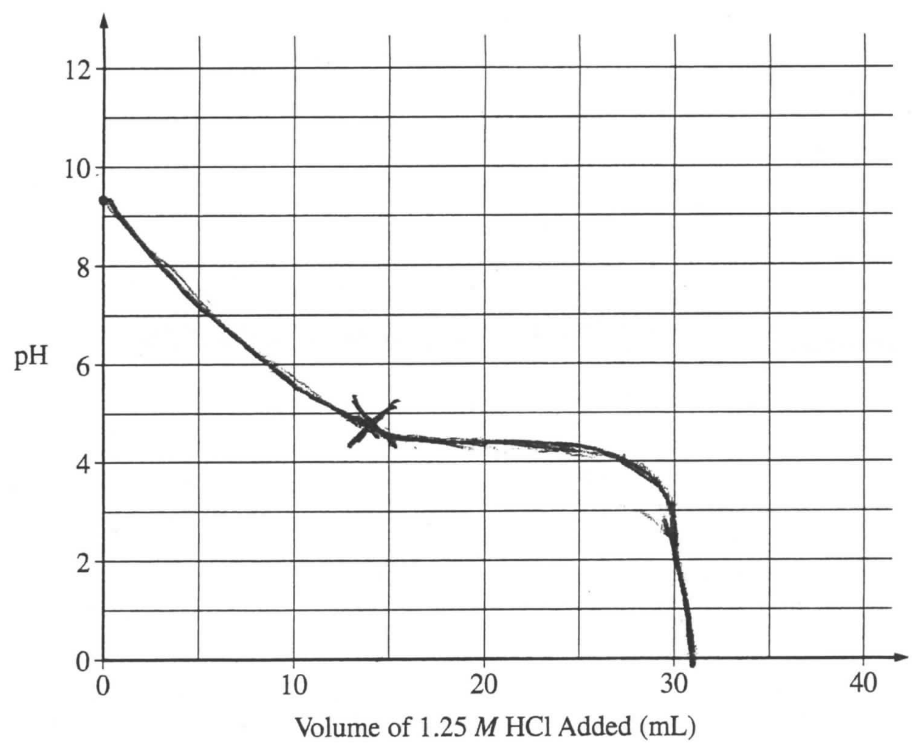

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(f) The pH of the soft drink is 3.37 after the addition of the $KC_6H_7O_2(aq)$. Which species, $HC_6H_7O_2$ or $C_6H_7O_2^-$, has a higher concentration in the soft drink? Justify your answer.

a) $C_6H_7O_2^- + H^+ \rightleftharpoons HC_6H_7O_2$

b) $\frac{1.25 \text{ mol } H^+}{1 \text{ L}} \times .02995 L = .0374 \text{ mol } H^+$

$.0374 \text{ mol } H^+ \times \frac{1 \text{ mol } C_6H_7O_2^-}{1 \text{ mol } H^+} \times \frac{1 \text{ mol } KC_6H_7O_2}{1 \text{ mol } C_6H_7O_2^-} = .0374 \text{ mol } KC_6H_7O_2$

$\frac{.0374 \text{ mol}}{.04500 L} = \boxed{.832 \text{ M } KC_6H_7O_2}$

c) Thymol blue is the best indicator for determining the end point of the titration because the indicator changes color when the pH = its pKa. Thymol blue has a pKa closest to the end point of the titration

d) at half-equivalence, [base] = [conjugate acid], so pH = pKa

$pH = -\log(1.7 \times 10^{-5})$

$\boxed{pH = 4.8}$

e) see graph

f) $HC_6H_7O_2$ has a higher concentration than $C_6H_7O_2^-$ because $HC_6H_7O_2$ is an acid and $C_6H_7O_2^-$ is a base and the pH of the soft drink is acidic. Also, $HC_6H_7O_2$ is a weak acid so it will barely dissociate to form $C_6H_7O_2^-$.

GO ON TO THE NEXT PAGE.

3. Potassium sorbate, $KC_6H_7O_2$ (molar mass 150. g/mol) is commonly added to diet soft drinks as a preservative. A stock solution of $KC_6H_7O_2(aq)$ of known concentration must be prepared. A student titrates 45.00 mL of the stock solution with 1.25 M HCl(aq) using both an indicator and a pH meter. The value of K_a for sorbic acid, $HC_6H_7O_2$, is 1.7×10^{-5}.

(a) Write the net-ionic equation for the reaction between $KC_6H_7O_2(aq)$ and HCl(aq).

(b) A total of 29.95 mL of 1.25 M HCl(aq) is required to reach the equivalence point. Calculate $[KC_6H_7O_2]$ in the stock solution.

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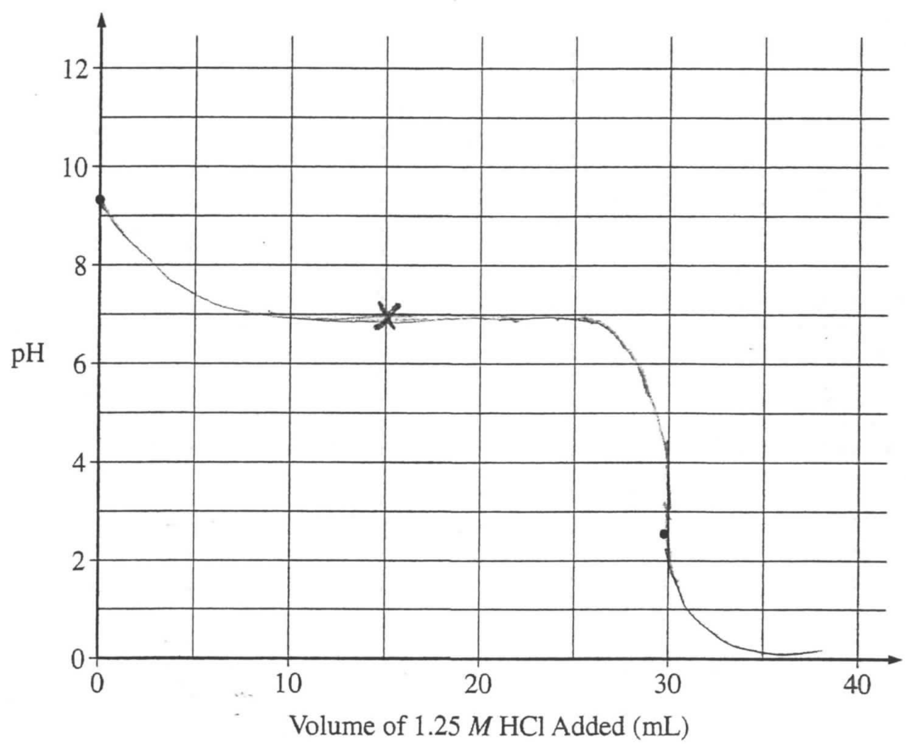

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(f) The pH of the soft drink is 3.37 after the addition of the $KC_6H_7O_2(aq)$. Which species, $HC_6H_7O_2$ or $C_6H_7O_2^-$, has a higher concentration in the soft drink? Justify your answer.

a) $KC_6H_7O_2 + HCl \rightarrow KCl + HC_6H_7O_2$

$C_6H_7O_2^- + H^+ \rightarrow HC_6H_7O_2$

b) $M_1V_1 = M_2V_2$

$(1.25)(29.95) = M_2(45)$

$M_2 = 0.83M$

C) Bromothymol Blue because Pka = pH at half the equivalence point and because the titration is acid into base, the initial pH is basic so at half the equivalence point (which is in the buffer zone) the pH will be closer to basic than it will acid. Since the pH at the equivalence point is 2.54 Bromothymol Blue makes the most sense because it is closer to the initial pH of the titration.

D) pH = pka at half the equivalence point so pH = 7.0 at half the equivalence point.

f) Since the pH is 3.37 the species of $HC_6H_7O_2$ has a higher concentration because the pH is acidic and $HC_6H_7O_2$ is an acid.

GO ON TO THE NEXT PAGE.

Question 3

Overview

Question 3 addressed a range of chemical concepts associated with acid-base chemistry. Students were provided a laboratory scenario that involved the titration of a known volume of weak base ($C_6H_7O_2^-$, sorbate ion) with a strong acid (HCl) of known concentration. In part (a) students were asked to write the net-ionic equation for the reaction between potassium sorbate ($KC_6H_7O_2$) and hydrochloric acid (HCl). In part (b) students were provided experimental data pertaining to the volume of HCl required to reach the equivalence point of the titration. Based on this data, the students were asked to calculate the concentration of the $KC_6H_7O_2$ stock solution. In part (c) students were provided an equivalence point pH and a table consisting of various indicators and their respective pK_a values. Based on the pH at the equivalence point, students were asked to choose the appropriate indicator and to justify their selection. In part (d) students were asked to calculate the pH at the half-equivalence point. In part (e) students were asked to sketch a titration curve representative of the curve generated by the titration of the sorbate ion with HCl. In part (f) students were asked to identify the component of the conjugate pair ($HC_6H_7O_2/C_6H_7O_2^-$) that is present in larger quantity at a particular pH.

Sample: 3A
Score: 10

This response earned 10 out of a possible 10 points. One point was earned in part (a) for correctly writing the chemical formula for the $C_6H_7O_2^-$ and hydrogen ions, including the correct charges, and then the correct formula for the product. The 2 points in part (b) were earned for calculating the correct number of moles of HCl, then indicating the number of moles of sorbate ion using the $C_6H_7O_2^-$: HCl mole ratio, and then subsequently calculating the correct [$KC_6H_7O_2$]. The first point in part (c) was earned for selecting thymol blue as the indicator to use in the titration. The second point was earned for indicating that the color change of the indicator will occur near the pH of the equivalence point and that the pK_a of thymol blue is closest to the pH at the equivalence point. One point was earned in part (d) for correctly calculating the pH at the half-equivalence point. The first point in part (e) was earned for correctly indicating the location of the half-equivalence at ~15 mL that is consistent with the pH reported in part (d). The second point in part (e) was earned for a curve that levels off to a relatively horizontal slope through the half-equivalence point. The third point in part (e) was earned for a relatively steep negative slope, in comparison to the slope through the half-equivalence point, through the equivalence point. One point was earned in part (f) for indicating that [$HC_6H_7O_2$] > [$C_6H_7O_2^-$] and for the justification. The student correctly applies the Henderson-Hasselbalch equation to support the selection of $HC_6H_7O_2$ as having the higher concentration.

Sample: 3B
Score: 8

This response earned 8 out of 10 possible points. One point was earned in part (a) for correctly writing the chemical formula for the $C_6H_7O_2^-$ and hydrogen ions, including the correct charges, and then the correct formula for the product. The 2 points in part (b) were earned for correctly calculating the concentration of the stock solution based on a mole-to-mole ratio between HCl and $C_6H_7O_2^-$. The first point in part (c) was earned for correctly choosing thymol blue as the indicator to use in the titration. The second point was earned for indicating that the color change of the indicator will occur near the pH of the end point and that the pK_a of thymol blue is closest to the end point. One point was earned in part (d) for correctly calculating the pH at the half-equivalence point. The first point in part (e) was earned for correctly indicating

Question 3 (continued)

the location of the half-equivalence within an acceptable range of volume. The second point in part (e) was not earned because the response indicated that the curve begins to level off after the half-equivalence point, or that the half-equivalence initiates the leveling-off, buffering activity. The third point in part (e) was earned for a steep negative slope (relative to the slope associated with the buffering action) through the equivalence point. Although the response correctly identifies the weak acid as having the higher concentration, the justification that the higher acid concentration is due to the soft drink being an acidic solution is not valid and did not earn the point in part (f).

Sample: 3C
Score: 6

This response earned 6 out of 10 possible points. One point was earned in part (a) for correctly writing the chemical formula for the $C_6H_7O_2^-$ and hydrogen ions, including the correct charges, and then the correct formula for the product. The 2 points in part (b) were earned for correctly employing an acceptable approach to solve for the unknown concentration in a monoprotic titration. The first point in part (c) was not earned because an incorrect indicator was chosen. The subsequent justification ties the pK_a of bromothymol blue to the pH at the half-equivalence point pH, so the second point in part (c) was not earned. The response did not earn the point in part (d) due to an incorrect pH at the half-equivalence point. The first point in part (e) was earned for correctly indicating the location of the half-equivalence point at ~15 mL and at a pH that is consistent with the pH reported in part (d). The second point in part (e) was earned for the relatively horizontal shape of the curve through the "X" and the third point in part (e) was earned for a steep, negatively sloped curve through the equivalence point. Although the student correctly chooses $HC_6H_7O_2$ as having the higher concentration, justification of "because the pH is acidic" did not earn the point in part (f).