AP® Chemistry
2002 Scoring Guidelines
Form B

Question 1

10 points

$$HC_3H_5O_3(aq) \rightleftarrows H^+(aq) + C_3H_5O_3^-(aq)$$

1. Lactic acid, $HC_3H_5O_3$, is a monoprotic acid that dissociates in aqueous solution, as represented by the equation above. Lactic acid is 1.66 percent dissociated in 0.50 M $HC_3H_5O_3(aq)$ at 298 K. For parts (a) through (d) below, assume the temperature remains at 298 K.

(a) Write the expression for the acid-dissociation constant, K_a , for lactic acid and calculate its value.

$K_a = \frac{[H^+][C_3H_5O_3^-]}{[HC_3H_5O_3]}$	1 point earned for equilibrium expression
$0.50\ M \times 0.0166 = 0.0083\ M = x$	1 point earned for amount of $HC_3H_5O_3$ dissociating
$HC_3H_5O_3(aq) \rightarrow H^+(aq) + C_3H_5O_3^-(aq)$ I: 0.50, ~0, 0 C: –x, +x, +x E: 0.50 – x, +x, +x	
$K_a = \frac{[H^+][C_3H_5O_3^-]}{[HC_3H_5O_3]} = \frac{[0.0083][0.0083]}{[0.50 - 0.0083]}$ $K_a = 1.4 \times 10^{-4}$	1 point earned for $[H^+] = [C_3H_5O_3^-]$ set up and solution

(b) Calculate the pH of 0.50 M $HC_3H_5O_3$.

From part (a): $[H^+] = 0.0083\ M$ $pH = -\log [H^+] = -\log (0.0083) = 2.08$	1 point earned for correctly calculating pH

Question 1 (cont'd.)

(c) Calculate the pH of a solution formed by dissolving 0.045 mole of solid sodium lactate, $NaC_3H_5O_3$, in 250. mL of 0.50 M $HC_3H_5O_3$. Assume that volume change is negligible.

$\frac{0.045 \text{ mol } NaC_3H_5O_3}{0.250 \text{ L}} = 0.18\ M\ C_3H_5O_3^-$	1 point earned for $[C_3H_5O_3^-]$ (or 0.250 L × 0.50 mol/L = 0.125 mol $HC_3H_5O_3$ and 0.045 mol $C_3H_5O_3^-$)
$HC_3H_5O_3(aq) \rightarrow H^+(aq) + C_3H_5O_3^-(aq)$ I: 0.50, ~0, 0.18 C: –x, +x, +x E: 0.50 – x, +x, 0.18 + x	
$K_a = \frac{[H^+][C_3H_5O_3^-]}{[HC_3H_5O_3]} = \frac{[x][0.18+x]}{[0.50-x]}$	
Assume that x << 0.18 M $K_a = 1.4 \times 10^{-4} = \frac{[x][0.18]}{[0.50]}$ $x = 3.9 \times 10^{-4}\ M = [H^+]$	1 point earned for $[H^+]$ (set up and calculation)
$pH = -\log[H^+] = -\log(3.9 \times 10^{-4}) = 3.41$ **OR** $pH = pK_a + \log \frac{0.18}{0.50}$ or $\frac{0.045}{0.125} = 3.41$	1 point earned for calculating the value of pH

Question 1 (cont'd.)

(d) A 100. mL sample of 0.10 M HCl is added to 100. mL of 0.50 M $HC_3H_5O_3$. Calculate the molar concentration of lactate ion, $C_3H_5O_3^-$, in the resulting solution.

$0.50\ M\ HC_3H_5O_3 \left(\frac{100\text{ mL}}{200\text{ mL}}\right) = 0.25\ M\ HC_3H_5O_3$ $0.10\ M\ HCl \left(\frac{100\text{ mL}}{200\text{ mL}}\right) = 0.050\ M\ H^+$	1 point earned for initial $[H^+]$ and $[HC_3H_5O_3]$ **OR** (10 mmol H^+; 50 mmol $HC_3H_5O_3$)
$HC_3H_5O_3(aq) \rightarrow H^+(aq) + C_3H_5O_3^-(aq)$ I: 0.25, 0.050, 0 C: –x, +x, + x E: 0.25 – x, 0.050 + x, + x	1 point earned for showing dilution or moles of each
$K_a = \frac{[H^+][C_3H_5O_3^-]}{[HC_3H_5O_3]} = \frac{[0.050 + x][x]}{[0.25 - x]}$ Assume x << 0.050 M $K_a = 1.4 \times 10^{-4} = \frac{[0.050][x]}{[0.25]}$ $x = 7.0 \times 10^{-4}\ M = [C_3H_5O_3^-]$	1 point earned for $[C_3H_5O_3^-]$ setup and calculation

Question 2

10 points

2. A rigid 8.20 L flask contains a mixture of 2.50 moles of H_2, 0.500 mole of O_2, and sufficient Ar so that the partial pressure of Ar in the flask is 2.00 atm. The temperature is 127ºC.

(a) Calculate the total pressure in the flask.

$P_{H_2} = \left(\frac{n_{H_2}RT}{V}\right) = \left(\frac{(2.50\text{ mol})(0.0821\frac{\text{L·atm}}{\text{mol·K}})(400K)}{8.20\text{ L}}\right) = 10.0\text{ atm}$	1 point earned for the partial pressure of H_2
$P_{O_2} = \left(\frac{n_{O_2}RT}{V}\right) = \left(\frac{(0.500\text{ mol})(0.0821\frac{\text{L·atm}}{\text{mol·K}})(400\text{ K})}{8.20\text{ L}}\right) = 2.00\text{ atm}$	1 point earned for the partial pressure of O_2
$P_{Ar} = 2.0\text{ atm}$	
$P_T = P_{H_2} + P_{O_2} + P_{Ar} = 10.0\text{ atm} + 2.0\text{ atm} + 2.0\text{ atm} = 14.0\text{ atm}$	1 point earned for the total pressure

(b) Calculate the mole fraction of H_2 in the flask.

$\text{Mol fraction}_{H_2} = \left(\frac{\text{mol}_{H_2}}{\text{mol}_{H_2} + \text{mol}_{O_2} + \text{mol}_{Ar}}\right)$	
$\text{mol}_{H_2} = 2.50\text{ mol}$	
$\text{mol}_{O_2} = 0.500\text{ mol}$	
$\text{mol}_{Ar} = \left(\frac{PV}{RT}\right) = \left(\frac{(2.00\text{ atm})(8.20\text{ L})}{(0.0821\frac{\text{L·atm}}{\text{mol·K}})(400\text{ K})}\right) = 0.500\text{ mol Ar}$	1 point earned for mol Ar
$\text{mol}_{H_2} + \text{mol}_{O_2} + \text{mol}_{Ar} = 2.50\text{ mol} + 0.500\text{ mol} + 0.500\text{ mol} = 3.50\text{ mol total}$	
$\text{Mol fraction}_{H_2} = \left(\frac{\text{mol}_{H_2}}{\text{mol}_{H_2} + \text{mol}_{O_2} + \text{mol}_{Ar}}\right) = \left(\frac{2.50\text{ mol}}{3.50\text{ mol}}\right) = 0.714$	1 point earned for mol fraction of H_2

Question 2 (cont'd.)

(c) Calculate the density (in g L^{-1}) of the mixture in the flask

$2.50 \text{ mol } H_2 \left(\frac{2.016 \text{ g } H_2}{1 \text{ mol } H_2}\right) = 5.04 \text{ g } H_2$ $0.500 \text{ mol } O_2 \left(\frac{32.0 \text{ g } O_2}{1 \text{ mol } O_2}\right) = 16.0 \text{ g } O_2$ $0.500 \text{ mol Ar} \left(\frac{40.0 \text{ g Ar}}{1 \text{ mol Ar}}\right) = 20.0 \text{ g Ar}$	1 point earned for mass of all species
total mass = 5.04 g + 16.0 g + 20.0 g = 41.0 g $\text{density} = \left(\frac{\text{total mass}}{\text{volume}}\right) = \left(\frac{41.0 \text{ g}}{8.20 \text{ L}}\right) = 5.00 \text{ g L}^{-1}$	1 point earned for density

The mixture in the flask is ignited by a spark, and the reaction represented below occurs until one of the reactants is entirely consumed.

$$2\,H_2(g) + O_2(g) \rightarrow 2H_2O(g)$$

(d) Give the mole fraction of all species present in the flask at the end of the reaction.

$2\,H_2(g) + O_2(g) \rightarrow 2\,H_2O(g)$ I: 2.50 0.500 0 C: – 1.00 – 0.500 2(+0.500) E: 1.50 0 1.00	1 point earned for 1.00 mol H_2O
total moles after reaction = $\text{mol}_{H_2} + \text{mol}_{H_2O} + \text{mol}_{Ar}$ = 1.50 mol + 1.00 mol + 0.500 mol = 3.00 mol total	1 point earned for total moles
$\text{mol fraction}_{H_2} = \left(\frac{1.50 \text{ mol } H_2}{3.00 \text{ mol}}\right) = 0.500$ $\text{mol fraction}_{O_2} = \left(\frac{0 \text{ mol } O_2}{3.00 \text{ mol}}\right) = 0$ (not necessary) $\text{mol fraction}_{Ar} = \left(\frac{0.500 \text{ mol Ar}}{3.00 \text{ mol}}\right) = 0.167$ $\text{mol fraction}_{H_2O} = \left(\frac{1.00 \text{ mol } H_2O}{3.00 \text{ mol}}\right) = 0.333$	1 point earned for any <u>two</u> mol fractions, excluding O_2

Question 3

10 points

3. Nitrogen monoxide, $NO(g)$, and carbon monoxide, $CO(g)$, are air pollutants generated by automobiles. It has been proposed that under suitable conditions these two gases could react to form $N_2(g)$ and $CO_2(g)$, which are components of unpolluted air.

(a) Write a balanced equation for the reaction described above. Indicate whether the carbon in CO is oxidized or whether it is reduced in the reaction. Justify your answer.

$2\,NO(g) + 2\,CO(g) \rightarrow N_2(g) + 2\,CO_2(g)$	1 point earned for the balanced reaction
CO is oxidized. Carbon in CO has an oxidation number of +2 and in CO_2 carbon has an oxidation number of +4. The oxidation number increases **OR** The number of oxygen atoms around the carbon atom increases; this is characteristic of oxidation.	1 point earned for the prediction and the explanation.

(b) Write the expression for the equilibrium constant, K_p, for the reaction.

$K_p = \dfrac{(P_{N_2})(P_{CO_2})^2}{(P_{NO})^2(P_{CO})^2} = \dfrac{[N_2][CO_2]^2}{[NO]^2[CO]^2}(RT)^{-1}$	1 point earned for the equilibrium expression according to part (a)

(c) Consider the following thermodynamic data.

	NO	CO	CO_2
ΔG_f° (kJ mol^{-1})	+86.55	−137.15	−394.36

(i) Calculate the value of ΔG° for the reaction at 298 K.

$\Delta G^\circ_{rxn} = \Sigma\Delta G_f^\circ(\text{products}) + \Sigma\Delta G_f^\circ(\text{reactants})$ $= 2\,\Delta G_f^\circ(CO_2) - [2\,\Delta G_f^\circ(NO) + 2\,\Delta G_f^\circ(CO)]$ $= 2(-394.36\text{ kJ}) - [2(86.55\text{ kJ}) + 2(-137.15\text{ kJ})]$ $= -788.72\text{ kJ} - [+173.10\text{ kJ} + (-274.30\text{ kJ})]$ $= -788.72\text{ kJ} - [-101.20\text{ kJ}]$ $= -687.52\text{ kJ}$ (units not required)	1 point earned for the correct coefficients 1 point earned for the answer, sign, and noting that it is products minus reactants

Question 3 (cont'd.)

(ii) Given that $\Delta H°$ for the reaction at 298 K is -746 kJ per mole of $N_2(g)$ formed, calculate the value of $\Delta S°$ for the reaction at 298 K. Include units with your answer.

$\Delta G°_{rxn} = \Delta H°_{rxn} - T\Delta S°_{rxn}$ $\Delta S°_{rxn} = \dfrac{\Delta H°_{rxn} - \Delta G°_{rxn}}{T}$ $\Delta S°_{rxn} = \dfrac{746\ \text{kJ·mol}^{-1}(687.5\ \text{kJ·mol}^{-1})}{298\ K}$ $\Delta S°_{rxn} = -196\ \dfrac{\text{J}}{\text{mol}\cdot\text{K}}$ or $-0.196\ \text{kJ K}^{-1}$	1 point earned for setup and substitution 1 point earned for the sign <u>and</u> units

(d) For the reaction at 298 K, the value of K_p is 3.3×10^{120}. In an urban area, typical pressures of the gases in the reaction are $P_{NO} = 5.0 \times 10^{-7}$ atm, $P_{CO} = 5.0 \times 10^{-5}$ atm, $P_{N_2} = 0.781$ atm, and $P_{CO_2} = 3.1 \times 10^{-4}$ atm.

(i) Calculate the value of ΔG for the reaction at 298 K when the gases are at the partial pressures given above.

$Q = \dfrac{(P_{N_2})(P_{CO_2})^2}{(P_{NO})^2(P_{CO})^2} = \dfrac{(0.781)(3.0\times10^{-4})^2}{(5.0\times10^{-7})^2(5.0\times10^{-5})^2}$ $= 1.1 \times 10^{14}$	1 point earned for the value of Q according to balanced equation
$\Delta G = \Delta G° + RT \ln Q$ $= -687.52\ \text{kJ} + 8.314 \times 10^{-3}\ \dfrac{\text{kJ}}{\text{mol K}}\ 298\ \text{K} \ln 1.1 \times 10^{14}$ $= -687.52\ \text{kJ} + 8.314 \times 10^{-3}\ \dfrac{\text{kJ}}{\text{mol K}}\ 298\ \text{K}\ (32.35)$ $= -687.52\ \text{kJ} + +80.\ \text{kJ}$ $= -607\ \text{kJ}$	1 point earned for the value of ΔG

Question 3 (cont'd.)

(ii) In which direction (to the right or to the left) will the reaction be spontaneous at 298 K with these partial pressures? Explain.

The reaction is spontaneous (→ right) because ΔG is negative. (Reference must be according to ΔG, **not** $\Delta G°$)	1 point earned for the explanation (must be according to sign)

Question 4

15 points

(a) A sample of 1-propanol is burned in air.

$C_3H_7OH + O_2 \rightarrow CO_2 + H_2O$	3 points

(b) Solutions of sodium chromate and lead nitrate are mixed.

$CrO_4^{2-} + Pb^{2+} \rightarrow PbCrO_4$	3 points

(c) A bar of iron metal is added to a solution of iron(III) chloride.

$Fe + Fe^{3+} \rightarrow Fe^{2+}$	3 points

(d) Concentrated ammonia solution is added to copper(II) sulfate solution.

$NH_3 + Cu^{2+} \rightarrow Cu(NH_3)_4^{2+}$ **OR** $OH^- + Cu^{2+} \rightarrow Cu(OH)_2$	3 points

Note: Other complex ions can also earn credit.

(e) Sulfur dioxide gas is bubbled into a beaker of water.

$SO_2 + H_2O \rightarrow H_2SO_3$ **OR** $SO_2 + H_2O \rightarrow H^+ + HSO_3^-$	3 points

Question 4 (cont'd.)

(f) Equal volumes of 0.1 *M* sodium phosphate and 0.1 *M* hydrochloric acid are mixed.

$PO_4^{3-} + H^+ \rightarrow HPO_4^{2-}$	3 points

(g) Hydrogen chloride gas is bubbled through a solution of potassium cyanide.

$HCl + CN^- \rightarrow HCN + Cl^-$	3 points

(h) Liquid bromine is carefully added to a solution of potassium iodide.

$Br_2 + I^- \rightarrow Br^- + I_2$	3 points

Question 5

10 points

Consider five unlabeled bottles, each containing 5.0 g of one of the following pure salts.

$AgCl$ $BaCl_2$ $CoCl_2$ $NaCl$ NH_4Cl

(a) Identify the salt that can be distinguished by its appearance alone. Describe the observation that supports your identification.

$CoCl_2$	1 point earned for the answer
Cobalt salts tend to have color. All of the other salts are colorless.	1 point earned for the explanation

(b) Identify the salt that can be distinguished by adding 10 mL of H_2O to a small sample of each of the remaining unidentified salts. Describe the observation that supports your identification.

AgCl	1 point earned for the answer
AgCl will not dissolve in water. All of the remaining solids dissolve, and the resulting solution in each case is colorless and clear.	1 point earned for the explanation

(c) Identify a chemical reagent that could be added to the salt identified in part (b) to confirm the salt's identity. Describe the observation that supports your confirmation.

[There is more than one possible answer, one of which is NH_3.]	1 point earned for a viable reagent
Add aqueous NH_3 to the solution. The AgCl will dissolve in aqueous ammonia. $AgCl + 2\ NH_3 \rightarrow Ag(NH_3)_2^+$	1 point earned for an explanation that fits the reagent chosen

Question 5 (cont'd.)

(d) Identify the salt that can be distinguished by adding 1.0 *M* Na_2SO_4 to a small sample of each of the remaining unidentified salts. Describe the observation that supports your identification.

$BaCl_2$	1 point earned for the answer
When Na_2SO_4 solution is added to the $BaCl_2$, a white precipitate forms. Adding the Na_2SO_4 solution to the NaCl or the NH_4Cl does not produce any change. $BaCl_2 + Na_2SO_4 \rightarrow BaSO_4 + 2\ NaCl$	1 point earned for the explanation

(e) Identify the salt that can be distinguished by adding 1.0 *M* NaOH to a small sample of each of the remaining unidentified salts. Describe the observation that supports your identification.

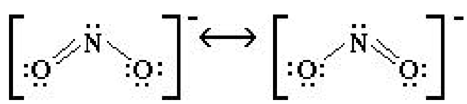
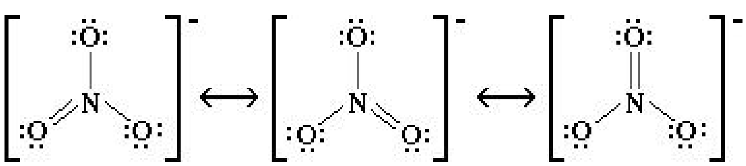
NH_4Cl	1 point earned for the answer
Adding NaOH to the NH_4Cl solution will produce an ammonia odor. No change is observed, felt, or smelled when adding NaOH to the NaCl solution. $NaCl + NaOH \rightarrow$ no reaction $NH_4Cl + NaOH \rightarrow NH_3 + H_2O + NaCl$	1 point earned for the explanation

Question 6

10 points

Using principles of chemical bonding and molecular geometry, explain each of the following observations. Lewis electron-dot diagrams and sketches of molecules may be helpful as part of your explanations. For each observation, your answer must include references to both substances.

(a) The bonds in nitrite ion, NO_2^-, are shorter than the bonds in nitrate ion, NO_3^-.

 According to the Lewis electron-dot diagram, two resonance structures are required to represent the bonding in the NO_2^- ion. The effective number of bonds between N and O is 1.5.	1 point earned for the difference in the effective number of bonds in both ions
 Three resonance structures are required to represent the bonding in the NO_3^- ion. The effective number of bonds between N and O is 1.33. The greater the effective number of bonds, the shorter the N–O bond length.	1 point earned for relating the effective number of bonds to bond length

(b) The CH_2F_2 molecule is polar, whereas the CF_4 molecule is not.

The molecular geometry in both CH_2F_2 and CF_4 is tetrahedral (or the same). The C-F bond is polar. In CF_4, the molecular geometry arranges the C-F dipoles so that they cancel out and the molecule is nonpolar. The C-H bond is less polar than the C-F bond. The two C-H dipoles do not cancel the two C-F dipoles in CH_2F_2.	1 point earned for discussing the similarity in molecular geometry 1 point earned for discussing the relationship between molecular geometry and the C-H and C-F bond dipoles

Question 6 (cont'd.)

(c) The atoms in a C_2H_4 molecule are located in a single plane, whereas those in a C_2H_6 molecule are not.

The carbon atoms in C_2H_4 have a molecular geometry around each carbon atom that is trigonal planar (AX_3), so all six atoms are in the same plane. The carbon atoms in C_2H_6 have a molecular geometry that is tetrahedral (AX_4), so the atoms are not all in the same plane. **OR** The carbon-carbon double bond in C_2H_4 results in a planar molecule whereas the carbon-carbon single bond in C_2H_6 results in a non-planar (tetrahedral) site at each carbon atom.	1 point earned for the bonding of the carbon atoms 1 point earned for the structure

(d) The shape of a PF_5 molecule differs from that of an IF_5 molecule.

In PF_5, the molecular geometry is trigonal bipyramidal because the phosphorus atom has five bonding pairs of electrons and no lone pairs of electrons. IF_5 has square pyramdal molecular geometry. The central iodine atom has five bonding pairs of electrons and one lone pair of electrons. The presence of the additional lone pair of electrons on the central iodine atom means the molecular geometry is different.	1 point earned for discussing the difference made by the lone pair of electrons in IF_5 and how it affects the geometry of the two molecules

(e) $HClO_3$ is a stronger acid than $HClO$.

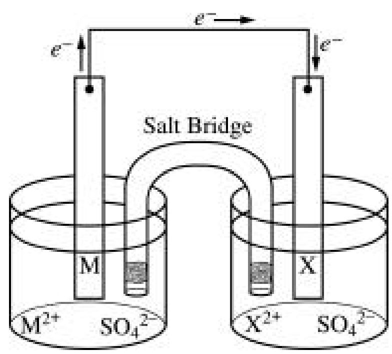
According to the formula for HOCl and $HOClO_2$, there are two additional terminal, electronegative oxygen atoms attached to the central chlorine atom. These additional terminal oxygen atom stabilize the negative charge on the anion ClO_3^- compared to ClO^-. The result is to reduce the electrostatic attraction between the H^+ and ClO_x^-. **OR** The two additional terminal electronegative O atoms bonded to the chlorine atom of ClO_3^- pull electron density away from the central chlorine atom. The net result is to weaken the H-O bond. Since HOCl has no additional terminal O atoms, its H-O bond is stronger. The weaker the H-O bond, the stronger the acid.	1 point earned for discussing the importance of the electronegativity of the terminal oxygen atoms in the two structures and/or the enhanced stability of the chlorate vs. the hypochlorite ion

Question 7

8 points

The diagram below shows the experimental setup for a typical electrochemical cell that contains two standard half-cells. The cell operates according to the reaction represented by the following equation.

$$Zn(s) + Ni^{2+}(aq) \rightarrow Ni(s) + Zn^{2+}(aq)$$

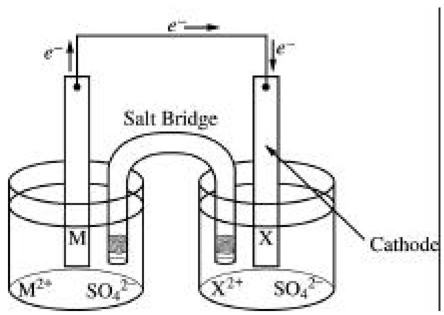


(a) Identify M and M^{2+} in the diagram and specify the initial concentration for M^{2+} in solution.

Electrons flow from the anode to the cathode in a voltaic electrochemical cell. The anode is where oxidation occurs, and in the reaction above, Zn(*s*) is oxidized. So, the anode electrode must be Zn (M) and the solution contains Zn^{2+} (M^{2+}). The $[Zn^{2+}]$ = 1.0 *M* in a standard cell. Additionally, the reduction potential for the Zn^{2+}/Zn redox couple is less than that for Ni^{2+}/Ni.	1 point earned for correct M and M^{2+} 1 point for the correct concentration of M^{2+} (Zn^{2+})

Question 7 (cont'd.)

(b) Indicate which of the metal electrodes is the cathode. Write the balanced equation for the reaction that occurs in the half-cell containing the cathode.

The cathode is Ni(*s*) , indicated by "X" 	1 point earned for labeling the cathode in the cell diagram
The half-reaction is $2\,e^- + Ni^{2+} \rightarrow Ni(s)$.	1 point earned for the half-reaction

(c) What would be the effect on the cell voltage if the concentration of Zn^{2+} was reduced to 0.100 *M* in the half-cell containing the Zn electrode?

$E_{cell} = E° - \frac{RT}{nF} \ln \frac{[Zn^{2+}]}{[Ni^{2+}]}$ When the $[Zn^{2+}]$ is lowered to 0.100 *M*, then $Q < 1$. The value of the cell potential under these nonstandard conditions is more positive than $E°$ (under standard conditions). The cell voltage increases. An argument involving LeChâtelier's principle is also acceptable: the decreased $[Zn^{2+}]$ increases the "potential" for the reaction to proceed to the right.	1 point earned for indicating that E_{cell} increases (is larger) 1 point earned for recognizing that $Q < 1$ and/or that the term $\frac{RT}{nF} \ln \frac{[Zn^{2+}]}{[Ni^{2+}]}$ must be added to the $E°$

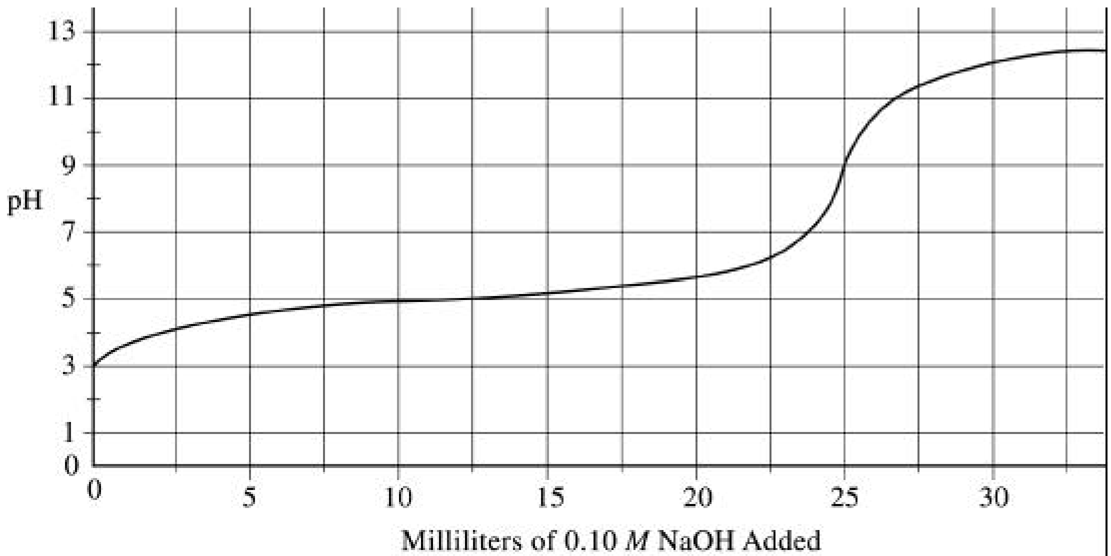
(d) Describe what would happen to the cell voltage if the salt bridge was removed. Explain.

The cell voltage drops to zero when the salt bridge is removed. This happens because the salt bridge is needed to allow charge balance to occur in the solutions the electrodes are immersed in. In the absence of the salt bridge, ions cannot flow to balance the buildup of cations in the anode compartment and the buildup of anions in the cathode compartment.	1 point earned for the effect 1 point earned for the explanation

Question 8

8 points

The graph below shows the result of the titration of a 25 mL sample of a 0.10 *M* solution of a weak acid, HA, with a strong base, 0.10 *M* NaOH.



(a) Describe two features of the graph above that identify HA as a weak acid.

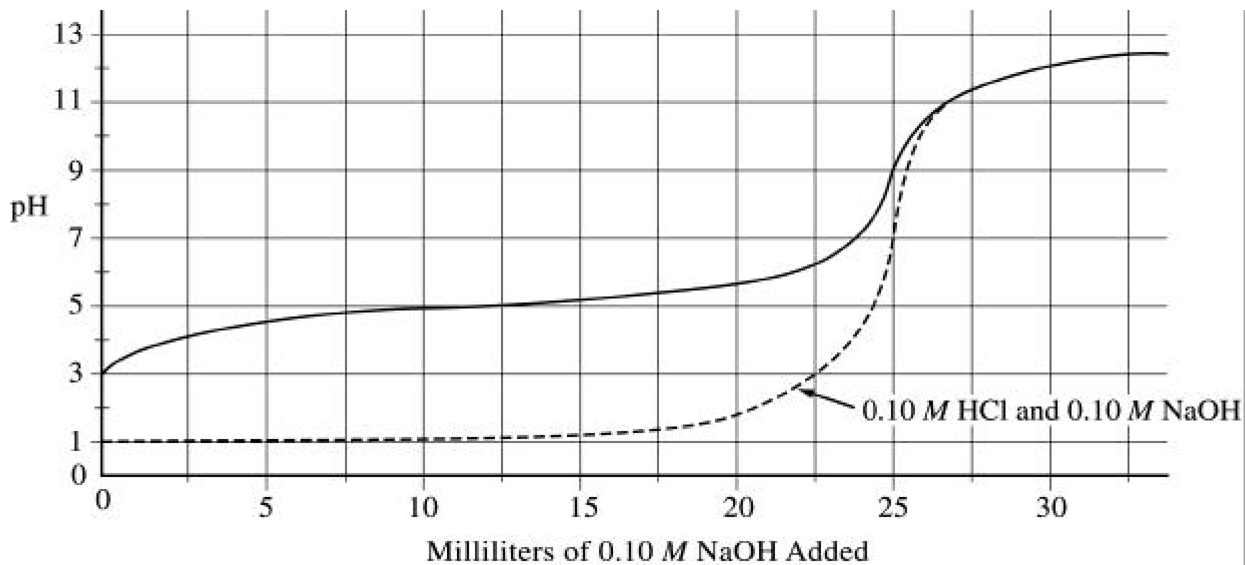
The initial pH of the solution before base has been added is greater than 1 (the pH expected for a 0.1 *M* strong acid). The pH at the equivalence point is greater than 7. **AND/OR** There is a rapid increase in the pH after adding a small amount of base at the beginning of the titration. The increase quickly diminishes on continued addition of base (buffer region).	1 point earned for initial pH > 1 1 point earned for pH > 7 at equivalence point

Question 8 (cont'd.)

(b) Describe one method by which the value of the acid-dissociation constant for HA can be determined using the graph above.

The K_a for the weak acid can be obtained by determining the pH at the: 1. half-equivalence point in the titration where $K_a = 10^{-pH}$ 2. zero volume of base 3. equivalence point (Any point on the titration curve is acceptable with justification.)	1 point earned for indicating any one of the first three points (at left) identified on the titration curve. 1 point earned for describing the determination of K_a from that point. (For *any* other point on the curve, 2 points for correct justification.)

(c) On the graph above, sketch the titration curve that would result if 25 mL of 0.10 M HCl were used instead of 0.10 M HA.



The graph should have the following features: 1. pH before adding any base is 1 2. the equivalence point pH is 7 at 25 mL 3. the titration curve beyond the equivalence point is nearly identical to the original curve	1 point earned for any two features and 2 points for all three. Beginning the pH at 1, the equivalence point at pH = 7 (when the volume is equal to the volume of the base required to neutralize the strong acid), and the ending pH of the solution is nearly the same as the original curve

Question 8 (cont'd.)

(d) A 25 mL sample of 0.10 *M* HA is titrated with 0.20 *M* NaOH.

(i) What volume of base must be added to reach the equivalence point?

2.5 mmol HA = 2.5 mmol OH^- $\frac{2.5\text{ mmol }OH^-}{0.20\text{ mmol/mL}} = 13\text{ mL}$	1 point earned for the correct volume

(ii) The pH at the equivalence point for this titration is slightly higher than the pH at the equivalence point in the titration using 0.10 *M* NaOH. Explain.

In the titration with 0.1 *M* NaOH, the total volume at the equivalence point is 50 mL. In the titration with 0.20 *M* NaOH the total volume at the equivalence point is 37.5 mL. The smaller volume in the titration with 0.2 *M* NaOH means the [A^-], the molar concentration of the conjugate base of HA, is larger compared to the [A^-] at the equivalence point with 0.1 *M* NaOH. Therefore, the pH is slightly higher.	1 point earned for correct explanation