

Question 1: Long Answer**10 points**

(a) For the correct calculated value: **1 point**

$$0.300 \text{ g C}_8\text{H}_8\text{O}_3 \times \frac{1 \text{ mol C}_8\text{H}_8\text{O}_3}{152.15 \text{ g C}_8\text{H}_8\text{O}_3} \times \frac{1 \text{ mol HC}_7\text{H}_5\text{O}_3}{1 \text{ mol C}_8\text{H}_8\text{O}_3} \times \frac{138.12 \text{ g HC}_7\text{H}_5\text{O}_3}{1 \text{ mol HC}_7\text{H}_5\text{O}_3} = 0.272 \text{ g HC}_7\text{H}_5\text{O}_3$$

(b) For the correct answer and a valid justification: **1 point**

Yes, the claim is consistent. The acid is soluble in water (2.2 g/L). If some of the crystals had dissolved in water during the rinsing step, the actual yield of the collected precipitate would be lower than expected, causing the percent yield to be less than 100%.

(c) For the correct calculated value of either q : **1 point**

Accept one of the following:

- $q_{\text{heat}} = mc\Delta T = (0.105 \text{ g})(1.17 \text{ J}/(\text{g}\cdot^\circ\text{C}))(159^\circ\text{C} - 25^\circ\text{C}) = 16.5 \text{ J}$
- $q_{\text{melt}} = 0.105 \text{ g} \times \frac{1 \text{ mol}}{138.12 \text{ g}} \times \frac{27.1 \text{ kJ}}{1 \text{ mol}} \times \frac{1000 \text{ J}}{1 \text{ kJ}} = 20.6 \text{ J}$

For the correct calculated value of the other q and the total heat: **1 point**

$$q_{\text{total}} = q_{\text{heat}} + q_{\text{melt}} = 16.5 \text{ J} + 20.6 \text{ J} = 37.1 \text{ J}$$

Total for part (c) 2 points

(d) For a correct explanation: **1 point**

The salicylic acid molecule has more hydrogen bonding sites than the methyl salicylate molecule, resulting in stronger intermolecular attractions and a higher melting point for salicylic acid.

(e) For the correct answer: **1 point**

The $\text{p}K_a$ is approximately 3.

(f) For the correct answer and a valid justification, consistent with part (e): **1 point**

Accept one of the following:

- *The conjugate base, $\text{C}_7\text{H}_5\text{O}_3^-$. When $\text{pH} = 4$, the titration is past the half-equivalence point, where $[\text{HC}_7\text{H}_5\text{O}_3] = [\text{C}_7\text{H}_5\text{O}_3^-]$. Therefore $[\text{C}_7\text{H}_5\text{O}_3^-]$ must be greater than $[\text{HC}_7\text{H}_5\text{O}_3]$.*
- *The conjugate base, $\text{C}_7\text{H}_5\text{O}_3^-$. The pH of the solution is 4, which is greater than the $\text{p}K_a$ of the acid. Therefore $[\text{C}_7\text{H}_5\text{O}_3^-]$ must be greater than $[\text{HC}_7\text{H}_5\text{O}_3]$.*

(g) For the correct calculated value: 1 point

$$\text{p}K_a = -\log K_a = -\log(6.3 \times 10^{-5}) = 4.20$$

(h) For a curve that shows a correct starting and half-equivalence point, consistent with part (g): 1 point

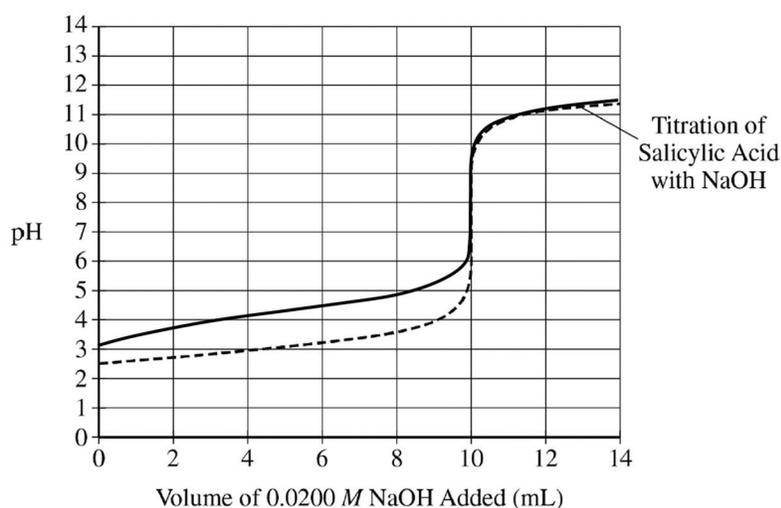
The curve starts at a pH value of approximately 3.11.

At 5 mL, the curve passes through a pH equal to the $\text{p}K_a$ value calculated in part (g).

An example curve is shown below as a solid line.

For a curve that shows the correct equivalence point: 1 point

The curve features a sharp rise at 10 mL, representing the volume of base needed to reach the equivalence point.



Total for part (h) 2 points

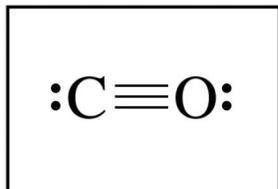
Total for question 1 10 points

Question 2: Long Answer**10 points**

(a) For the correct answer and a valid justification: **1 point**

The H atoms are reduced because they change from an oxidation number of +1 to zero.

(b) For the correct answer: **1 point**



(c)(i) For the correct stoichiometry (may be implicit): **1 point**

$$\Delta S_{rxn}^{\circ} = \sum S^{\circ} \text{ products} - \sum S^{\circ} \text{ reactants}$$

$$\Delta S_{rxn}^{\circ} = (S^{\circ}_{\text{CO}(g)} + 2(S^{\circ}_{\text{H}_2(g)})) - (S^{\circ}_{\text{CH}_3\text{OH}(g)})$$

For the correct calculated value: **1 point**

$$\Delta S_{rxn}^{\circ} = 198 + (2)(131) - 240. = +220. \text{ J}/(\text{mol}_{rxn} \cdot \text{K})$$

(ii) For the correct calculated value, consistent with (c)(i): **1 point**

$$\Delta G_{rxn}^{\circ} = \Delta H_{rxn}^{\circ} - T\Delta S_{rxn}^{\circ}$$

$$\Delta G_{rxn}^{\circ} = 90.0 \text{ kJ}/\text{mol}_{rxn} - (375 \text{ K})(0.220 \text{ kJ}/(\text{mol}_{rxn} \cdot \text{K})) = +7.5 \text{ kJ}/\text{mol}_{rxn}$$

Total for part (c) 3 points

(d) For the correct calculated value: **1 point**

$$P_{\text{CO}} = \frac{3}{10}(12.0 \text{ atm}) = 3.6 \text{ atm}$$

(e) For the correct expression: **1 point**

$$K_p = \frac{(P_{\text{CO}})(P_{\text{H}_2})^2}{(P_{\text{CH}_3\text{OH}})}$$

(f) For the correct calculated value, consistent with part (e): 1 point

$$K_p = \frac{(P_{\text{CO}})(P_{\text{H}_2})^2}{(P_{\text{CH}_3\text{OH}})} = \frac{(4.2)(8.4)^2}{(2.7)} = 110$$

(g) For a correct comparison of Q and K : 1 point

Accept one of the following:

- *The change in volume causes the partial pressure of each gas to decrease by a factor of 2. There are more moles of gaseous products than reactants. In the Q expression, the numerator is smaller than the denominator, causing Q_p to be less than K_p .*

- $$Q_p = \frac{\left(\frac{P_{\text{CO}}}{2}\right)\left(\frac{P_{\text{H}_2}}{2}\right)^2}{\left(\frac{P_{\text{CH}_3\text{OH}}}{2}\right)} = \left(\frac{1}{4}\right)K_p = \left(\frac{1}{4}\right)(110) = 27.5, \text{ which is less than } K_p$$

For the correct answer and a valid justification: 1 point

Decrease. Because Q_p is less than K_p , the partial pressures (moles) of the products will increase and the partial pressure (moles) of CH_3OH will decrease as equilibrium is re-established.

Total for part (g) 2 points

Total for question 2 10 points

Question 3: Long Answer**10 points**

(a) For a correct electron configuration: **1 point**

Accept one of the following:

- $1s^2 2s^2 2p^6 3s^2 3p^1$
- $[\text{Ne}] 3s^2 3p^1$

(b) For a correct explanation: **1 point**

The electrons in the highest occupied energy level ($n=3$) of Al are at a greater average distance from the nucleus than the electrons in highest occupied energy level ($n=2$) of Al^{3+} .

(c) For the correct steps to dissolve the solute in water (steps may be combined): **1 point**

- *Partially fill a 200.00 mL volumetric flask with some distilled water*
- *Add the weighed sample of $\text{AgNO}_3(s)$ to the volumetric flask*
- *Swirl to dissolve the solid*

For the correct step to ensure quantitative dilution: **1 point**

- *After the solid is dissolved, fill the flask with water up to the calibration mark (200.00 mL) and mix.*

Total for part (c) 2 points

(d) For a drawing that shows product formation and indicates the conservation of matter: **1 point**

*The drawing should contain 8 Ag particles and 4 Al particles.
(See sample drawing on next page).*

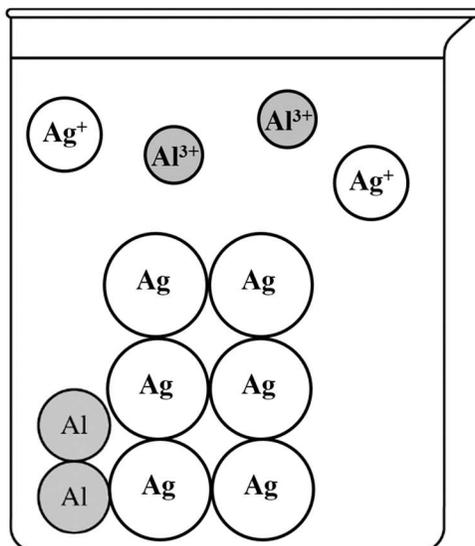
For a drawing that shows product formation and conservation of charge: **1 point**

*The drawing should contain 2 Ag^+ ions and 2 Al^{3+} ions.
(See sample drawing on next page).*

For a drawing that shows product formation and correct phases of matter for all species: **1 point**

*The drawing should contain 6 Ag atoms in the solid phase and 2 Al^{3+} ions in the aqueous phase.
(See sample drawing on next page).*

Total for part (d) 3 points



(e) For the correct calculated value: 1 point

Accept one of the following:

- $E_{cell}^{\circ} = E_{red}^{\circ} - E_{ox}^{\circ} = (+0.80 \text{ V}) - (-1.66 \text{ V}) = +2.46 \text{ V}$
- $E^{\circ} = 0.80 \text{ V} + 1.66 \text{ V} = 2.46 \text{ V}$

(f) For the correct answer and a valid justification, consistent with part (e): 1 point

Negative. The reaction has a positive value of E° , which indicates that it is thermodynamically favorable and would have a negative value of ΔG° . ($\Delta G^{\circ} = -nFE^{\circ}$)

(g) For the correct answer and a valid justification: 1 point

Accept one of the following:

- *Zero. If the reaction appears to stop progressing, $E_{cell} = 0$, and there is no longer a driving force for the reaction.*
- *Zero. If the reaction appears to stop progressing, equilibrium is established and $\Delta G = 0$ at equilibrium.*

Total for question 3 10 points

Question 4: Short Answer**4 points**

(a) For the correct calculated value: 1 point

$$1.0 \text{ L} \times \frac{0.0016 \text{ g NH}_2\text{Cl}}{1 \text{ L}} \times \frac{1 \text{ mol NH}_2\text{Cl}}{51.48 \text{ g NH}_2\text{Cl}} = 3.1 \times 10^{-5} \text{ mol NH}_2\text{Cl}$$

(b) For the correct identification of intermolecular forces between each substance and water: 1 point

Accept one of the following:

- *Both NH₂Cl and NCl₃ can participate in hydrogen bonding with water.*
- *Both NH₂Cl and NCl₃ have dipole-dipole attractions to water.*

For a correct explanation: 1 point

The intermolecular forces between NH₂Cl molecules and water are stronger than those between NCl₃ molecules and water. This explains why NH₂Cl is more soluble in water.

Total for part (b) 2 points

(c) For the correct calculated value: 1 point

$$15.0 \text{ g NCl}_3 \times \frac{1 \text{ mol NCl}_3}{120.36 \text{ g NCl}_3} \times \frac{32.9 \text{ kJ}}{1 \text{ mol NCl}_3} = 4.10 \text{ kJ}$$

Total for question 4 4 points

Question 5: Short Answer**4 points**

(a) For the correct calculated value: **1 point**

Accept one of the following:

- $k = \frac{0.693}{t_{1/2}} = \frac{0.693}{1.67 \text{ hr}} = 0.415 \text{ hr}^{-1}$
- $k = \frac{\ln[A]_0 - \ln[A]_t}{t} = \frac{\ln(0.160) - \ln(0.0800)}{1.67 \text{ hr}} = 0.415 \text{ hr}^{-1}$
- $k = \frac{\ln[A]_0 - \ln[A]_t}{t} = \frac{\ln(0.160) - \ln(0.0400)}{3.33 \text{ hr}} = 0.416 \text{ hr}^{-1}$
- $k = \frac{\ln[A]_0 - \ln[A]_t}{t} = \frac{\ln(0.160) - \ln(0.0200)}{5.00 \text{ hr}} = 0.416 \text{ hr}^{-1}$

For the correct units, consistent with the calculated value: **1 point**

hr⁻¹

Total for part (a) 2 points

(b) For the correct answer and a valid justification: **1 point**

Step 1 is the rate-determining step. The rate law of this elementary reaction is rate = k[N₂O₅], which is consistent with the first-order kinetics of the overall rate law.

(c) For the correct answer: **1 point**

The value of k would remain the same. The rate constant, k, is independent of concentration and will remain the same at constant temperature.

Total for question 5 4 points

Question 6: Short Answer**4 points**

(a) For the correct answer: **1 point**

525 nm

(b)(i) For the correct answer: **1 point**

92.0 mL

(ii) For the correct calculated value: **1 point**

$$M_1V_1 = M_2V_2$$

$$V_1 = \frac{M_2V_2}{M_1} = \frac{(1.68 \times 10^{-3} M)(100.0 \text{ mL})}{(2.40 \times 10^{-3} M)} = 70.0 \text{ mL}$$

Total for part (b) 2 points

(c) For the correct answer and a valid justification: **1 point**

The student could have improperly executed step 3. If the cuvette were not rinsed with the standard solution prior to being filled for the measurement of absorbance, the standard solution would be diluted by the remaining distilled water, and the measured value for absorbance would be too low.

Total for question 6 4 points

Question 7: Short Answer**4 points**

(a) For the correct answer: 1 point



(b)(i) For the correct answer: 1 point

$$K_{sp} = [\text{Ag}^+]^2[\text{C}_2\text{O}_4^{2-}]$$

(ii) For the correct calculated value, consistent with (b)(i): 1 point

$$(2s)^2(s) = 4s^3 = 5.40 \times 10^{-12}$$

$$\text{molar solubility of Ag}_2\text{C}_2\text{O}_4 = s = \sqrt[3]{\frac{5.40 \times 10^{-12}}{4}} = 1.11 \times 10^{-4} \text{ M}$$

(iii) For a correct equation (state symbols not required): 1 point

Accept one of the following:

- $\text{C}_2\text{O}_4^{2-}(aq) + \text{H}^+(aq) \rightarrow \text{HC}_2\text{O}_4^-(aq)$
- $\text{C}_2\text{O}_4^{2-}(aq) + \text{H}_3\text{O}^+(aq) \rightarrow \text{HC}_2\text{O}_4^-(aq) + \text{H}_2\text{O}(l)$
- $\text{C}_2\text{O}_4^{2-}(aq) + 2 \text{H}^+(aq) \rightarrow \text{H}_2\text{C}_2\text{O}_4(aq)$
- $\text{C}_2\text{O}_4^{2-}(aq) + 2 \text{H}_3\text{O}^+(aq) \rightarrow \text{H}_2\text{C}_2\text{O}_4(aq) + 2 \text{H}_2\text{O}(l)$

Total for part (b) 3 points

Total for question 7 4 points