2022

# AP® Chemistry

## Scoring Guidelines

## Question 1: Long Answer — 10 points

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

$$0.300\text{ g } C_8H_8O_3 \times \frac{1\text{ mol } C_8H_8O_3}{152.15\text{ g}} \times \frac{1\text{ mol } HC_7H_5O_3}{1\text{ mol } C_8H_8O_3} \times \frac{138.12\text{ g}}{1\text{ mol } HC_7H_5O_3} = 0.272\text{ g } HC_7H_5O_3$$

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

*Yes (consistent). Because the acid is soluble in water, some crystals may dissolve during rinsing, causing the mass of the collected precipitate to be lower than expected. This would lead to a percent yield less than 100%.*

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

Accept one of the following:

- $q_{heat} = mc\Delta T = (0.105\text{ g})(1.17\text{ J/(g} \cdot \text{°C)})(159\text{°C} - 25\text{°C}) = 16.5\text{ J}$
- $q_{melt} = 0.105\text{ g} \times \frac{1\text{ mol}}{138.12\text{ g}} \times \frac{27{,}100\text{ J}}{1\text{ mol}} = 20.6\text{ J}$

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

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

**Total for part (c)** **2 points**

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

*Molecules of salicylic acid have more hydrogen bonding sites than molecules of methyl salicylate have, which leads to stronger intermolecular forces and a higher melting point for salicylic acid.*

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

*The* $pK_a$ *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,* $C_7H_5O_3^-$. *When* $pH = 4$, *the titration is beyond the half-equivalence point, where* $[HC_7H_5O_3] = [C_7H_5O_3^-]$. *Thus,* $[C_7H_5O_3^-]$ *must be greater than* $[HC_7H_5O_3]$.
- *The conjugate base,* $C_7H_5O_3^-$. *Because the* pH *of the solution is greater than the* $pK_a$ *of the acid, the majority of the molecules will be deprotonated.*

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

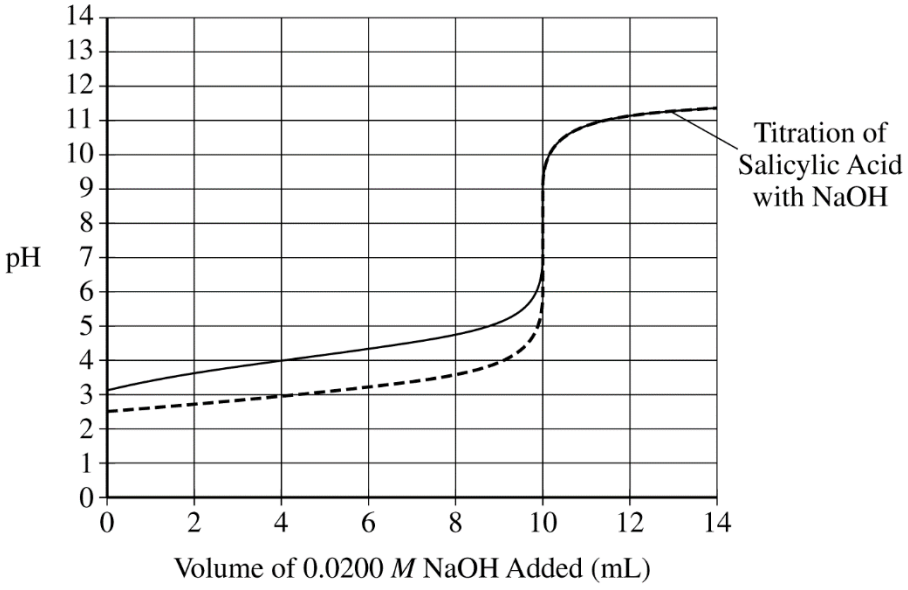
$pK_a = -\log(6.3 \times 10^{-5}) = 4.20$

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

*The curve starts at* pH ≈ 3.11 *and passes through the* $pK_a$ *calculated in part (g) at* 5 *mL*.
*See example response below.*

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

*The curve inflects vertically at* 10 *mL showing the same volume of base needed to reach the equivalence point.*




**Total for part (h) 2 points**

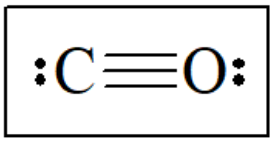
**Total for question 1 10 points**

## 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 0.*

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



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

$$\Delta S°_{rxn} = \Sigma \Delta S°_{products} - \Sigma \Delta S°_{reactants}$$

$$\Delta S°_{rxn} = \left(\Delta S°_{CO(g)} + 2(\Delta S°_{H_2(g)})\right) - \left(\Delta S°_{CH_3OH(g)}\right)$$

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

$$\Delta S°_{rxn} = 198 + 2(131) - 240. = 220. \frac{\text{J}}{\text{K}\cdot\text{mol}_{rxn}}$$

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

$$\Delta G° = \Delta H° - T\Delta S°$$

$$\Delta G° = 90.0 \frac{\text{kJ}}{\text{mol}_{rxn}} - (375\text{ K})(0.220 \frac{\text{kJ}}{\text{K}\cdot\text{mol}_{rxn}}) = +7.5\text{ kJ/mol}_{rxn}$$

**Total for part (c)** **3 points**

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

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

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

$$K_p = \frac{(P_{CO})(P_{H_2})^2}{(P_{CH_3OH})}$$

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

$$K_p = \frac{(P_{CO})(P_{H_2})^2}{(P_{CH_3OH})} = \frac{(4.2)(8.4)^2}{(2.7)} = 110$$

**(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 species to decrease by a factor of two. Because there are more moles of gaseous products than reactants, the decrease of the numerator in Q will be larger than that in the denominator, making* $Q_p < K_p$.
- $Q_p = \dfrac{\left(\dfrac{P_{CO}}{2}\right)\left(\dfrac{P_{H_2}}{2}\right)^2}{\left(\dfrac{P_{CH_3OH}}{2}\right)} = \dfrac{K_p}{4} \approx 27 < K_p$

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

*Decrease. Given that* $Q_p < K_p$*, the partial pressures (moles) of the products will increase as equilibrium re-establishes, decreasing the number of moles of* $CH_3OH$.

**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:

- $1s^2 2s^2 2p^6 3s^2 3p^1$
- [Ne] $3s^2 3p^1$

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

*The highest occupied electron shell (n=3) of* Al *is at a greater average distance from the nucleus than the highest occupied electron shell (n=2) of* $Al^{3+}$.

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

*2. Partially fill the volumetric flask with some distilled water*

*3. Add the weighed* $AgNO_3(s)$ *to the volumetric flask*

*4. Swirl to dissolve the solid*

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

*5. After the solid is dissolved, fill the flask to the calibration (*200.00 mL*) mark and mix.*

**Total for part (c) 2 points**

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

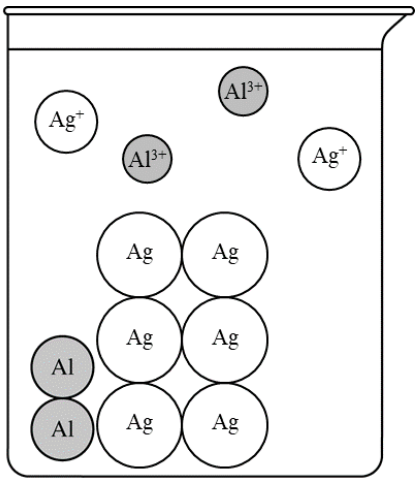
4 Al *and* 8 Ag *particles in the beaker on right (see sample drawing below)*

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

2 $Ag^+$ *ions and* 2 $Al^{3+}$ *ions in the beaker on the right (see sample drawing below)*

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

6 Ag *atoms that are solid and* 2 $Al^{3+}$ *ions that are aqueous in the beaker on the right*




**Total for part (d) 3 points**

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

Accept one of the following:

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

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

*Negative. The reaction has a positive value of $E°$, indicating that it is thermodynamically favorable and would therefore have a negative value of $\Delta G°$. ($\Delta G° = -nFE°$)*

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

Accept one of the following:

- *Zero. The observation that the reaction stops progressing implies that $E_{cell} = 0$, indicating that there is no longer a driving force for the reaction.*
- *Zero. The observation that reaction stops progressing implies that equilibrium is established, and $\Delta G = 0$ at equilibrium.*

**Total for question 3 10 points**

## Question 4: Short Answer — 4 points

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

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

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

Accept one of the following:

- *Both* $NH_2Cl$ *and* $NCl_3$ *can participate in hydrogen bonding with water.*
- *Both* $NH_2Cl$ *and* $NCl_3$ *have dipole-dipole attractions to water.*

For a correct explanation: **1 point**

*The intermolecular forces between* $NH_2Cl$ *molecules and water are stronger than those between* $NCl_3$ *molecules and water, which leads to the greater solubility of* $NH_2Cl$ *in water.*

**Total for part (b) 2 points**

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

$$15.0\text{ g } NCl_3 \times \frac{1\text{ mol}}{120.36\text{ g}} \times \frac{32.9\text{ kJ}}{1\text{ mol}} = 4.10\text{ kJ}$$

**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:

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

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

$\text{hr}^{-1}$

**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 elementary step 1 is* $\text{rate} = k[\text{N}_2\text{O}_5]$, *which is consistent with the first order kinetics of the overall rate law.*

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

*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:<br>525 nm | **1 point** |
| **(b)(i)** | For the correct answer:<br>92.0 mL | **1 point** |
| **(ii)** | For the correct calculated value:<br>$V_1 = \frac{M_2 V_2}{M_1} = \frac{\left(1.68 \times 10^{-3}\ M\right)(100.0\ \text{mL})}{\left(2.40 \times 10^{-3}\ M\right)} = 70.0\ \text{mL}$ | **1 point** |
| | **Total for part (b)** | **2 points** |
| **(c)** | For the correct answer and a valid justification:<br>*The student could have improperly executed step 3. If the cuvette was 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 absorbance would be lower than what it should be.* | **1 point** |
| | **Total for question 6** | **4 points** |

## Question 7: Short Answer — 4 points

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

$sp^2$

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

$K_{sp} = [Ag^+]^2[C_2O_4{}^{2-}]$

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

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

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

$s = 1.11 \times 10^{-4}\ M$

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

Accept one of the following:

- $C_2O_4{}^{2-}(aq) + H_3O^+(aq) \rightarrow HC_2O_4{}^-(aq) + H_2O(l)$
- $C_2O_4{}^{2-}(aq) + H^+(aq) \rightarrow HC_2O_4{}^-(aq)$
- $C_2O_4{}^{2-}(aq) + 2\ H_3O^+(aq) \rightarrow H_2C_2O_4(aq) + 2\ H_2O(l)$
- $C_2O_4{}^{2-}(aq) + 2\ H^+(aq) \rightarrow H_2C_2O_4(aq)$

**Total for part (b) 3 points**

**Total for question 7 4 points**