2024

AP

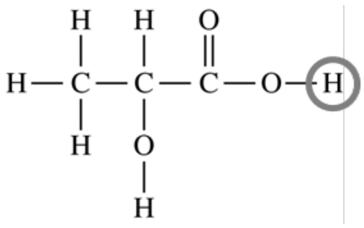
AP® Chemistry

Scoring Guidelines

Question 1: Long Answer — 10 points

(a) For the correct circled atom: **1 point**

The rightmost hydrogen atom should be circled.



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

$$\frac{(10.22\text{ g})\left(\frac{1\text{ mol}}{40.00\text{ g}}\right)}{0.500\text{ L}} = 0.511\ M$$

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

3.9 *(acceptable range: 3.7 – 4.0)*

(d) (i) For the X at the correct point: **1 point**

The X should be at a point greater than or equal to 3 mL *and less than* 8 mL.

(ii) For a correct justification: **1 point**

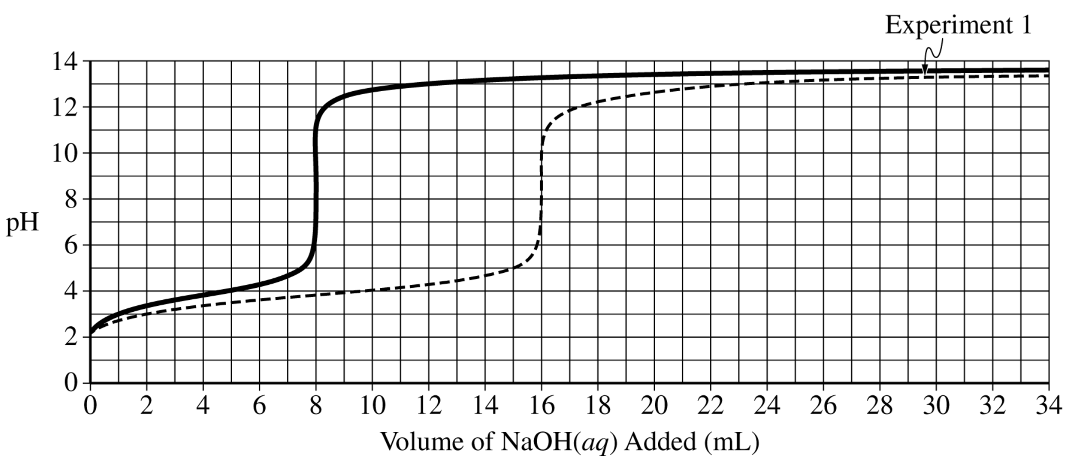
More acid particles are present than conjugate base particles, meaning that the titration is before the half-equivalence point.

(iii) For a curve showing the correct equivalence point: **1 point**

The equivalence point should be at 8 mL. *See example response below.*

For a curve with appropriate initial and final pH with a correct shape: **1 point**

The drawn curve should begin at the same pH, *gradually increase, rise sharply at a volume different than* 16 mL, *and end at a* pH *similar to the first curve.*



Total for part (d) 4 points

(e) (i)	For the correct calculated value: $q = mc\Delta T = (200.0\text{ g})(4.2\text{ J/(g}\cdot{}^\circ\text{C}))(23.2^\circ\text{C} - 20.0^\circ\text{C}) = 2700\text{ J}$	**1 point**
(ii)	For the correct calculated value: $q_{rxn} = -q_{soln} = -2700\text{ J} = -2.7\text{ kJ}$ $\Delta H_{rxn} = \frac{q_{rxn}}{\text{mol}} = \frac{-2.7\text{ kJ}}{(0.100\text{ L})(0.500\text{ mol/L})} = -54\text{ kJ/mol}_{rxn}$	**1 point**
(iii)	For the correct answer and a valid justification: *Agree. The heat lost from the system would result in a lower final temperature, which results in values of* ΔT, q_{soln}, *and* ΔH *that are smaller than the actual value.*	**1 point**
	Total for part (e)	**3 points**
	Total for question 1	**10 points**

Question 2: Long Answer — 10 points

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

$$0.0114 \text{ mol } CO_2 \times \frac{44.01 \text{ g}}{1 \text{ mol}} = 0.502 \text{ g } CO_2$$

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

$PV = nRT$

$$V = \frac{nRT}{P} = \frac{(0.0114 \text{ mol})(0.08206 \frac{\text{L·atm}}{\text{mol·K}})(293 \text{ K})}{1.25 \text{ atm}} = 0.219 \text{ L}$$

Total for part (a) 2 points

(b) (i) For a correct claim: **1 point**

The surface area of the solid reactants increases.

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

Shorter than. The powdered solids have a larger surface area than the solid chunks, thus collisions between water and the surface particles occur more frequently, resulting in a faster rate of dissolution and a shorter amount of time to dissolve the solids.

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

Equal to. Both experiments begin with the same amount of reactants, so they will produce the same number of moles of $CO_2(g)$ *under the same conditions of pressure and temperature; therefore, the final volume will be the same.*

Total for part (b) 3 points

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

Accept one of the following:

- $NaHCO_3$ *is the limiting reactant because changing the mass of* $NaHCO_3$ *alters the amount of* CO_2 *produced.*
- $NaHCO_3$ *is the limiting reactant because the amount present has a smaller theoretical yield of the* CO_2 *product.*

$$1.543 \text{ g } H_2C_4H_2O_4 \times \frac{1 \text{ mol } H_2C_4H_2O_4}{116.07 \text{ g}} \times \frac{2 \text{ mol } CO_2}{1 \text{ mol } H_2C_4H_2O_4} = 0.02659 \text{ mol } CO_2$$

$$1.251 \text{ g } NaHCO_3 \times \frac{1 \text{ mol } NaHCO_3}{84.01 \text{ g}} \times \frac{2 \text{ mol } CO_2}{2 \text{ mol } NaHCO_3} = 0.01489 \text{ mol } CO_2$$

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

The entropy change is positive because the aqueous reactants produce 2 moles of gas particles, according to the balanced chemical equation. Gases are far more dispersed (occupy a greater number of microstates) than condensed phases, so the entropy of the products is greater than that of the reactants.

(e)	For the correct answer and a valid justification: Accept one of the following: • *Disagree. The reaction is endothermic and has a positive entropy change. Thus, the reaction is only thermodynamically favorable at a high enough temperature such that the magnitude of* $-T\Delta S$ *is greater than that of* ΔH. • *Disagree. For the reaction to be thermodynamically favorable* $(\Delta G < 0)$ *at all temperatures, the reaction must be exothermic* $(\Delta H < 0)$ *and have a positive entropy change* $(\Delta S > 0)$.	**1 point**
(f)	For the correct calculated value: $\text{p}K_{a_2} = -\log\left(8.5 \times 10^{-7}\right) = 6.07$	**1 point**
(g)	For the correct calculated value: $\text{pH} = \text{p}K_{a_2} + \log\dfrac{[C_4H_2O_4{}^{2-}]}{[HC_4H_2O_4{}^{-}]}$ $\dfrac{[C_4H_2O_4{}^{2-}]}{[HC_4H_2O_4{}^{-}]} = 10^{(\text{pH}-\text{p}K_{a_2})} = 10^{(7.00-6.07)} = 8.5$	**1 point**

Total for question 2 10 points

Question 3: Long Answer — 10 points

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

$Ag(s)$ ___0___ $Ag_2S(s)$ ___+1___

(b) (i) For a valid explanation: **1 point**

Silver and copper have similar radii, so the alloy would be substitutional versus interstitial.

(ii) For a valid explanation: **1 point**

Silver has more occupied electron shells $(n = 5)$ *than copper* $(n = 4)$*; the electrons in the fifth shell experience weaker Coulombic attractions and are farther away from the nucleus.*

Total for part (b) 2 points

(c) For the correct calculated mass of Ag_2S (may be implicit): **1 point**

$409.21 \text{ g} - 398.94 \text{ g} = 10.27 \text{ g}$

For the correct calculated moles of Ag: **1 point**

$$10.27 \text{ g} \times \frac{1 \text{ mol } Ag_2S}{247.80 \text{ g } Ag_2S} \times \frac{2 \text{ mol Ag}}{1 \text{ mol } Ag_2S} = 0.08289 \text{ mol Ag}$$

Total for part (c) 2 points

(d) (i) For the correct balanced equation (state symbols not required): **1 point**

$$4\ Rh^{3+}(aq) + 6\ H_2O(l) \rightarrow 4\ Rh(s) + 3\ O_2(g) + 12\ H^+(aq)$$

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

$E^\circ_{cell} = +0.80 \text{ V} - 1.23 \text{ V} = -0.43 \text{ V}$

(iii) For a correct explanation, consistent with part (d)(ii): **1 point**

E°_{cell} *is negative, which means the reaction is not thermodynamically favorable.*

Total for part (d) 3 points

(e) For the correct calculated value of moles of electrons (may be implicit): **1 point**

$$2.8 \text{ g Rh} \times \frac{1 \text{ mol Rh}}{102.9 \text{ g Rh}} \times \frac{3 \text{ mol } e^-}{1 \text{ mol Rh}} = 0.082 \text{ mol } e^-$$

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

$$0.082 \text{ mol } e^- \times \frac{96{,}485 \text{ C}}{1 \text{ mol } e^-} \times \frac{1 \text{ second}}{2.0 \text{ C}} = 3900 \text{ seconds}$$

Total for part (e) 2 points

Total for question 3 10 points

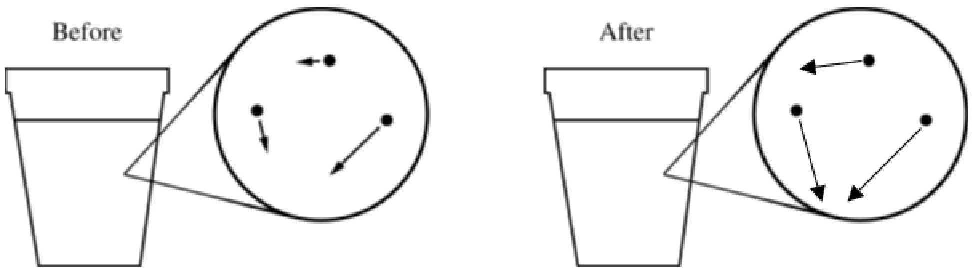
Question 4: Short Answer — 4 points

(a) For the correct answer, reported to the correct decimal place: **1 point**

38.5°C

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

The "After" drawing should contain arrows that are longer, on average.



(c) For the correct calculated value, consistent with part (a): **1 point**

$q = mc\Delta T$

$$c_{metal} = \frac{q_{metal}}{m_{metal}\Delta T_{metal}} = \frac{-2940\text{ J}}{(98.1\text{ g})(38.5^{\circ}\text{C} - 100.0^{\circ}\text{C})} = 0.487\,\frac{\text{J}}{\text{g}\cdot{}^{\circ}\text{C}}$$

(d) For a valid explanation, consistent with part (c): **1 point**

Accept one of the following:

- *The value of* ΔT_{Al} *will be smaller because Al has a greater specific heat capacity than the metal in the original experiment. Therefore, the same thermal energy transfer applied to the same mass will result in a smaller change in temperature, according to the equation* $q = mc\Delta T$.
- $q = mc\Delta T$

  $$|\Delta T_{\text{Al}}| = \left|\frac{q_{\text{Al}}}{m_{\text{Al}}c_{\text{Al}}}\right| = \left|\frac{-2940\text{ J}}{(98.1\text{ g})(0.897\,\frac{\text{J}}{\text{g}\cdot{}^{\circ}\text{C}})}\right| = 33.4^{\circ}\text{C}$$

  $$|\Delta T_{metal}| = |38.5^{\circ}\text{C} - 100.0^{\circ}\text{C}| = 61.5^{\circ}\text{C}$$

  Thus, $\Delta T_{\text{Al}} < \Delta T_{metal}$

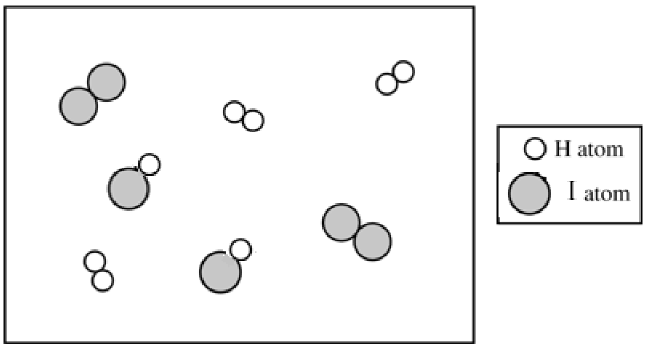
Total for question 4 — 4 points

Question 5: Short Answer — 4 points

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

$$K_c = \frac{[HI]^2}{[H_2][I_2]}$$

(b) (i) For the correct drawing consistent with part (a): **1 point**



(ii) For a valid hypothesis: **1 point**

Accept one of the following:

- *Decreased the temperature.*
- *Added more* H_2 *and/or* I_2 *to the reaction vessel.*

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

Accept one of the following:

- *Remain unchanged. The number of moles in the numerator and denominator of* Q *(or* K *) are equal; changing the volume of the container would not alter the value of* Q *, which is still equal to* K *, so the number of moles of* HI *will remain the same.*
- *Remain unchanged. The increase in volume will decrease the concentration of reactants and products by an equal proportion. Because there are equal moles of gaseous reactants and products in the balanced chemical equation, there is no shift in the equilibrium position, and the number of moles of* HI *will remain the same.*

Total for part (b) 3 points

Total for question 5 4 points

Question 6: Short Answer — 4 points

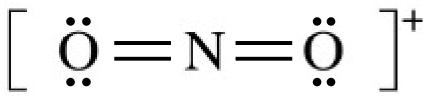
(a) For a correct explanation: **1 point**

The plot of $\frac{1}{[NO_2]}$ *versus time is the most linear, indicating that the reaction is second order with respect to* NO_2.

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

$$6.52 \times 10^{-7}\, M/\text{s} \times \frac{1 \text{ mol } O_2}{2 \text{ mol } NO_2} = 3.26 \times 10^{-7}\, M/\text{s}$$

(c) (i) For the correct Lewis diagram: **1 point**



(ii) For the correct answer and a valid justification, consistent with part (c)(i): **1 point**

Accept one of the following:

- *Agree. The angle of* NO_2^+ *is different from the angle in* NO_2 *because there would no longer be a nonbonding electron on the central atom in* NO_2, *and the* O *atoms would spread farther apart, forming a linear structure with a* $180°$ *bond angle.*
- *Agree. The hybridization of* N *in* NO_2 *is* sp^2, *which would result in a bond angle of approximately* $120°$. *The hybridization of* N *in* NO_2^+ *is* sp, *which would result in a bond angle of* $180°$.

Total for part (c) 2 points

Total for question 6 4 points

Question 7: Short Answer — 4 points

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

$$0.1000 \text{ L} \times \frac{0.340 \text{ mol}}{1 \text{ L}} \times \frac{58.44 \text{ g}}{1 \text{ mol}} = 1.99 \text{ g NaCl}$$

(b) For a correct description of step 2: **1 point**

Combine the solid NaCl *and some distilled water in a* 100.0 mL *volumetric flask.*

For a correct description of step 4: **1 point**

Fill the volumetric flask with distilled water to the calibration (100.0 mL) *mark.*

Total for part (b) 2 points

(c) For the correct prediction and a valid explanation: **1 point**

It would decrease. The solvent front will not travel as far in the second experiment, so the separation will be smaller.

Total for question 7 4 points