2023

AP® Chemistry

Scoring Guidelines

Question 1: Long Answer — 10 points

(a) (i)	For the correct answer: Accept one of the following: • $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^5$ • $[Ar]\ 4s^2 3d^5$	**1 point**
(ii)	For the correct answer, consistent with part (a)(i): $4s$	**1 point**
	Total for part (a)	**2 points**
(b)	For the correct calculated value: $62.673\text{ g} - 61.262\text{ g} = 1.411\text{ g Cl}$	**1 point**
(c)	For the correct calculated value, consistent with part (b): $1.411\text{ g Cl} \times \frac{1\text{ mol Cl}}{35.45\text{ g Cl}} = 0.03980\text{ mol Cl}$	**1 point**
(d)	For the correct answer, consistent with part (c): $\frac{0.03980\text{ mol Cl}}{0.0199\text{ mol Mn}} = \frac{2\text{ mol Cl}}{1\text{ mol Mn}} \Rightarrow \text{MnCl}_2$	**1 point**
(e)	For the correct answer and a valid justification: *Less than. If some of the mass of aqueous Mn_xCl_y is lost due to splattering, the final mass of the dry beaker and Mn_xCl_y will be decreased, which will decrease the calculated mass and number of moles of chlorine in the dry solid.*	**1 point**

(f) (i)	For the correct balanced equation: $2\ MnO_2(s) + H_2O(l) + 2\ e^- \rightarrow Mn_2O_3(s) + 2\ OH^-(aq)$ $Zn(s) + 2\ OH^-(aq) \rightarrow ZnO(s) + H_2O(l) + 2\ e^-$ $2\ MnO_2(s) + Zn(s) \rightarrow Mn_2O_3(s) + ZnO(s)$	**1 point**
(ii)	For the correct calculated value, consistent with part (f)(i): $E^\circ_{cell} = 0.15\text{ V} - (-1.28\text{ V}) = 1.43\text{ V}$	**1 point**
(iii)	For the correct calculated value, consistent with part (f)(ii): $\Delta G^\circ = -nFE^\circ = -\frac{2\text{ mol } e^-}{1\text{ mol}_{rxn}} \times \frac{96{,}485\text{ C}}{1\text{ mol } e^-} \times \frac{1.43\text{ J}}{1\text{ C}} \times \frac{1\text{ kJ}}{1000\text{ J}} = -276\text{ kJ/mol}_{rxn}$	**1 point**
(iv)	For the correct answer and a valid justification: Accept one of the following: • *Disagree. The battery is enclosed, so no change in the total mass will occur.* • *Disagree. All reactants and products are in the solid phase, so the mass of the sealed battery will remain the same (no gases enter or exit the battery).*	**1 point**
	Total for part (f)	**4 points**
	Total for question 1	**10 points**

Question 2: Long Answer 10 points

(a) For the correct calculated value reported with the correct number of significant figures: **1 point**

$$1.25 \text{ mol AlCl}_3 \times \frac{3 \text{ mol Cl}}{1 \text{ mol AlCl}_3} \times \frac{35.45 \text{ g Cl}}{1 \text{ mol Cl}} = 133 \text{ g Cl}$$

(b) For the correct algebraic manipulation of either ΔH_2° or ΔH_4° (may be implicit): **1 point**

Accept one of the following:

- *Reversing reaction 2:*

  $AlCl_3(g) \rightarrow Al(s) + \frac{3}{2}Cl_2(g) \quad \Delta H_{rxn}^\circ = -(-583) = +583 \text{ kJ/mol}_{rxn}$

- *Multiplying reaction 4 by $\frac{3}{2}$:*

  $\frac{3}{2}(Cl_2(g) \rightarrow 2\,Cl(g)) \quad \Delta H_{rxn}^\circ = \frac{3}{2}(+243) = +365 \text{ kJ/mol}_{rxn}$

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

$$\Delta H_1^\circ = -\Delta H_2^\circ + \Delta H_3^\circ + 1.5(\Delta H_4^\circ) = -(-583) + 326 + 1.5(243) = 1274 \text{ kJ/mol}_{rxn}$$

Total for part (b) 2 points

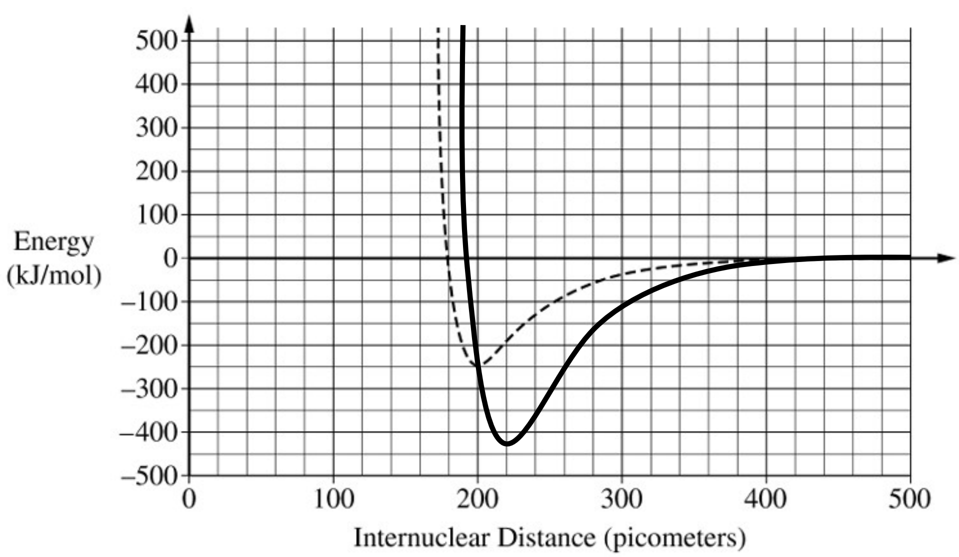
(c) (i) For the correct answer: **1 point**

200 picometers (±10 pm)

(ii) For a curve with a minimum at an internuclear distance of 220 ± 10 pm: **1 point**

See sample curve below

For a curve with a minimum energy value of -425 ± 20 kJ/mol that approaches zero as the internuclear distance approaches 500 pm: **1 point**



Total for part (c) 3 points

(d) (i)	For the correct answer and a valid justification: *Diagram 2. Al has four electron domains in Diagram 2, which would be trigonal pyramidal, not trigonal planar.*	**1 point**
(ii)	For the correct answer and a valid justification: *Diagram 1. All atoms in diagram 1 have a formal charge of zero, whereas atoms in diagrams 2 and 3 have nonzero formal charges.*	**1 point**
	Total for part (d)	**2 points**
(e)	For the correct answer: $K_p = \dfrac{P_{Al_2Cl_6}}{(P_{AlCl_3})^2}$	**1 point**
(f)	For the correct calculated value, consistent with part (e): $K_p = \dfrac{\chi_{Al_2Cl_6}(P_{total})}{\left(\chi_{AlCl_3}(P_{total})\right)^2} = \dfrac{\frac{3}{10}(22.1)}{\left(\frac{7}{10}(22.1)\right)^2} = 0.0277$	**1 point**
	Total for question 2	**10 points**

Question 3: Long Answer 10 points

(a)	For the correct balanced equation (state symbols not required): Accept one of the following: • $CaCO_3(s) + 2\,H^+(aq) \rightarrow Ca^{2+}(aq) + CO_2(g) + H_2O(l)$ • $CaCO_3(s) + 2\,H_3O^+(aq) \rightarrow Ca^{2+}(aq) + CO_2(g) + 3\,H_2O(l)$	**1 point**
(b)	For a correct explanation: Accept one of the following: • *Even though the concentration of* HCl *is greater in trial 5 than in trial 2, the reaction time is significantly longer. Both trial 2 and 5 occur under otherwise identical conditions. The trend for trial 1 and 4 indicates that the higher concentration of* HCl *results in a shorter time of reaction.* • *The time of reaction in trial 5, with small chunks of calcium carbonate, is longer than trial 6 with large chunks. Both trial 5 and 6 occur under otherwise identical conditions. The trend for trials 1, 2, and 3 shows that larger chunks of the solid result in longer time of reaction.*	**1 point**
(c)	For a correct explanation of the effect of surface area on reaction time: *The time of reaction in trial 2 is shorter than that in trial 3 because the calcium carbonate in trial 2 has a larger surface area (meaning that more particles of calcium carbonate are exposed to the* H^+ *particles in the solution).*	**1 point**
	For a correct explanation of the effect of particle collisions on reaction rate: *The larger interface between the two reacting substances means there will be more collisions between the particles in a given amount of time, and thus, a higher frequency of successful collisions in which the particles react to form the products.*	**1 point**
	Total for part (c)	**2 points**
(d)	For the correct answer and a valid justification: Accept one of the following: • *Disagree. If the reaction was zeroth order with respect to* HCl, *then changing the concentration of* HCl *would not affect the rate of reaction, and the time of reaction would be the same for trials in which the only difference was* [HCl]. *The student's data for trials 1 and 4 (likewise for 3 and 6) show that changing* [HCl] *significantly alters the time of reaction.* • *Disagree. The reaction appears to be first order, not zeroth order, with respect to* [HCl]. *Tripling* [HCl] *results in a reaction time that is 1/3 of that when* [HCl] = *1.00 M, which means the reaction rate has also tripled, indicating a first-order process.*	**1 point**

(e)	For the correct calculated moles of HCl reacted (may be implicit): $1.00 \text{ g } CaCO_3 \times \frac{1 \text{ mol}}{100.09 \text{ g}} = 0.00999 \text{ mol } CaCO_3$ $0.00999 \text{ mol } CaCO_3 \times \frac{2 \text{ mol HCl}}{1 \text{ mol } CaCO_3} = 0.0200 \text{ mol HCl reacted}$	**1 point**
	For the correct calculated $[HCl]$ remaining, consistent with the number of moles reacted: $0.0500 \text{ L} \times \frac{1.00 \text{ mol HCl}}{1 \text{ L}} = 0.0500 \text{ mol HCl initially present}$ $0.0500 \text{ mol} - 0.0200 \text{ mol} = 0.0300 \text{ mol remaining}$ $\frac{0.0300 \text{ mol}}{0.0500 \text{ L}} = 0.600\ M \text{ HCl remaining}$	**1 point**
	Total for part (e)	**2 points**
(f)	For the correct answer and a valid justification: *Exothermic. The solution temperature increases as the reaction proceeds.*	**1 point**
(g) (i)	For the correct calculated value (sign not required): $q_{surr} = mc\Delta T = (51.0 \text{ g})(4.0 \frac{\text{J}}{\text{g}\cdot°\text{C}})(21.90°\text{C} - 21.20°\text{C}) = 140 \text{ J}$	**1 point**
(ii)	For the correct calculated value, consistent with (g)(i), and the correct sign, consistent with (f): $q_{sys} = -q_{surr} = -140 \text{ J} = -0.14 \text{ kJ}$ $1.00 \text{ g } CaCO_3 \times \frac{1 \text{ mol } CaCO_3}{100.09 \text{ g } CaCO_3} \times \frac{1 \text{ mol}_{rxn}}{1 \text{ mol } CaCO_3} = 0.00999 \text{ mol}_{rxn}$ $\Delta H^\circ_{rxn} = \frac{-0.14 \text{ kJ}}{0.00999 \text{ mol}_{rxn}} = -14 \text{ kJ/mol}_{rxn}$	**1 point**
	Total for part (g)	**2 points**
	Total for question 3	**10 points**

Question 4: Short Answer — 4 points

(a)	For the correct calculated value:	**1 point**
	$0.00250 \text{ mol } CH_3NH_3Cl \times \frac{67.52 \text{ g}}{1 \text{ mol}} = 0.169 \text{ g}$	
(b)	For a correct description of step 1:	**1 point**
	Accept one of the following: • *Use the spatula, balance, and weighing paper to measure out exactly* 0.169 g *of* $CH_3NH_3Cl(s)$. • *Use the balance to weigh out the mass of solid in part (a).*	
	For a correct description of step 4:	**1 point**
	Rinse the buret with a small amount of $0.100\ M\ CH_3NH_2(aq)$*, drain, and refill with* $0.100\ M\ CH_3NH_2(aq)$.	
	Total for part (b)	**2 points**
(c)	For the correct answer and a valid justification:	**1 point**
	Equal to. The ratio of weak acid to conjugate base is still 1:1.	
	Total for question 4	**4 points**

Question 5: Short Answer — 4 points

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

$$n = \frac{PV}{RT} = \frac{(7.45 \text{ atm})(6.00 \text{ L})}{(0.08206 \frac{\text{L}\cdot\text{atm}}{\text{mol}\cdot\text{K}})(296 \text{ K})} = 1.84 \text{ mol}$$

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

Accept one of the following:

- $\frac{P_1}{T_1} = \frac{P_2}{T_2}$

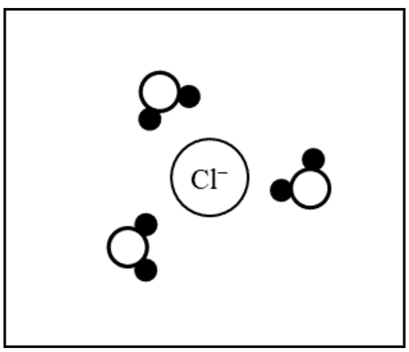
  $$P_2 = \frac{(P_1)(T_2)}{T_1} = \frac{(7.45 \text{ atm})(271 \text{ K})}{296 \text{ K}} = 6.82 \text{ atm}$$

- $$P = \frac{nRT}{V} = \frac{(1.84 \text{ mol})(0.08206 \frac{\text{L}\cdot\text{atm}}{\text{mol}\cdot\text{K}})(271 \text{ K})}{6.00 \text{ L}} = 6.82 \text{ atm}$$

Total for part (a) 2 points

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

The drawing should show three water molecules with a hydrogen atom (dark circle) oriented towards the Cl^- *ion.*



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

HNO_2. *The diagram shows most of the molecules in their un-ionized form, indicating a weak acid with a* K_a *value less than 1, which is consistent with* HNO_2.

Total for question 5 4 points

Question 6: Short Answer — 4 points

(a)	For the correct answer: $HBr(l)$: *London dispersion forces, dipole-dipole attractions* $HF(l)$: *London dispersion forces, dipole-dipole attractions, hydrogen bonding*	**1 point**
(b) (i)	For a correct explanation: ΔH°_{vap} *is greater for* $HF(l)$ *than* $HBr(l)$ *because the overall intermolecular forces in* $HF(l)$ *are stronger than those in* $HBr(l)$ *due to hydrogen bonding attractions present in* $HF(l)$, *so more energy is required to separate the molecules in* $HF(l)$.	**1 point**
(ii)	For the correct calculated value: $6.85\text{ g HF} \times \frac{1\text{ mol}}{20.01\text{ g}} \times \frac{25.2\text{ kJ}}{1\text{ mol}} = 8.63\text{ kJ}$	**1 point**
	Total for part (b)	**2 points**
(c)	For a correct explanation: Br *has two additional occupied electron shells (n = 3 and n = 4) compared to* F *(n = 2). The extra electron shells increase the distance between the* H *and* Br *nuclei, giving* HBr *the greater bond length.*	**1 point**
	Total for question 6	**4 points**

Question 7: Short Answer — 4 points

(a)	For a correct answer: Accept one of the following: • *The student's drawing shows an incorrect ratio of* Sr^{2+} *and* OH^- *ions.* • *The student's drawing is not charge-balanced.*	**1 point**
(b) (i)	For the correct calculated value: $\frac{0.043 \text{ mol } Sr^{2+}}{1 \text{ L}} \times \frac{2 \text{ mol } OH^-}{1 \text{ mol } Sr^{2+}} = 0.086\ M\ OH^-$	**1 point**
(ii)	For the correct calculated value, consistent with (b)(i): $K_{sp} = [Sr^{2+}][OH^-]^2 = (0.043)(0.086)^2 = 3.2 \times 10^{-4}$	**1 point**
	Total for part (b)	**2 points**
(c)	For the correct answer and a valid justification: *Less than. Because the* $Sr(NO_3)_2(aq)$ *solution already contains a common ion,* $Sr^{2+}(aq)$, *the solubility of* $Sr(OH)_2$ *will be decreased, resulting in a lower value of* $[OH^-]$.	**1 point**
	Total for question 7	**4 points**