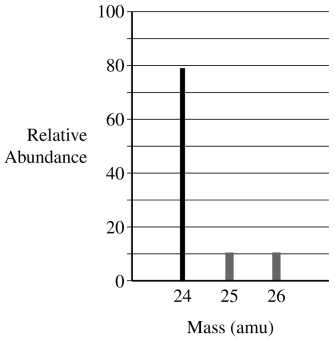
Question 1: Long Answer — 10 points

A (i) For the correct plotted lines: **Point 01**

The abundance for the two lines should be between 10 and 11.



(ii) For the correct answer: **Point 02**

Magnesium-26 has one more neutron than magnesium-25 does.

B (i) For a correct explanation: **Point 03**

The charge on the sodium ion is less than the charge on the magnesium ion. A smaller charge results in a weaker Coulombic attraction between Na^+ *and water.*

(ii) For a correct explanation: **Point 04**

The Na^+ *ion is larger than the* Mg^{2+} *ion, so the distance between the* Na^+ *and the oxygen on the water molecule will be greater. As distance increases, Coulombic attraction decreases.*

C For the correct calculated value: **Point 05**

$$pOH = -\log(2.80 \times 10^{-4}) = 3.553$$

$$pH = 14 - pOH = 14 - 3.553 = 10.447$$

D For the correct calculated value: **Point 06**

$$M_1V_1 = M_2V_2$$

$$M_2 = \frac{(1.85 \times 10^{-3}\,M)(0.03500\text{ L})}{(0.03500\text{ L} + 0.05000\text{ L})} = 7.62 \times 10^{-4}\,M$$

E (i) For the correct expression: **Point 07**

$$K_{sp} = [Mg^{2+}][OH^-]^2$$

(ii) For the correct calculated value, consistent with part D and part E (i): **Point 08**

$$Q = [Mg^{2+}][OH^-]^2 = (7.62 \times 10^{-4})(1.65 \times 10^{-4})^2 = 2.07 \times 10^{-11}$$

(iii) For the correct prediction and justification, consistent with part E (ii). **Point 09**

Examples of acceptable responses may include the following:

- $Q > K_{sp}$*, so a precipitate will form.*
- *The concentration of the ions in solution (represented by Q) is greater than that of a saturated solution, so a precipitate will form.*

F For the correct answer and justification: **Point 10**

Decrease. The H^+ *from* $HNO_3(aq)$ *will react with* OH^-*, decreasing* $[OH^-]$ *and causing* $Q < K_{sp}$*. As a result, more* $Mg(OH)_2(s)$ *will dissolve until equilibrium is reestablished, resulting in less* $Mg(OH)_2(s)$*.*

Question 2: Long Answer — 10 points

A (i) For the correct calculated value: **Point 01**

$$2.883 \text{ g } H_2O \times \frac{1 \text{ mol } H_2O}{18.02 \text{ g } H_2O} = 0.1600 \text{ mol } H_2O$$

(ii) For the correct calculated number of moles of H (may be implicit): **Point 02**

$$0.1600 \text{ mol } H_2O \times \frac{2 \text{ mol H}}{1 \text{ mol } H_2O} = 0.3200 \text{ mol H}$$

For the correct empirical formula. **Point 03**

Examples of acceptable responses may include the following:

- $x : y : z$ = (moles of C):(moles of H):(moles of O)
  $x : y : z = 0.2400 : 0.3200 : 0.2400 = 3 : 4 : 3$
  Therefore, the empirical formula of ascorbic acid is $C_3H_4O_3$.
- $0.2400 \text{ mol } CO_2 \times \frac{1 \text{ mol C}}{1 \text{ mol } CO_2} = 0.2400 \text{ mol C}$
  $\frac{0.3200 \text{ mol H}}{0.2400 \text{ mol C}} = \frac{4 \text{ H}}{3 \text{ C}}$
  Given that the ratio of C:O *is* 1:1, *the empirical formula of ascorbic acid is* $C_3H_4O_3$.

B (i) For the correct calculated value: **Point 04**

$$0.0160 \text{ L NaOH} \times \frac{0.0550 \text{ mol NaOH}}{1 \text{ L NaOH}} \times \frac{1 \text{ mol HAsc}}{1 \text{ mol NaOH}} = 8.80 \times 10^{-4} \text{ mol HAsc}$$

$$\frac{8.80 \times 10^{-4} \text{ mol HAsc}}{0.0100 \text{ L}} = 0.0880 \ M \text{ HAsc}$$

(ii) For the correct pK_a: **Point 05**

4.1 (*acceptable range:* 4.0 – 4.3)

(iii) For the correct ratio, consistent with part B (ii): **Point 06**

Using the Henderson-Hasselbalch equation:

$$pH = pK_a + \log\left(\frac{[Asc^-]}{[HAsc]}\right)$$

$$4.7 = 4.1 + \log\left(\frac{[Asc^-]}{[HAsc]}\right)$$

$$\frac{[Asc^-]}{[HAsc]} = 10^{0.6} = 4.0$$

C (i) For a correct explanation. **Point 07**

Examples of acceptable responses may include the following:

- $\frac{4.914 \times 10^{-4}}{2.457 \times 10^{-4}} = \left(\frac{0.900}{0.450}\right)^a$, thus $a = 1$
- *Comparing trials 1 and 3, the rate doubles when the concentration of ascorbic acid is doubled and the triiodide ion concentration is constant, indicating that the process is first order with respect to ascorbic acid.*

(ii) For the correct calculated value: **Point 08**

$rate = k[HAsc][I_3^-]$

Using trial 1 data:

$$k = \frac{rate}{[HAsc][I_3^-]} = \frac{2.457 \times 10^{-4} \ M/s}{(0.450 \ M)(1.200 \ M)} = 4.55 \times 10^{-4} M^{-1} \text{ s}^{-1}$$

For the correct units: **Point 09**

M^{-1} s^{-1}

D For the correct answer: **Point 10**

Ion-dipole attractions are present between I_3^- *ions and water but not between* I_2 *molecules and water.*

Question 3: Long Answer — 10 points

A For the correct diagram: **Point 01**

B (i) For a correct explanation: **Point 02**

Because gas particles are more dispersed (have more microstates) than solids, the entropy decreases as the reactants (which include a gas) convert to the solid product.

(ii) For the correct answer and a valid justification: **Point 03**

Yes. Given that $\Delta G^\circ_{rxn} = \Delta H^\circ_{rxn} - T\Delta S^\circ_{rxn}$*, the reaction must have* $\Delta G^\circ_{rxn} < 0$ *to be favorable. Because the reaction is exothermic,* $\Delta H^\circ_{rxn} < 0$ *and enthalpy contributes to favorability.* $\Delta S^\circ_{rxn} < 0$*, so entropy does not contribute to favorability.*

C (i) For the correct calculated value reported with the correct number of significant figures: **Point 04**

$q = mc\Delta T = (100.1\text{ g})(4.18\text{ J/(g}\cdot\text{°C)})(22.38\text{°C} - 22.00\text{°C})$

$q = 160\text{ J} = 0.16\text{ kJ}$

(ii) For the correct calculated value, consistent with part C (i): **Point 05**

$q_{rxn} = -q_{surr} = -0.16\text{ kJ}$

$$\Delta H^\circ_{rxn} = \frac{-0.16\text{ kJ}}{0.100\text{ g } P_4O_{10}} \times \frac{283.9\text{ g } P_4O_{10}}{1\text{ mol } P_4O_{10}} \times \frac{1\text{ mol } P_4O_{10}}{1\text{ mol}_{rxn}} = -450\text{ kJ/mol}_{rxn}$$

For the correct sign: **Point 06**

-450 kJ/mol_{rxn}

D For the correct answer and a valid justification: **Point 07**

Less than. If less P_4O_{10} *is present, less thermal energy will be transferred to the water during the reaction, causing the temperature increase to be less than it was with* 0.100 g *of* P_4O_{10}*.*

E For the correct calculated value: **Point 08**

Using Hess's law:

$$\Delta H^\circ_{f,\,PCl_5(g)} = \frac{1}{4}\Delta H^\circ_1 + \Delta H^\circ_2$$

$$\Delta H^\circ_{f,\,PCl_5(g)} = \frac{1}{4}(-1148) + (-88) = -375\text{ kJ/mol}$$

F (i) For the correct calculated value: **Point 09**

$$K_p = \frac{P_{PCl_5}}{\left(P_{PCl_3}\right)\left(P_{Cl_2}\right)} = \frac{4.00}{(2.00)(6.00)} = \frac{1}{3} = 0.333$$

(ii) For the correct answer and a valid justification: **Point 10**

Decrease. The negative value of ΔH°_2 *indicates that the reaction is exothermic. Because exothermic reactions favor reactant formation at higher temperature, the value of* K_p *decreases.*

Question 6: Short Answer — 4 points

A — For the correct equation (state symbols not required): **Point 01**

$$Al(s) \rightarrow Al^{3+}(aq) + 3\,e^-$$

B — For the correct balanced net ionic equation (state symbols not required): **Point 02**

$$2\,Al(s) + 3\,Zn^{2+}(aq) \rightarrow 2\,Al^{3+}(aq) + 3\,Zn(s)$$

C — For the correct answer and a valid justification that correctly compares the masses of Al and Zn based on their molar masses and the stoichiometry of the balanced equation. **Point 03**

Examples of acceptable responses may include the following:

- Zn *experiences a greater change in mass. Assuming the entire* Al *anode reacts:*

$$50.0\text{ g Al} \times \frac{1\text{ mol Al}}{26.98\text{ g Al}} \times \frac{3\text{ mol Zn}}{2\text{ mol Al}} \times \frac{65.38\text{ g Zn}}{1\text{ mol Zn}} = 182\text{ g Zn}$$

- Zn *experiences a greater change in mass.*

$$1\text{ mol}_{rxn} \times \frac{3\text{ mol Zn}}{1\text{ mol}_{rxn}} \times \frac{65.38\text{ g Zn}}{1\text{ mol Zn}} = 196.1\text{ g Zn}$$

$$1\text{ mol}_{rxn} \times \frac{2\text{ mol Al}}{1\text{ mol}_{rxn}} \times \frac{26.98\text{ g Al}}{1\text{ mol Al}} = 53.96\text{ g Al}$$

Thus, for however many moles of reaction that proceed, the mass of Zn *produced will be greater than the mass of* Al *consumed.*

- Zn *experiences a greater change in mass. As the reaction proceeds, three moles of* Zn *are used for every two moles of* Al*. Thus, for every* 196 g *of* Zn *that are produced,* 54 g *of* Al *are consumed.*

D — For the correct calculated value. **Point 04**

Examples of acceptable responses may include the following:

- $E^\circ_{cell} = 1.50\text{ V} + 0.76\text{ V} = 2.26\text{ V}$
- $Au^{3+}(aq) + 3\,e^- \rightarrow Au(s) \quad +1.50\text{ V}$

  $Zn(s) \rightarrow Zn^{2+}(aq) + 2\,e^- \quad +0.76\text{ V}$

  $E^\circ_{cell} = 2.26\text{ V}$

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: **1 point**

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 $(\Delta S > 0)$.*

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

$$pK_{a_2} = -\log\left(8.5 \times 10^{-7}\right) = 6.07$$

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

$$pH = pK_{a_2} + \log\frac{[C_4H_2O_4{}^{2-}]}{[HC_4H_2O_4{}^{-}]}$$

$$\frac{[C_4H_2O_4{}^{2-}]}{[HC_4H_2O_4{}^{-}]} = 10^{(pH - pK_{a_2})} = 10^{(7.00 - 6.07)} = 8.5$$

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

Question 1: Long Answer — 10 points

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

Accept one of the following:

- $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^5$
- $[\text{Ar}]\ 4s^2 3d^5$

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

$4s$

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

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

$62.673\ \text{g} - 61.262\ \text{g} = 1.411\ \text{g Cl}$

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

$$1.411\ \text{g Cl} \times \frac{1\ \text{mol Cl}}{35.45\ \text{g Cl}} = 0.03980\ \text{mol Cl}$$

(d) For the correct answer, consistent with part (c): **1 point**

$$\frac{0.03980\ \text{mol Cl}}{0.0199\ \text{mol Mn}} = \frac{2\ \text{mol Cl}}{1\ \text{mol Mn}} \Rightarrow \text{MnCl}_2$$

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

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.

(f) (i) For the correct balanced equation: **1 point**

$$2\ \text{MnO}_2(s) + \text{H}_2\text{O}(l) + 2\ e^- \rightarrow \text{Mn}_2\text{O}_3(s) + 2\ \text{OH}^-(aq)$$
$$\text{Zn}(s) + 2\ \text{OH}^-(aq) \rightarrow \text{ZnO}(s) + \text{H}_2\text{O}(l) + 2\ e^-$$
$$2\ \text{MnO}_2(s) + \text{Zn}(s) \rightarrow \text{Mn}_2\text{O}_3(s) + \text{ZnO}(s)$$

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

$E^\circ_{cell} = 0.15\ \text{V} - (-1.28\ \text{V}) = 1.43\ \text{V}$

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

$$\Delta G^\circ = -nFE^\circ = -\frac{2\ \text{mol}\ e^-}{1\ \text{mol}_{rxn}} \times \frac{96{,}485\ \text{C}}{1\ \text{mol}\ e^-} \times \frac{1.43\ \text{J}}{1\ \text{C}} \times \frac{1\ \text{kJ}}{1000\ \text{J}} = -276\ \text{kJ/mol}_{rxn}$$

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

Accept one of the following:

- *Disagree. The battery is enclosed, so no change in the <u>total</u> 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).*

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

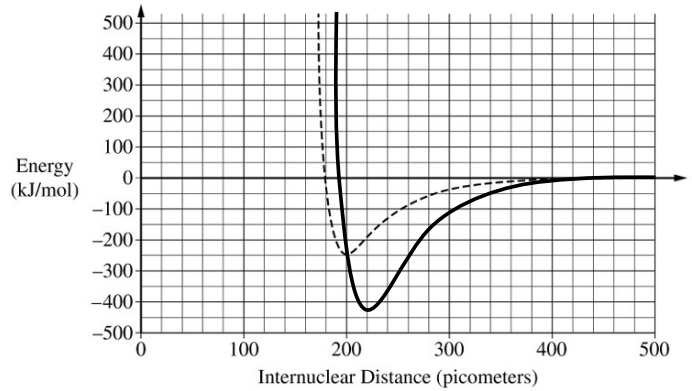
(c) (i) For the correct answer: **1 point**

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: **1 point**

Diagram 2. Al has four electron domains in Diagram 2, which would be trigonal pyramidal, not trigonal planar.

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

Diagram 1. All atoms in diagram 1 have a formal charge of zero, whereas atoms in diagrams 2 and 3 have nonzero formal charges.

Total for part (d) 2 points

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

$$K_p = \frac{P_{Al_2Cl_6}}{(P_{AlCl_3})^2}$$

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

$$K_p = \frac{\chi_{Al_2Cl_6}(P_{total})}{\left(\chi_{AlCl_3}(P_{total})\right)^2} = \frac{\frac{3}{10}(22.1)}{\left(\frac{7}{10}(22.1)\right)^2} = 0.0277$$

Total for question 2 10 points

Question 3: Long Answer — 10 points

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

Accept one of the following:

- $CaCO_3(s) + 2\,H^+(aq) \rightarrow Ca^{2+}(aq) + CO_2(g) + H_2O(l)$
- $CaCO_3(s) + 2\,H_3O^+(aq) \rightarrow Ca^{2+}(aq) + CO_2(g) + 3\,H_2O(l)$

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

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.*

(c) For a correct explanation of the effect of surface area on reaction time: **1 point**

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).*

For a correct explanation of the effect of particle collisions on reaction rate: **1 point**

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.

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

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

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.*

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

$$1.00\text{ g } CaCO_3 \times \frac{1\text{ mol}}{100.09\text{ g}} = 0.00999\text{ mol } CaCO_3$$

$$0.00999\text{ mol } CaCO_3 \times \frac{2\text{ mol HCl}}{1\text{ mol } CaCO_3} = 0.0200\text{ mol HCl reacted}$$

For the correct calculated [HCl] remaining, consistent with the number of moles reacted: **1 point**

$$0.0500\text{ L} \times \frac{1.00\text{ mol HCl}}{1\text{ L}} = 0.0500\text{ mol HCl initially present}$$

$$0.0500\text{ mol} - 0.0200\text{ mol} = 0.0300\text{ mol remaining}$$

$$\frac{0.0300\text{ mol}}{0.0500\text{ L}} = 0.600\ M\ \text{HCl remaining}$$

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

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

Exothermic. The solution temperature increases as the reaction proceeds.

(g) (i) For the correct calculated value (sign not required): **1 point**

$$q_{surr} = mc\Delta T = (51.0\text{ g})\left(4.0\tfrac{\text{J}}{\text{g}\cdot^\circ\text{C}}\right)(21.90^\circ\text{C} - 21.20^\circ\text{C}) = 140\text{ J}$$

(ii) For the correct calculated value, consistent with (g)(i), and the correct sign, consistent with (f): **1 point**

$$q_{sys} = -q_{surr} = -140\text{ J} = -0.14\text{ kJ}$$

$$1.00\text{ g } CaCO_3 \times \frac{1\text{ mol } CaCO_3}{100.09\text{ g } CaCO_3} \times \frac{1\text{ mol}_{rxn}}{1\text{ mol } CaCO_3} = 0.00999\text{ mol}_{rxn}$$

$$\Delta H^\circ_{rxn} = \frac{-0.14\text{ kJ}}{0.00999\text{ mol}_{rxn}} = -14\text{ kJ/mol}_{rxn}$$

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 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**

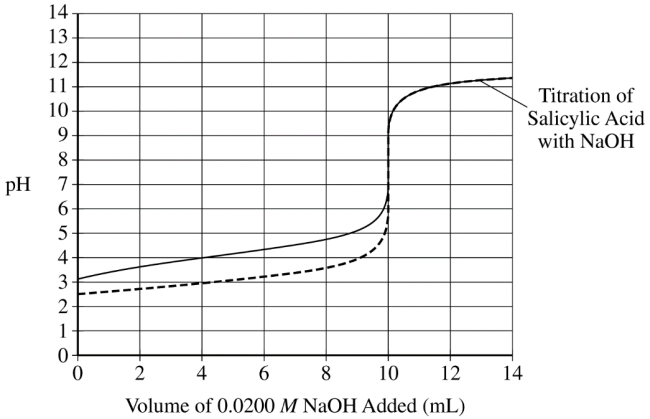
$$pK_a = -\log(6.3 \times 10^{-5}) = 4.20$$

(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