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 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**

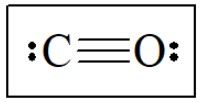
Total for question 1 **10 points**

Question 2: Long Answer — 10 points

(a) For the correct 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**

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

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

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

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

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* $Q_p < K_p$.
- $Q_p = \dfrac{\left(\frac{P_{CO}}{2}\right)\left(\frac{P_{H_2}}{2}\right)^2}{\left(\frac{P_{CH_3OH}}{2}\right)} = \dfrac{K_p}{4} \approx 27 < K_p$

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**