

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 $\Delta G_{rxn}^{\circ} = \Delta H_{rxn}^{\circ} - T\Delta S_{rxn}^{\circ}$, the reaction must have $\Delta G_{rxn}^{\circ} < 0$ to be favorable. Because the reaction is exothermic, $\Delta H_{rxn}^{\circ} < 0$ and enthalpy contributes to favorability. $\Delta S_{rxn}^{\circ} < 0$, so entropy does not contribute to favorability.

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

Point 04

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

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

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

Point 05

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

$$\Delta H_{rxn}^{\circ} = \frac{-0.16 \text{ kJ}}{0.100 \text{ g P}_4\text{O}_{10}} \times \frac{283.9 \text{ g P}_4\text{O}_{10}}{1 \text{ mol P}_4\text{O}_{10}} \times \frac{1 \text{ mol P}_4\text{O}_{10}}{1 \text{ mol}_{rxn}} = -450 \text{ kJ/mol}_{rxn}$$

For the correct sign:

Point 06

$$-450 \text{ kJ/mol}_{rxn}$$

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:*

$$\Delta H_{f, \text{PCl}_5(g)}^\circ = \frac{1}{4} \Delta H_1^\circ + \Delta H_2^\circ$$

$$\Delta H_{f, \text{PCl}_5(g)}^\circ = \frac{1}{4}(-1148) + (-88) = -375 \text{ kJ/mol}$$

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

$$K_p = \frac{P_{\text{PCl}_5}}{(P_{\text{PCl}_3})(P_{\text{Cl}_2})} = \frac{4.00}{(2.00)(6.00)} = \frac{1}{3} = 0.333$$

(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**

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

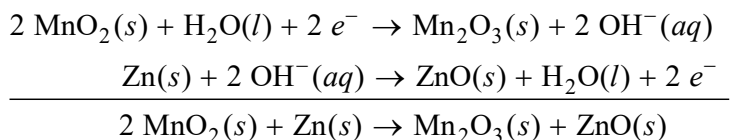
(d) For the correct answer, consistent with part (c): **1 point**

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

(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**



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

$$E_{\text{cell}}^{\circ} = 0.15 \text{ V} - (-1.28 \text{ V}) = 1.43 \text{ V}$$

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

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

(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 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).*

Total for part (f) 4 points

Total for question 1 10 points

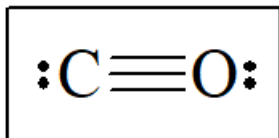
Question 2: Long Answer

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

$$\Delta S^\circ_{\text{rxn}} = \Sigma \Delta S^\circ_{\text{products}} - \Sigma \Delta S^\circ_{\text{reactants}}$$

$$\Delta S^\circ_{\text{rxn}} = (\Delta S^\circ_{\text{CO(g)}} + 2(\Delta S^\circ_{\text{H}_2\text{(g)}})) - (\Delta S^\circ_{\text{CH}_3\text{OH(g)}})$$

- For the correct calculated value: 1 point

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

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

$$\Delta G^\circ = \Delta H^\circ - T\Delta S^\circ$$

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

Total for part (c) 3 points

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

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

- (e) For the correct expression: 1 point

$$K_p = \frac{(P_{\text{CO}})(P_{\text{H}_2})^2}{(P_{\text{CH}_3\text{OH}})}$$

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

$$K_p = \frac{(P_{\text{CO}})(P_{\text{H}_2})^2}{(P_{\text{CH}_3\text{OH}})} = \frac{(4.2)(8.4)^2}{(2.7)} = 110$$

(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 $Q_p < K_p$.*

- $$Q_p = \frac{\left(\frac{P_{\text{CO}}}{2}\right)\left(\frac{P_{\text{H}_2}}{2}\right)^2}{\left(\frac{P_{\text{CH}_3\text{OH}}}{2}\right)} = \frac{K_p}{4} \approx 27 < K_p$$

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