2025

AP® Chemistry

Sample Student Responses and Scoring Commentary

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Free-Response Question 3

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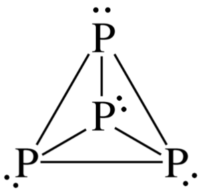
Question 3: Long Answer 10 points

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**

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

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

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

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

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

For the correct sign: **Point 06**

-450 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:

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

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

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

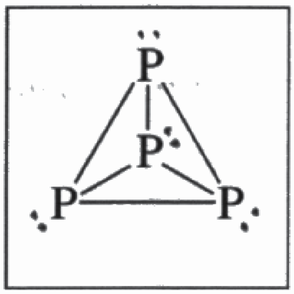
$$K_p = \frac{P_{\mathrm{PCl_5}}}{\left(P_{\mathrm{PCl_3}}\right)\left(P_{\mathrm{Cl_2}}\right)} = \frac{4.00}{(2.00)(6.00)} = \frac{1}{3} = 0.333$$

(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 3

Part A



Part B

i) $\Delta S°$ is negative because as the reaction progresses, gas molecules are used to produce solid molecules. Solids have less entropy than gases because there are less possible locations and positions of the solid molecules compared to the gas molecules. The solid molecules also move slower. So, the entropy of the system decreases and $\Delta S°$ is negative.

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

The student is correct. A reaction is thermodynamically favorable when $\Delta G°$ is negative. Since $\Delta S°$ is negative, $-T\Delta S°$ will be a positive value. The only way that the reaction can be thermodynamically favorable is if $\Delta H°$ is negative.

Question 3 is continued on the next page.

Use a pencil or a pen with black or dark blue ink. Do NOT write your name. Do NOT write outside the box.

Question 3

Part C

i) $q = (100.0g)(4.18 J/g°C)(22.38°C - 22.00°C)$

$= 160 J$

$= \boxed{0.16 kJ}$

ii) $\frac{0.100 \text{ g } P_4O_{10}}{1} \times \frac{1 \text{ mol } P_4O_{10}}{283.9 \text{ g}} \times \frac{1 \text{ mol}_{rxn}}{1 \text{ mol } P_4O_{10}} = 0.000352 \text{ mol}_{rxn}$

$\Delta H^\circ_{rxn} = \frac{-0.16 \text{ kJ}}{0.000352 \text{ mol}_{rxn}} = \boxed{-450 \text{ kJ/mol}_{rxn}}$

Part D

ΔT would less than ΔT of the first trial. P_4O_{10} is the limiting reactant, so the moles of P_4O_{10} present determines how many reactions occur. when there is less P_4O_{10} in the calorimeter, less reactions ocurr, so less heat is transferred to the water. So, the water experiences less change in temperatvre.

Question 3 is continued on the next page.

Question 3

Part E

$$\frac{1}{4}P_{4(s)} + \frac{6}{4}Cl_{2(g)} \rightarrow \cancel{PCl_{3(g)}} \qquad \Delta H_1^\circ = \frac{1}{4}(-1148\ kJ/mol\ rxn)$$

$$\cancel{PCl_{3(g)}} + Cl_{2(g)} \rightleftarrows PCl_{5(g)} \qquad \Delta H_2^\circ = -88\ kJ/mol\ rxn \quad +$$

$$\frac{1}{4}P_{4(s)} + \frac{5}{2}Cl_{2(g)} \rightarrow PCl_{5(g)} \qquad \boxed{\Delta H_f^\circ = -375\ kJ/mol\ rxn}$$

Part F

i) $K_p = \dfrac{P_{PCl_5}}{P_{PCl_3}\cdot P_{Cl_2}} = \dfrac{(4.00)}{(2.00)(6.00)} = \boxed{0.333}$

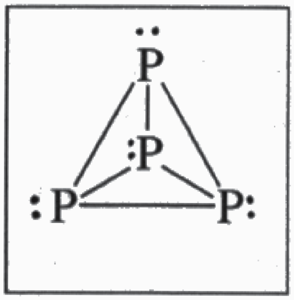
ii) $PCl_3 + Cl_2 \rightleftarrows PCl_5 + 88\ kJ/mol\ rxn$

K_p decreases when the temperature is raised. ΔH_2° is negative, so the reaction is exothermic. when heat is added, the reaction will shift towards the reactants and produce more PCl_3 and Cl_2. when the concentrations of PCl_3 and Cl_2 increase, K_p decreases.

Continue to Question 4.

Question 3

Part A



Part B

i) The entropy decreases because as the reaction progresses $P_4(s)$ will react with gas O_2 to form $P_4O_{10}(s)$. Since there will be no gas as a product and the particles turned to solid, there is less distribution of molecules and less dispersion & randomness of molecules, decreasing entropy

ii) The student's claim is correct. Based on the equation $\Delta G° = \Delta H° - T\Delta S°$, the reaction will be favorable if $\Delta H°$ is negative and $\Delta S°$ is positive. In this reaction, $\Delta H°$ is negative, but $\Delta S°$ is also negative, so the reaction favorability is only driven by enthalpy.

Question 3 is continued on the next page.

Question 3

Part C

i) $q = mc\Delta T$ total mass = 100.0 g + 0.100 g = 100.1 g

[illegible]

$q = (100.1\ g)(4.18\ \frac{J}{g\ °C})(22.38°C - 22.00°C)$

[illegible] [illegible] → 159 J × $\frac{1\ kJ}{1000\ J}$ = $\boxed{\text{0.159 kJ of heat is released}}$

ii) $\Delta H°_{rxn} \rightarrow \frac{kJ}{mol_{rxn}}$

Equation: $P_4O_{10}(s) + 6H_2O(l) \rightarrow 4H_3PO_4(aq)$

$P_4O_{10}(s)$ ↓ 0.159 kJ/mol rxn $6H_2O(l)$ ↓ 0.0265 kJ/mol rxn $4H_3PO_4(aq)$ ↓ 0.03985 kJ/mol rxn

$\Delta H°_{rxn} = [0.0398\ kJ/mol_{rxn}] - [0.0265 + 0.159] = \boxed{-0.146\ kJ/mol_{rxn}}$

Part D

$q = mc\Delta T \rightarrow \Delta T = \frac{q}{mc}$

compared to the first trial, the ΔT for the second trial would be greater. using the equation $q = mc\Delta T$, [illegible] there is an inverse relation between mass and ΔT. so if mass decreases, ΔT increases

Question 3 is continued on the next page.

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Question 3

Part E

First equation : ~~divide to~~ multiply by $\frac{1}{4}$
second equation: remains the same

$\frac{1}{4} P_{4(s)} + \frac{6}{4} Cl_{2\,(g)} \rightarrow \cancel{PCl_3}_{(g)} \quad \Delta H_1^\circ = (-1148 \text{ KJ/molrxn}) \frac{1}{4}$

$+ \; \cancel{PCl_3}_{(g)} + Cl_{2\,(g)} \rightleftarrows PCl_{5\,(g)} \quad \Delta H_2^\circ = -88 \text{ KJ molrxn}$

$\frac{1}{4} P_{4(s)} + \frac{5}{2} Cl_{2(g)} \rightarrow PCl_{5\,(g)} \quad \boxed{\Delta H_f^\circ = -375 \text{ KJ/molrxn}}$

Part F

i) ~~$K_p = (P_{PCl_3})$~~ ~~$K_p = \frac{(P_{Cl_5})}{(PCl_3)(P}$~~ $K_p = \frac{(P_{PCl_5})}{(P_{PCl_3})(P_{Cl_2})}$

$K_p = \frac{(1.00 \text{ atm})}{(1.00 \text{ atm})(1.00 \text{ atm})} = \boxed{1.00} \quad K_p = 1.00$

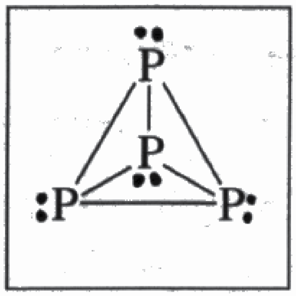
ii) If the tempreture increases, then the value of K_p should ~~increase.~~ decrease because ΔH° is negative / exothermic.

Continue to Question 4.

Use a pencil or a pen with black or dark blue ink. Do NOT write your name. Do NOT write outside the box.

Question 3

Part A



Part B

i.) As the reaction progreses, more solid P_4O_{10} will form. Solids will create less collisions and they are more orderly than the gas O_2. Since there will be more order, the amount of disorder, spontaneousness, will decrease therefore be negative.

ii.) No, the Student is incorrect. ΔG is favorable when it is a negative value. All factors including both enthalpy and entropy contribute to the favorability. Since the ΔH is negative and the ΔS is also negative, the reaction will be favorable at low temperatures. $(\underset{\ominus}{\Delta G} = \underset{\ominus}{\Delta H} - \underset{\oplus}{\underset{\ominus\ominus}{T\Delta S}})$

Question 3 is continued on the next page.

Question 3

Part C

i.) $\boxed{q = 0.159\ \text{kJ}}$

ii.) $\boxed{\Delta H^\circ_{rxn} = 11.2}$

$q = (100)(4.18)(22.38 - 22)$

$4.18\ \text{J} \cdot \frac{1\ \text{kJ}}{1000\ \text{J}} = 0.00418$

$\frac{0.159\ \text{kJ}}{1\ \text{mol}\ P_4O_{10}} \cdot \frac{2\ \text{mol}}{283.9\ \text{g}} \cdot \frac{4\ \text{mol}}{1\ \text{mol}}$

$\frac{0.159\ \text{kJ}}{1\ \text{mol}} \cdot \frac{283\ \text{g}}{1\ \text{mol}} \cdot \frac{1\ \text{mol}}{4\ \text{mol}} = 11.25$

Part D

$\boxed{\text{Equal to}}$ the mass of P_4O_{10}, regardless of being the limiting reactant does not affect the change in temprature of the trials.

Question 3 is continued on the next page.

Question 3

Part E

$\frac{1}{4}P_{4(s)} + \frac{3}{2}Cl_{2(g)} \rightarrow \cancel{4}\,P\cancel{Cl}_3 \quad \times\frac{1}{4}$

$P\cancel{Cl}_3 + \frac{2}{2}Cl_2 \rightarrow PCl_5$

$\boxed{\Delta H_f^\circ = -375\ \text{kJ}/\cancel{\text{mol}}}$

$(-1148 \times \frac{1}{4}) + (-88) = \boxed{-375}$

Part F

$2PCl_3 + \cancel{6}Cl_2 \rightleftharpoons 4PCl_5$

i.) $K_p = \frac{4}{(6)(2)}$

$\boxed{K_p = 0.33}$

ii.) $\boxed{\text{increase}}$, as temperature increases, pressure increases. A higher temp will increase the pressure cause they are directly porportional.

Continue to Question 4.

Question 3

Note: Student samples are quoted verbatim and may contain spelling and grammatical errors.

Overview

NEW for 2025: The question overviews can be found in the *Chief Reader Report on Student Responses* on AP Central.

Sample: 3A
Score: 10

Point 01: 1
Part A: The point was earned for correctly placing two lone pair electrons on each phosphorus atom.

Point 02: 1
Part B (i): The point was earned for correctly explaining how the reaction has gas molecules as reactants and no gas molecules as products, and solids have "less possible locations and positions," indicating that the solid has fewer possible microstates than the gas molecules.

Point 03: 1
Part B (ii): The point was earned for correctly stating that the student is correct, using the mathematical relationship of ΔG°, ΔH°, and ΔS°, and correctly discussing how ΔH° must be negative in order for ΔG° to be negative and therefore "thermodynamically favorable."

Point 04: 1
Part C (i): The point was earned for correctly calculating the heat (q) that was released from the reaction and showing the supporting setup. The answer is reported to the correct number of significant figures (two).

Point 05: 1
Part C (ii): The point was earned for correctly calculating the magnitude of ΔH°_{rxn}.

Point 06: 1
Part C (ii): The point was earned for including the negative sign on the final answer, indicating that reaction is exothermic.

Point 07: 1
Part D: The point was earned for correctly stating that ΔT would be "less than," and explaining that less heat is transferred to the water, due to "less P_4O_{10}," and indicating "less reactions occur," resulting in a smaller ΔT.

Point 08: 1
Part E: The point was earned for correctly using Hess's law to calculate ΔH°_f for the given reaction.

Point 09: 1
Part F (i): The point was earned for correctly setting up a K_p expression, using the particle diagram to determine the partial pressures of each gas, and calculating the value of K_p.

Point 10: 1
Part F (ii): The point was earned for correctly stating that "K_p decreases" and relating an increase in temperature to a shift towards the reactants, which results in a smaller value of K_p.

Question 3 (continued)

Sample: 3B
Score: 5

Point 01: 1
Part A: The point was earned for correctly drawing two lone pair electrons on each phosphorus atom.

Point 02: 1
Part B (i): The point was earned for correctly explaining how the reaction has gas reactants and solid products, and "there is less distribution of molecules and less dispersion of molecules" in solids.

Point 03: 1
Part B (ii): The point was earned for correctly stating that the student is correct, using the mathematical relationship of ΔG°, ΔH°, and ΔS°, and correctly discussing how "ΔH° is negative, but ΔS° is also negative," and so the "favorability is only driven by enthalpy."

Point 04: 0
Part C (i): The point was not earned because even though the response correctly calculated the heat (q) that was released, the answer was reported to the incorrect number of significant figures (three instead of two).

Point 05: 0
Part C (ii): The point was not earned due to an incorrect setup and calculation for ΔH°_{rxn}. The response incorrectly divides q by the stoichiometric coefficients in the balanced reaction equation and subtracts (products − reactants) instead of dividing q by the calculated moles of P_4O_{10}.

Point 06: 1
Part C (ii): The point was earned for including the negative sign on the final answer, indicating that the reaction is exothermic.

Point 07: 0
Part D: The point was not earned for incorrectly stating that "ΔT increases," which results from using an incorrect application of $q = mc\Delta T$.

Point 08: 1
Part E: The point was earned for correctly using Hess's law to calculate ΔH°_f for the given reaction.

Point 09: 0
Part F (i): The point was not earned. Although the K_p expression is set up correctly, the partial pressures substituted into the expression are not consistent with the particle diagram.

Point 10: 0
part F (ii): The point was not earned. The response correctly states that "K_p should decrease," but the response fails to mention that exothermic reactions favor the reactants at higher temperatures.

Question 3 (continued)

Sample: 3C
Score: 3

Point 01: 1
Part A: The point was earned for correctly drawing two lone pair electrons on each phosphorus atom.

Point 02: 0
Part B (i): The point was not earned because the response incorrectly states that "[s]olids will create less collisions and they are more orderly" and does not use particle-level reasoning. The response could have earned the point had it explained that the gaseous reactant particles have greater dispersal, more degrees of freedom, a greater number of microstates, or more possible arrangements than the solid product.

Point 03: 0
Part B (ii): The point was not earned for stating "the student is incorrect" and incorrectly stating, "All factors including both enthalpy and entropy contribute to the favorability." The response addresses the conceptual relationship between the temperature dependence of ΔG° based on ΔH° and ΔS°, but it does not address the prompt, which asks which factor is the driving force for thermodynamic favorability.

Point 04: 0
Part C (i): The point was not earned because the final answer, while calculated correctly, was not reported to the correct number of significant figures (three instead of two).

Point 05: 0
Part C (ii): The point was not earned due to using an incorrectly calculated number of moles of P_4O_{10} in the setup and calculation for the magnitude of ΔH°_{rxn}. The response uses the molar mass of P_4O_{10} and the moles of H_3PO_4 in the balanced chemical equation instead of calculating the number of moles present in $0.100\text{ g }P_4O_{10}$.

Point 06: 0
Part C (ii): The point was not earned because the negative sign was omitted on the final answer, which is required to indicate that the reaction is exothermic.

Point 07: 0
Part D: The point was not earned for incorrectly stating "Equal to" and incorrectly discussing that the error "does not affect the change in temperature."

Point 08: 1
Part E: The point was earned for correctly using Hess's law to calculate ΔH°_f for the given reaction.

Point 09: 1
Part F (i): The point was earned for correctly using the particle diagram to determine the partial pressure of each gas and calculating a correct value of K_p. Significant figures are not assessed on this point.

Point 10: 0
Part F (ii): The point was not earned for incorrectly stating that K_p would "increase," and providing an invalid justification based on the relationship between the pressure and temperature of a gas instead of discussing the effect of temperature on the equilibrium position.