Question 2: Long-Answer

2. The following questions relate to sulfur and some of its compounds.

   (a) Write the balanced equation for the combustion of $S_8(s)$ to form $SO_2(g)$.

   (b) Calculate the volume of $O_2(g)$, measured at 1.00 atm and 298 K, that is required to completely combust a 500.0 g sample of pure $S_8(s)$.

   (c) A student claims that the combustion of S_8 is an oxidation-reduction reaction. Justify the claim by identifying the oxidation numbers of sulfur and oxygen both before and after the reaction.

   (d) In the box below, draw a Lewis electron-dot diagram for one valid resonance structure of SO_2.

   (e) Based on the diagram you drew in part (d), what is the approximate oxygen-sulfur-oxygen bond angle in SO_2?

   SO_2 can be oxidized to form SO_3 according to the following equation.

$$2\ SO_2(g) + O_2(g) \rightarrow 2\ SO_3(g) \quad \Delta H^\circ = -198\ \text{kJ/mol}_{rxn}$$

   (f) Is the value of ΔS° for the reaction represented above positive or negative? Justify your answer.

$$2\ SO_2(g) + O_2(g) \rightarrow 2\ SO_3(l)$$

   (g) Is the magnitude of ΔH° for the reaction to form $SO_3(l)$, represented above, greater than, less than, or equal to the magnitude of ΔH° for the reaction to form $SO_3(g)$? Justify your answer.

   (h) Based on the information above, how does the thermodynamic favorability of the reaction change as the temperature of the reaction system is decreased? Justify your answer.

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Scoring Guidelines for Question 2: Long-Answer — 10 points

Learning Objectives: TRA-1.B | TRA-2.A | SPQ-4.A | SAP-4.A | SAP-4.C | ENE-3.D | ENE-4.A | ENE-4.C

(a) Write the balanced equation for the combustion of $S_8(s)$ to form $SO_2(g)$. — **1 point** (5.E, TRA-1.B)

One point for the balanced equation.

$S_8(s) + 8\ O_2(g) \rightarrow 8\ SO_2(g)$

(b) Calculate the volume of $O_2(g)$, measured at 1.00 atm and 298 K, that is required to completely combust a 500.0 g sample of pure $S_8(s)$. — **1 point** (5.F, SPQ-4.A)

One point for calculating the moles of O_2.

$$500.0\ g\ S_8 \times \frac{8\ \text{mol}\ O_2}{256.5\ g\ S_8} \times \frac{8\ \text{mol}\ O_2}{1\ \text{mol}\ S_8} = 15.60\ \text{mol}\ O_2$$

One point for calculating the volume of O_2. — **1 point** (5.F, SPQ-4.A)

$$V = \frac{nRT}{P} = \frac{(15.60\ \text{mol})(0.08206\ \text{L}\cdot\text{atm}\cdot\text{mol}^{-1}\cdot\text{K}^{-1})(298\ \text{K})}{1.00\ \text{atm}} = 381\ \text{L}$$

Total for part (b) — **2 points**

(c) A student claims that the combustion of $S_8(s)$ is an oxidation-reduction reaction. Justify the claim by identifying the oxidation numbers of sulfur and oxygen both before and after the reaction. — **1 point** (1.A, TRA-2.A)

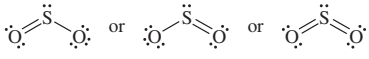
One point for all four correct oxidation numbers.

Oxidation numbers before the reaction: S = 0, O = 0

Oxidation numbers after the reaction: S = +4, O = –2

(d) In the box below, draw a complete Lewis electron-dot diagram for one valid resonance structure of $SO_2(g)$. — **1 point** (3.B, SAP-4.A)

Any one of the three following diagrams is acceptable.



One point for the correct number of electrons.

One point for a valid Lewis diagram. — **1 point** (3.B, SAP-4.A)

Total for part (d) — **2 points**

(e) Based on the diagram you drew in part (d), what is the approximate oxygen-sulfur-oxygen bond? — **1 point** (1.A, SAP-4.C)

One point for an angle that is consistent with the student's Lewis structure: 120°

(f) Is the value of $\Delta S°$ for the reaction represented above positive or negative? Justify your answer. — **1 point** (4.C, ENE-4.A)

One point for indicating negative with a valid explanation that mentions the smaller number of moles of gas in the products.

- *Negative, because the reactants are three moles of gas but the products are only two moles of gas.*

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(g) Is the magnitude of $\Delta H°$ for the reaction to form SO_3 (l), represented above, greater than, less than, or equal to the magnitude of $\Delta H°$ for the reaction to form SO_3 (g)? Justify your answer.

1 point

6.D

ENE-3.D

One point for indicating greater magnitude with a valid justification:.

- *Greater, because the enthalpy of SO_3 (l) is lower than the enthalpy of SO_3 (g) (by an amount equal to the enthalpy of vaporization of SO_3 (l)), which makes the difference between the enthalpy of the reactants and the enthalpy of the products a larger amount.*

(h) Based on the information above, how does the thermodynamic favorability of the reaction change as the temperature of the reaction system is decreased? Justify your answer.

1 point

S.C

ENE-4.C

One point for indicating an increased thermodynamic favorability along with a valid justification.

- *$\Delta G_{rxn} = \Delta H_{rxn} - T\Delta S_{rxn}$. Assuming that both ΔH_{rxn} and ΔS_{rxn} are constant, as the value of T is decreased, the smaller in value the term ($T\Delta S_{rxn}$) becomes, making the term ($\Delta H_{rxn} - T\Delta S_{rxn}$) more negative. Thus ΔG_{rxn} becomes more negative, increasing the thermodynamic favorability of the reaction.*

Total for question 2 **10 points**

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