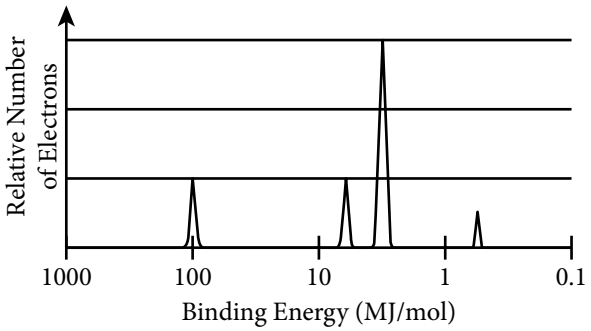
Scoring Guidelines

Question 1: Short-Answer



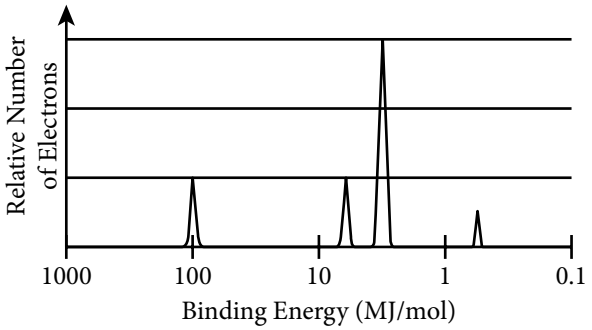
1. The complete photoelectron spectrum of an unknown element is given above.
   (a) Draw an X above the peak that corresponds to the orbital with electrons that are, on average, closest to the nucleus. Justify your answer in terms of Coulomb's law.
   (b) Based on the spectrum, write the complete electron configuration of the element.
   (c) On the graph, draw the peak(s) corresponding to the valence electrons of the element that has one more proton in its nucleus than the unknown element has.

Scoring Guidelines for Question 1: Short-Answer — 4 points

Learning Objectives: SAP-1.B

(a) Draw an X above the peak that corresponds to the orbital with electrons that are, on average, closest to the nucleus. Justify your answer in terms of Coulomb's law.

1 point
4.C
SAP-1.B



See the student's drawing.

One point for the X located above the leftmost peak (at 100 MJ/mol) in the spectrum with the justification that the electrons closest to the nucleus have the greatest binding energy because the strength of attraction between the charges (electron and nucleus) is greatest when the distance between them (r) is the least.

(b) Based on the spectrum, write the complete electron configuration of the element.

1 point
3.B
SAP-1.B

One point for the correct configuration.

$1s^2\ 2s^2\ 2p^6\ 3s^1$

(c) On the graph, draw the peak(s) corresponding to the valence electrons of the element that has one more proton in its nucleus than the unknown element has.

1 point
3.A
SAP-1.B

See the student's drawing.

One point if the peak is located just to the left of the rightmost peak in the spectrum.

One point if the height of the peak is twice the height of the rightmost peak in the spectrum.

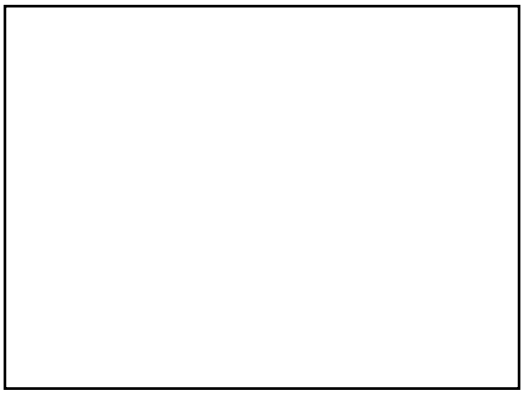
1 point
3.A
SAP-1.B

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

Total for question 1 **4 points**

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.

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.

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

(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.

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

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

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

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)

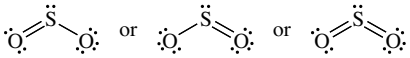
One point for all four correct oxidation numbers.

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 angle in SO_2? — **1 point** (1.A; SAP-4.C)

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

$2\ SO_2(g) + O_2(g) \rightarrow 2\ SO_3(g) \quad \Delta H° = -198\ kJ/mol_{rxn}$

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.*

(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**