2018

AP CollegeBoard

AP Chemistry

Sample Student Responses and Scoring Commentary

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Question 1

$$Na_2S_2O_3(aq) + 4\ NaOCl(aq) + 2\ NaOH(aq) \rightarrow 2\ Na_2SO_4(aq) + 4\ NaCl(aq) + H_2O(l)$$

A student performs an experiment to determine the value of the enthalpy change, ΔH°_{rxn}, for the oxidation-reduction reaction represented by the balanced equation above.

(a) Determine the oxidation number of Cl in NaOCl.

+1	1 point is earned for the correct answer.

(b) Calculate the number of grams of $Na_2S_2O_3$ needed to prepare 100.00 mL of 0.500 *M* $Na_2S_2O_3(aq)$.

$100.00\text{ mL} \times \frac{0.500\text{ mol } Na_2S_2O_3}{1000\text{ mL}} \times \frac{158.10\text{ g } Na_2S_2O_3}{1\text{ mol } Na_2S_2O_3}$ $= 7.90\text{ g } Na_2S_2O_3$	1 point is earned for the correct number of moles of $Na_2S_2O_3$ (may be implicit). 1 point is earned for the correct calculation of mass of $Na_2S_2O_3$ consistent with the number of moles.

In the experiment, the student uses the solutions shown in the table below.

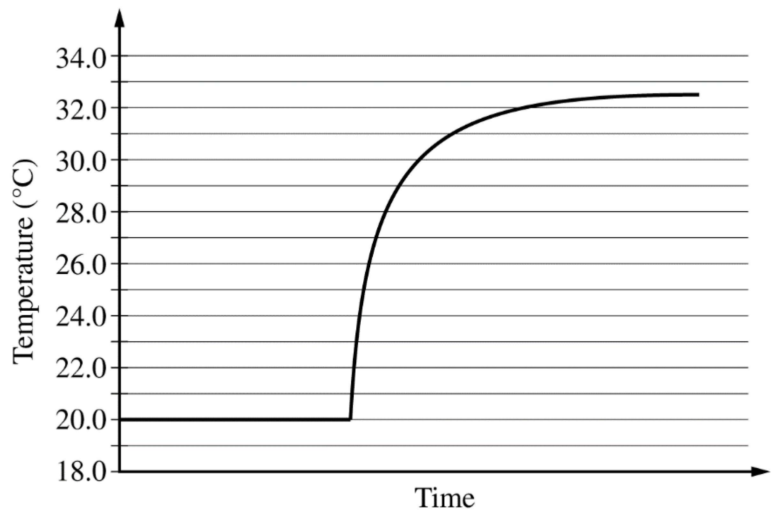
Solution	Concentration (*M*)	Volume (mL)
$Na_2S_2O_3(aq)$	0.500	5.00
$NaOCl(aq)$	0.500	5.00
$NaOH(aq)$	0.500	5.00

(c) Using the balanced equation for the oxidation-reduction reaction and the information in the table above, determine which reactant is the limiting reactant. Justify your answer.

NaOCl is the limiting reactant. Given that equal numbers of moles of each reactant were present initially, it follows from the coefficients of the reactants in the balanced equation that NaOCl will be depleted first.	1 point is earned for identifying the limiting reactant <u>and</u> providing a valid justification.

Question 1 (continued)

The solutions, all originally at 20.0 C, are combined in an insulated calorimeter. The temperature of the reaction mixture is monitored, as shown in the graph below.



(d) According to the graph, what is the temperature change of the reaction mixture?

From the graph the final temperature is 32.5°C. $\Delta T = T_f - T_i = 32.5°C - 20.0°C = 12.5°C$	1 point is earned for the correct value of ΔT.

(e) The mass of the reaction mixture inside the calorimeter is 15.21 g.

(i) Calculate the magnitude of the heat energy, in joules, that is released during the reaction. Assume that the specific heat of the reaction mixture is 3.94 J/(g·°C) and that the heat absorbed by the calorimeter is negligible.

$q = mc\Delta T$ $= (15.21 \text{ g})(3.94 \text{ J/(g·°C)})(12.5°C) = 749 \text{ J}$	1 point is earned for the correct calculation of q consistent with the ΔT value from part (d).

(ii) Using the balanced equation for the oxidation-reduction reaction and your answer to part (c), calculate the value of the enthalpy change of the reaction, ΔH°_{rxn}, in kJ/mol$_{rxn}$. Include the appropriate algebraic sign with your answer.

Question 1 (continued)

$n_{\text{NaOCl}} = 5.00\text{ mL} \times \dfrac{0.500\text{ mol NaOCl}}{1000\text{ mL NaOCl}} = 0.00250\text{ mol NaOCl}$ $n_{rxn} = 0.00250\text{ mol NaOCl} \times \dfrac{1\text{ mol}_{rxn}}{4\text{ mol NaOCl}} = 0.000625\text{ mol}_{rxn}$ $\Delta H^\circ_{rxn} = \dfrac{-0.749\text{ kJ}}{0.000625\text{ mol}_{rxn}} = -1.20 \times 10^3\text{ kJ/mol}_{rxn}$	1 point is earned for correctly calculating the value of mol_{rxn} consistent with the limiting reactant in part (c). 1 point is earned for a negative ΔH°_{rxn} obtained by dividing the calculated value of q by the calculated value of mol_{rxn}.

The student repeats the experiment, but this time doubling the volume of each of the reactants, as shown in the table below.

Solution	Concentration (M)	Volume (mL)
$Na_2S_2O_3(aq)$	0.500	10.0
$NaOCl(aq)$	0.500	10.0
$NaOH(aq)$	0.500	10.0

(f) The magnitude of the enthalpy change, ΔH°_{rxn}, in kJ/mol_{rxn}, calculated from the results of the second experiment is the same as the result calculated in part (e)(ii). Explain this result.

By doubling the volumes, the number of moles of the reactants are doubled, which doubles the amount of energy produced. Therefore the amount of heat per mole will remain the same. OR In the second experiment, $\Delta H^\circ_{rxn} = \dfrac{2mc\Delta T}{2n} = \dfrac{mc\Delta T}{n} = \Delta H^\circ_{rxn}$. Thus the magnitude is the same as calculated in the first experiment.	1 point is earned for a valid explanation.

(g) Write the balanced net ionic equation for the given reaction.

$S_2O_3^{2-}(aq) + 4\ OCl^-(aq) + 2\ OH^-(aq) \rightarrow 2\ SO_4^{2-}(aq) + 4\ Cl^-(aq) + H_2O(l)$	1 point is earned for the correct net ionic equation.

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(a) +1

(b) $\frac{0.500 \text{ mol}}{L} \times 0.10000 L \times \frac{158.1 \text{ g } Na_2S_2O_3}{\text{mol}} = 7.91 \text{ g } Na_2S_2O_3$

(c) $\frac{0.500 \text{ mol } Na_2S_2O_3}{L} \times 0.00500 L \times \frac{1 \text{ mol } H_2O}{1 \text{ mol } Na_2S_2O_3} = 0.00250 \text{ mol } H_2O$

$\frac{0.500 \text{ mol NaOCl}}{L} \times 0.00500 L \times \frac{1 \text{ mol } H_2O}{4 \text{ mol NaOCl}} = 6.25 \times 10^{-4} \text{ mol } H_2O$

$\frac{0.500 \text{ mol NaOH}}{L} \times 0.00500 L \times \frac{1 \text{ mol } H_2O}{2 \text{ mol NaOH}} = 0.00125 \text{ mol } H_2O$

NaOCl is the limiting reactant

(d) $\Delta T = 32.5 - 20.0 = 12.5 \ ^\circ C$

(e)

(i) $Q = mC\Delta T = (15.21)(3.94)(12.5) = 749 \text{ J}$

(ii) $-749 \text{ J} \times \frac{1 \text{ kJ}}{1000 \text{ J}} \times \frac{1}{6.25 \times 10^{-4} \text{ mol rxn}} = -1.20 \times 10^3 \frac{\text{kJ}}{\text{mol rxn}}$

(f) The kJ produced by this reaction will be 2x greater than that in part e but kJ/mol rxn will be the same b/c there are also 2x more mols of reactants in this experiment.

(g) ~~$2Na^+$~~ $+ S_2O_3^{2-}$ + ~~$4Na^+$~~ $+ 4OCl^-$ + ~~$2Na^+$~~ $+ 2OH^- \rightarrow$ ~~$4Na^+$~~ $+ 2SO_4^- +$ ~~$4Na^+$~~ $+ 4Cl^- + H_2O$

$S_2O_3^{2-}(aq) + 4OCl^-(aq) + 2OH^-(aq) \rightarrow 2SO_4^{2-}(aq) + 4Cl^-(aq) + H_2O(l)$

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PAGE FOR ANSWERING QUESTION 1

1a) $\overset{1+}{(Na)}OCl$ $\quad OCl \rightarrow -1$ (total) $\quad \overset{2-}{(O)}\overset{1+}{(Cl)}$

oxidation # for Cl = 1+

1b) $M_{Na_2S_2O_3} = (22.99\times2)+(32.06\times2)+(16.00\times3) = 158.1\,g/mol$

$m_{Na_2SO_3} = Mn$

$n = [Na_2SO_3]V$

$m_{Na_2S_2O_3} = M[Na_2SO_3]V = \left(\frac{158.1g}{mol}\right)\left(\frac{0.500\,mol}{L}\right)(100.00\times10^{-3}L)$

$m = 7.905g \rightarrow$ 7.91g

1c) NaOCl

- n = [solution] V
- all solutions have same molarity & volume → same # of mol
- 4mol of NaOCl is required for every 2mol of NaOH & 1mol of $Na_2S_2O_3$

→ NaOCl will run out before anything else runs out

1d) $\Delta T = T_f - T_i = 32.5°C - 20.0°C =$ 12.5°C

1e) i) $q = mc\Delta T = (15.21g)\left(\frac{3.94J}{g\cdot°C}\right)(12.5°C) = 749.0925J$

→ 749 J is released

1e) ii) $\Delta H = -749J$

$\Delta H°_{rxn} = \frac{\Delta H}{n_{Na_2SO_4}}$

NaOCl is limiting reagent.

4mol NaOCl ≏ 2mol Na_2SO_4

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$n_{Na_2SO_4} = (n_{NaOCl})\left(\frac{2}{4}\right) = [NaOCl](V_{NaOCl})(0.5) = \left(\frac{0.500\,mol}{L}\right)(5.00 \times 10^{-3}\,L)(0.5)$

$n_{Na_2SO_4} = 0.00125\,mol$

$\Delta H°_{rxn} = \frac{\Delta H}{n_{Na_2SO_4}} = \frac{-749 \times 10^{-3}\,kJ}{0.00125\,mol} = 599.2\,kJ/mol \rightarrow$ $\boxed{599\,kJ/mol}$

1f) - $\Delta H°_{rxn}$ is a value of heat absorbed / released per 1 mol of rxn

$\Rightarrow \Delta H°_{rxn} = \frac{\Delta H}{n}$

- if n doubles, ΔH also doubles since ΔH is directly proportional to the amount of reactants available
- if both top & bottom of fraction is multiplied by 2, there is no change to value of $\Delta H°_{rxn}$

g) $S_2O_3^{2-}(aq) + 4OCl^-(aq) + 2OH^-(aq) \rightarrow 2SO_4^{2-}(aq) + 4Cl^-(aq) + H_2O(l)$

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a. $\overset{+3}{Na}\overset{-2}{O}\overset{-1}{Cl}$

Oxidation number for Cl is -1

b. Mol = $\frac{m}{L}$ 0.500 M = $\frac{x}{\frac{160 mL}{1} \cdot \frac{1 L}{1000 mL}}$

$\frac{.05 \text{ mol } Na_2S_2O_3}{1} \cdot \frac{158 \text{ g/mol}}{1 \text{ mol}}$ = 7.90 g $Na_2S_2O_3$

2(23) + 2(32) + 3(16) = 158

c. $Na_2S_2O_3 + 4NaOCl + 2NaOH \rightarrow 2Na_2SO_4 + 4NaCl + H_2O$

0.500 M $Na_2S_2O_3$ · 0.005 mL = 0.0025 mol $Na_2S_2O_3$

0.500 M NaOCl · 0.005 mL = 0.0025 mol NaOCl

0.500 M NaOH · 0.005 mL = 0.0025 mol NaOH

$\frac{.0025 \text{ mol } Na_2S_2O_3}{1} \cdot \frac{2 \text{ mol } Na_2SO_4}{1 \text{ mol } Na_2S_2O_3}$ = 0.005 mol Na_2SO_4

$\frac{.0025 \text{ mol NaOCl}}{1} \cdot \frac{2 \text{ mol } Na_2SO_4}{4 \text{ mol NaOCl}}$ = 0.00125 mol Na_2SO_4

$\frac{.0025 \text{ mol NaOH}}{1} \cdot \frac{2 \text{ mol } Na_2SO_4}{2 \text{ mol NaOH}}$ = 0.0025 mol Na_2SO_4

NaOCl is the limiting reactant because it would produce the smallest amount of Na_2SO_4 out of the 3 reactants

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d. $\Delta T = T_f - T_i$

$\Delta T = 32.5°C - 20.0°C$

$\Delta T = 12.5°C$

Temperature change is 12.5°C

e. i $q = mc\Delta T$ $q = (15.21g)(3.94\ J/g°C)(12.5°C)$

$q = 749\ J$

ii $\frac{749J}{1} \cdot \frac{1kJ}{1000J} = 0.749\ kJ$

$\frac{0.0025\ mol\ NaOH}{1} \cdot \frac{0.749\ kJ}{2\ mol\ NaOH} = 9.4 \cdot 10^{-4}$

$\Delta H° = 9.4 \cdot 10^{-4}$ kJ/mol rxn

f. This happens because the same ratio of heat to moles is being used.

g. $H^+(aq) + OH^-(aq) \rightarrow H_2O(l)$

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AP® CHEMISTRY
2018 SCORING COMMENTARY

Question 1

Overview

Parts (a) through (c) explored fundamental concepts including oxidation numbers, stoichiometry, and limiting reactants within the context of an oxidation-reduction reaction. In the second grouping, parts (d) through (f) focused on the interpretation of calorimetry data for the redox reaction by determining the standard enthalpy change of the reaction, ΔH°_{rxn}. Part (g) explored student understanding of net-ionic equations.

Students were asked in part (a) to determine the oxidation number of the chlorine atom in NaOCl (LO 3.8; SP 6.1). In part (b) students were asked to determine the mass of $Na_2S_2O_3$ necessary to prepare 100.00 mL of a solution of given concentration (LO 1.4; SP 7.1). In part (c) students were asked to determine the limiting reactant in the reaction, given the balanced chemical equation and the concentrations and volumes of solutions of each reactant (LO 3.4; SP 2.2, 5.1, 6.4). Part (d) asked students to interpret a graph of temperature versus time to determine the temperature change of the reaction mixture (LO 3.1; SP 1.5, 7.1). This answer carries forward to part (e)(i), where students were asked to calculate the magnitude of the heat energy released during the reaction (LO 5.7; SP 4.2, 5.1, 6.4). In part (e)(ii) students were asked to calculate the standard enthalpy change for the reaction (LO 5.7; SP 4.2, 5.1, 6.4). In part (f) students were asked to explain why the calculated value of ΔH°_{rxn} remains unchanged in a second experiment where the volume of each solution of reactant was doubled (LO 3.3; SP 2.2, 5.1). In part (g) students were asked to provide a balanced net-ionic equation for the reaction (LO 3.2; SP 1.5, 7.1).

Sample: 1A
Score: 10

In part (a) the response earned 1 point for the correct oxidation number of +1. In part (b) 1 point was earned for showing the calculation for moles of $Na_2S_2O_3$. The second point was earned for the correct calculation of 7.91 g of $Na_2S_2O_3$. In part (c) 1 point was earned for correctly identifying NaOCl as the limiting reactant and for showing correct calculations indicating that NaOCl will produce fewer moles of H_2O than the other two reactants. In part (d) 1 point was earned for correctly reading the graph to determine that $\Delta T = 12.5°C$. In part (e)(i) 1 point was earned for correctly calculating q using the ΔT from part (d). In part (e)(ii) 1 point was earned for correctly determining the moles of reaction as 6.25×10^{-4}, with work shown in part (c). The second point was earned for dividing the calculated q from part (e)(i) by the moles of reaction and making it negative to indicate that heat was produced. In part (f) 1 point was earned for correctly explaining that both the moles of reaction and the heat produced would be doubled, which would leave ΔH_{rxn} unchanged. In part (g) 1 point was earned for the correct, balanced net ionic equation.

Sample: 1B
Score: 8

In part (a) the response earned 1 point for the correct oxidation number of +1. In part (b) 1 point was earned for showing the calculation for moles of $Na_2S_2O_3$. The second point was earned for the correct calculation of 7.91 g of $Na_2S_2O_3$. In part (c) 1 point was earned for correctly identifying NaOCl as the limiting reactant and for correctly explaining that because there were equal moles of each reactant, the mole ratios from the balanced equation would cause NaOCl to run out first. In part (d) 1 point was earned for correctly reading the graph to determine that $\Delta T = 12.5°C$. In part (e)(i) 1 point was earned for correctly calculating q using the ΔT from part (d). In part (e)(ii) neither point was earned. The number of moles of reaction is not determined correctly. Although the student correctly divides a negative q by the calculated moles of reaction, a positive ΔH_{rxn} is reported. In part (f)

Question 1 (continued)

1 point was earned for correctly explaining that when moles are doubled ΔH is also doubled, which would leave ΔH_{rxn} unchanged. In part (g) 1 point was earned for the correct, balanced net ionic equation.

Sample: 1C
Score: 5

In part (a) no point was earned. The oxidation number is incorrectly determined to be –1. In part (b) 1 point was earned for correctly calculating moles of $Na_2S_2O_3$. The second point was earned for the correct calculation of 7.90 g of $Na_2S_2O_3$. In part (c) 1 point was earned for correctly identifying NaOCl as the limiting reactant and for showing correct calculations indicating that NaOCl would produce fewer moles of Na_2SO_4 than the other two reactants. In part (d) 1 point was earned for correctly reading the graph to determine that $\Delta T = 12.5°C$. In part (e)(i) 1 point was earned for correctly calculating q using the ΔT from part (d). In part (e)(ii) neither point was earned. The number of moles of reaction is not determined correctly and is not consistent with the limiting reactant identified in part (c). The calculated q from part (e)(i) is multiplied by the mol_{rxn} rather than divided, and the reported ΔH is not negative. In part (f) no point was earned. The response indicates that there is the same ratio of heat to moles but does not sufficiently apply this statement to the experiment. In part (g) the point was not earned. The equation provided is simply the formation of water from its ions, rather than a complete net ionic equation for the reaction.