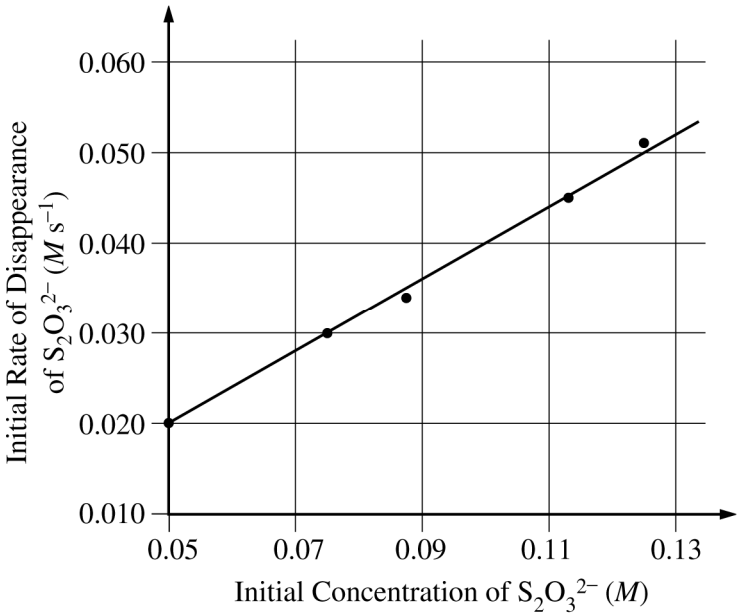
AP® CHEMISTRY
2009 SCORING GUIDELINES (Form B)

Question 2 (8 points)

$$S_2O_3^{2-}(aq) \xrightarrow{H^+} SO_3^{2-}(aq) + S(s)$$

A student performed an experiment to investigate the decomposition of sodium thiosulfate, $Na_2S_2O_3$, in acidic solution, as represented by the equation above. In each trial the student mixed a different concentration of sodium thiosulfate with hydrochloric acid at constant temperature and determined the rate of disappearance of $S_2O_3^{2-}(aq)$. Data from five trials are given below in the table on the left and are plotted in the graph on the right.

Trial	Initial Concentration of $S_2O_3^{2-}$ (aq) (M)	Initial Rate of Disappearance of $S_2O_3^{2-}$ (aq) $(M\ s^{-1})$
1	0.050	0.020
2	0.075	0.030
3	0.088	0.034
4	0.112	0.045
5	0.125	0.051



(a) Identify the independent variable in the experiment.

The initial concentration of $S_2O_3^{2-}(aq)$	One point is earned for the correct answer.

(b) Determine the order of the reaction with respect to $S_2O_3^{2-}$. Justify your answer by using the information above.

Using trials 1 and 2: $\frac{\text{rate}_2}{\text{rate}_1} = \frac{k_2[S_2O_3^{2-}]^{m_2}}{k_1[S_2O_3^{2-}]^{m_1}}$ $\frac{0.030\ M\ s^{-1}}{0.020\ M\ s^{-1}} = \frac{[0.075]^m}{[0.050]^m}$ $1.5 = (1.5)^m$, so $m = 1$ and the reaction is **first order** with respect to $S_2O_3^{2-}$. Note: Other correct justifications are acceptable.	One point is earned for the correct order. One point is earned for a correct justification.

Question 2 (continued)

(c) Determine the value of the rate constant, k, for the reaction. Include units in your answer. Show how you arrived at your answer.

rate $= k[S_2O_3^{2-}] \Rightarrow k = \dfrac{\text{rate}}{[S_2O_3^{2-}]}$ Using the data from trial 1, $k = \dfrac{0.020\ M\ s^{-1}}{0.050\ M} =$ **0.40 s^{-1}** **OR** the rate constant is equal to the slope of the line $k = \dfrac{(0.052 - 0.020)\,M\,s^{-1}}{(0.13 - 0.05)\,M} = \dfrac{0.032\,M\,s^{-1}}{0.08\,M} =$ **0.40 s^{-1}**	One point is earned for the correct value. One point is earned for the correct units.

(d) In another trial the student mixed 0.10 M $Na_2S_2O_3$ with hydrochloric acid. Calculate the amount of time it would take for the concentration of $S_2O_3^{2-}$ to drop to 0.020 M.

$\ln[A]_t - \ln[A]_0 = -kt \Rightarrow \ln\dfrac{[A]_t}{[A]_0} = -kt$ $\ln\dfrac{[S_2O_3^{2-}]_t}{[S_2O_3^{2-}]_0} = -kt$ $\ln\dfrac{0.020}{0.10} = (-0.40\ s^{-1})(t) \Rightarrow t = \dfrac{-1.61}{-0.40\ s^{-1}} =$ **4.0 s**	One point is earned for the correct setup. One point is earned for the correct answer with units.

(e) On the graph above, sketch the line that shows the results that would be expected if the student repeated the five trials at a temperature lower than that during the first set of trials.

The line drawn should start on the *y*-axis at a lower point than the line already plotted and should have a less steep slope.	One point is earned for an acceptable line.

$$S_2O_3^{2-}(aq) \xrightarrow{H^+} SO_3^{2-}(aq) + S(s)$$

2. A student performed an experiment to investigate the decomposition of sodium thiosulfate, $Na_2S_2O_3$, in acidic solution, as represented by the equation above. In each trial the student mixed a different concentration of sodium thiosulfate with hydrochloric acid at constant temperature and determined the rate of disappearance of $S_2O_3^{2-}(aq)$. Data from five trials are given below in the table on the left and are plotted in the graph on the right.

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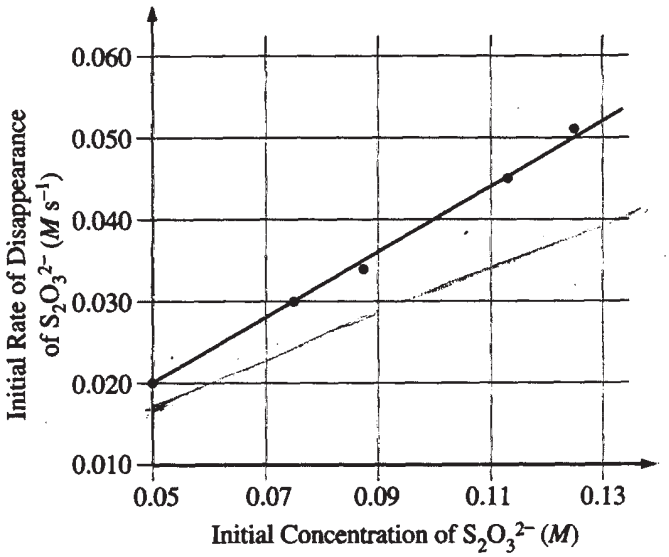

(a) Identify the independent variable in the experiment.

(b) Determine the order of the reaction with respect to $S_2O_3^{2-}$. Justify your answer by using the information above.

(c) Determine the value of the rate constant, k, for the reaction. Include units in your answer. Show how you arrived at your answer.

(d) In another trial the student mixed 0.10 M $Na_2S_2O_3$ with hydrochloric acid. Calculate the amount of time it would take for the concentration of $S_2O_3^{2-}$ to drop to 0.020 M.

(e) On the graph above, sketch the line that shows the results that would be expected if the student repeated the five trials at a temperature lower than that during the first set of trials.

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ADDITIONAL PAGE FOR ANSWERING QUESTION 2

2a) Independent variable: Initial concentration of $S_2O_3^{2-}$ (M)

b) $\frac{Rate_2}{Rate_1} = \left(\frac{[S_2O_3^{2-}]_2}{[S_2O_3^{2-}]_1}\right)^n$ → Order respect to $S_2O_3^{2-}$ = 1st order

$\frac{0.030}{0.020} = \left(\frac{0.075}{0.050}\right)^n$

$1.5 = (1.5)^n$

$n = 1$

c) $Rate = k[S_2O_3^{2-}]$

$(0.020 Ms^{-1}) = k(0.050 M)$

$k = 0.40\ s^{-1}$

d) $\ln[A]_t - \ln[A]_0 = -kt$

$\ln(0.02M) - \ln(0.10M) = -(0.40\ s^{-1})t$

$-1.61 = (-0.40 s^{-1})t$

$t = 4.0$ secs

e) on graph

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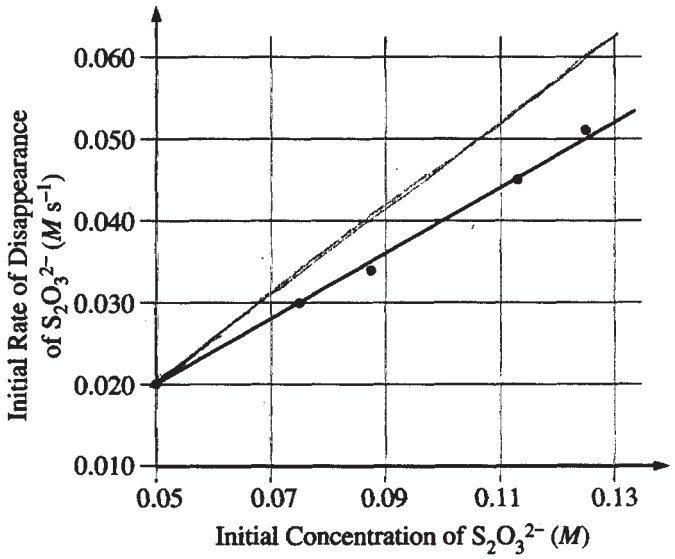

(a) Identify the independent variable in the experiment.

(b) Determine the order of the reaction with respect to $S_2O_3^{2-}$. Justify your answer by using the information above.

(c) Determine the value of the rate constant, k, for the reaction. Include units in your answer. Show how you arrived at your answer.

(d) In another trial the student mixed 0.10 M $Na_2S_2O_3$ with hydrochloric acid. Calculate the amount of time it would take for the concentration of $S_2O_3^{2-}$ to drop to 0.020 M.

(e) On the graph above, sketch the line that shows the results that would be expected if the student repeated the five trials at a temperature lower than that during the first set of trials.

2. (a) Independent variable is Initial Concentration of $S_2O_3^{2-}$

(b) $\frac{\text{rate 2}}{\text{rate 1}} = \frac{k(0.03)}{k(0.02)} \rightarrow \frac{(0.075)^x}{(0.05)^x} \rightarrow 1.5 = (1.5)^x$

$\therefore x = 1$ so that it is first-order reaction.

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ADDITIONAL PAGE FOR ANSWERING QUESTION 2

(c) $\text{rate} = k[S_2O_3^{2-}]$

$\therefore k = \frac{\text{rate}}{[S_2O_3^{2-}]} = \frac{0.02\,M\,s^{-1}}{0.05\,M} = 0.4\,s^{-1}$

(d) In first order reaction $\ln[A]_t - \ln[A_0] = -kt$

$\ln[S_2O_3^{2-}]_t - \ln[S_2O_3^{2-}]_0 = -0.4\,s^{-1}\,t$

$\ln(0.02)_t - \ln(0.1) = -0.4\,s^{-1}\,t$

$-t = \ln\left(\frac{0.02}{0.1}\right) \times \frac{s}{0.4} = -4.023$

$t = 4.023$

(e) on the graph

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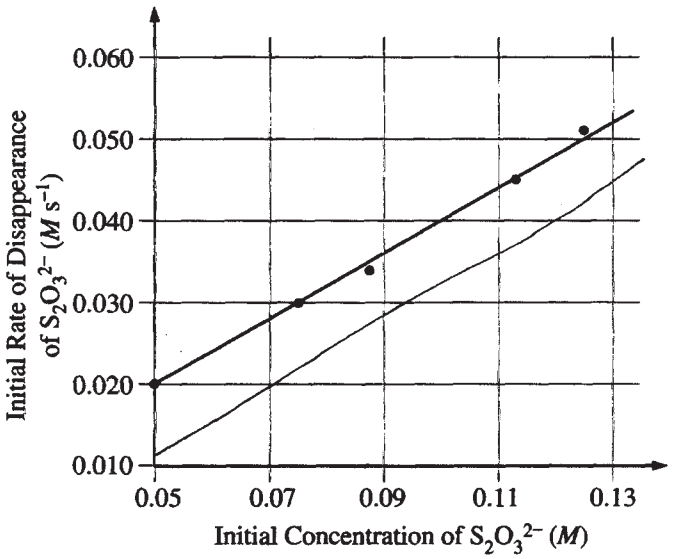

(a) Identify the independent variable in the experiment.

(b) Determine the order of the reaction with respect to $S_2O_3^{2-}$. Justify your answer by using the information above.

(c) Determine the value of the rate constant, k, for the reaction. Include units in your answer. Show how you arrived at your answer.

(d) In another trial the student mixed 0.10 M $Na_2S_2O_3$ with hydrochloric acid. Calculate the amount of time it would take for the concentration of $S_2O_3^{2-}$ to drop to 0.020 M.

(e) On the graph above, sketch the line that shows the results that would be expected if the student repeated the five trials at a temperature lower than that during the first set of trials.

a) HCl is independent variable

b) from trial 1 → 2

concentration of $S_2O_3^{2-}$: $\frac{0.074}{0.05} = \left(\frac{0.03}{0.02}\right)^n$

$1.5 = (1.5)^n$ $n=1$ It is first order rate law.

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ADDITIONAL PAGE FOR ANSWERING QUESTION 2

To check again, trial 1 → 5

$$\frac{0.125}{0.05} = \left(\frac{0.05}{0.02}\right)^n$$

$n = 1$

Because $n=1$, it is first order rate law.

c) Rate = $k[S_2O_8^{2-}]$

from trial 1 : $0.020 = k \cdot 0.050$

$k = 0.4\ s^{-1}$

d) Rate = $k \cdot 0.1M = 0.04\ M/s$

Decreased amount from $0.1M$ to $0.02M = 0.1M - 0.02M = 0.08M$

$0.08M = 0.04M/s \cdot t$

$t = 2$ second

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AP® CHEMISTRY
2009 SCORING COMMENTARY (Form B)

Question 2

Sample: 2A
Score: 8

This response earned all 8 points: 1 for part (a), 2 for part (b), 2 for part (c), 2 for part (d), and 1 for part (e).

Sample: 2B
Score: 6

This response earned 6 of the possible 8 points. In part (a) 1 point was earned for correctly identifying the independent variable as the initial concentration of the thiosulfate ion. In part (b) 1 point was earned for correctly determining the order of the reaction with respect to the thiosulfate ion, and 1 point was earned for justifying the answer by calculating the order using two trials in the experiment. In part (c) 1 point was earned for using the experimental rate law to correctly determine the value of the rate constant, and 1 point was earned for correctly stating the units. In part (d) 1 point was earned for correctly setting up the integrated rate law. The response did not earn the second point because the answer, though numerically correct, does not include the units. In part (e) the response did not earn the point because the line drawn starts at the same point on the *y*-axis and has a steeper slope than the original data line.

Sample: 2C
Score: 4

This response earned 4 of the possible 8 points. In part (a) the response incorrectly identifies HCl as the independent variable, so the point was not earned. In part (b) 1 point was earned for correctly determining the order of the reaction with respect to the thiosulfate ion, and 1 point was earned for justifying the answer by calculating the order using two trials in the experiment. In part (c) 1 point was earned for using the experimental rate law to correctly determine the value of the rate constant, and 1 point was earned for including the correct units. In part (d) the response uses an incorrect setup and arrives at an incorrect answer, so neither point was earned. In part (e) the line does begin lower on the *y*-axis than the original line, but it has the same slope as the initial line (not a lesser slope), so it did not earn the point.