2022

AP® CollegeBoard

AP® Chemistry

Sample Student Responses and Scoring Commentary

Inside:

Free-Response Question 5

- ☑ **Scoring Guidelines**
- ☑ **Student Samples**
- ☑ **Scoring Commentary**

Question 5: Short Answer — 4 points

(a) For the correct calculated value: **1 point**

Accept one of the following:

- $k = \frac{0.693}{t_{1/2}} = \frac{0.693}{1.67\ \text{hr}} = 0.415\ \text{hr}^{-1}$
- $k = \frac{\ln[\text{A}]_0 - \ln[\text{A}]_t}{t} = \frac{\ln(0.160) - \ln(0.0800)}{1.67\ \text{hr}} = 0.415\ \text{hr}^{-1}$
- $k = \frac{\ln[\text{A}]_0 - \ln[\text{A}]_t}{t} = \frac{\ln(0.160) - \ln(0.0400)}{3.33\ \text{hr}} = 0.416\ \text{hr}^{-1}$
- $k = \frac{\ln[\text{A}]_0 - \ln[\text{A}]_t}{t} = \frac{\ln(0.160) - \ln(0.0200)}{5.00\ \text{hr}} = 0.416\ \text{hr}^{-1}$

For the correct units, consistent with the calculated value: **1 point**

hr^{-1}

Total for part (a) 2 points

(b) For the correct answer and a valid justification: **1 point**

Step 1 is the rate-determining step. The rate law of elementary step 1 is $\text{rate} = k[\text{N}_2\text{O}_5]$, *which is consistent with the first order kinetics of the overall rate law.*

(c) For the correct answer: **1 point**

Remain the same. The rate constant, k, is independent of concentration and will remain the same at constant temperature.

Total for question 5 4 points

Question 5

Begin your response to **QUESTION 5** on this page.

5. The following equation represents the decomposition of N_2O_5, for which the rate law is rate = $k[N_2O_5]$.

$$2\ N_2O_5(g) \rightarrow 4\ NO_2(g) + O_2(g)$$

A sample of pure $N_2O_5(g)$ is placed in an evacuated container and allowed to decompose at a constant temperature of 300 K. The concentration of $N_2O_5(g)$ in the container is measured over a period of time, and the measurements are recorded in the following table.

Time (hr)	$[N_2O_5](M)$
0	0.160
1.67	0.0800
3.33	0.0400
5.00	0.0200

(a) Determine the value of the rate constant, k, for the reaction. Include units in your answer.

$\ln[0.08] - \ln[0.16] = -k(1.67)$

$k = 0.415\ \ hr^{-1}$

(b) The following mechanism is proposed for the decomposition of $N_2O_5(g)$.

Step 1: $N_2O_5(g) \rightarrow NO_2(g) + NO_3(g)$
Step 2: $NO_2(g) + NO_3(g) \rightarrow NO_2(g) + NO(g) + O_2(g)$
Step 3: $N_2O_5(g) + NO(g) \rightarrow 3\ NO_2(g)$

Identify which step of the proposed mechanism (1, 2, or 3) is the rate-determining step. Justify your answer in terms of the rate law given.

Step 1 is the rate-determining step because the rate law for step 1 : rate = $k[N_2O_5]$ is consistent with the overall rate law : rate = $k[N_2O_5]$.

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Question 5

Continue your response to **QUESTION 5** on this page.

(c) If this experiment was repeated at the same temperature but with twice the initial concentration of N_2O_5, would the value of k increase, decrease, or remain the same? Explain your reasoning.

The value of k remains the same. because the temperature of the experiment was kept the same.

The value of k is not dependent on the concentration of N_2O_5.

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$$2\ N_2O_5(g) \rightarrow 4\ NO_2(g) + O_2(g)$$

A sample of pure $N_2O_5(g)$ is placed in an evacuated container and allowed to decompose at a constant temperature of 300 K. The concentration of $N_2O_5(g)$ in the container is measured over a period of time, and the measurements are recorded in the following table.

Time (hr)	$[N_2O_5](M)$
0	0.160
1.67	0.0800
3.33	0.0400
5.00	0.0200

(a) Determine the value of the rate constant, k, for the reaction. Include units in your answer.

~~1.67~~ hr $t_{1/2} = 0.693/k$

$k = 0.693/t_{1/2}$

$k = 0.693/1.67\ hr$

$k = \boxed{0.415\ hr^{-1}}$

The value of k is $0.415\ hr^{-1}$.

(b) The following mechanism is proposed for ~~the decomposition of~~ $N_2O_5(g)$.

Step 1: $N_2O_5(g) \rightarrow NO_2(g) + NO_3(g)$
Step 2: $NO_2(g) + NO_3(g) \rightarrow NO_2(g) + NO(g) + O_2(g)$
Step 3: $N_2O_5(g) + NO(g) \rightarrow 3\ NO_2(g)$

Identify which step of the proposed mechanism (1, 2, or 3) is the rate-determining step. Justify your answer in terms of the rate law given.

Step 1 is the rate determing step.
This is because step 1 has $N_2O_5(g)$
as the single reactant, and the rate law
is rate = $k[N_2O_5]$.

Question 5

Continue your response to **QUESTION 5** on this page.

(c) If this experiment was repeated at the same temperature but with twice the initial concentration of N_2O_5, would the value of k increase, decrease, or remain the same? Explain your reasoning.

The value of K would increase because since the reaction is first order, the ~~rate~~ ~~is~~ value of K and the rate are dependent on the concentration of $[N_2O_5]$.

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Question 5

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5. The following equation represents the decomposition of N_2O_5, for which the rate law is rate $= k[N_2O_5]$.

$$2\ N_2O_5(g) \rightarrow 4\ NO_2(g) + O_2(g)$$

A sample of pure $N_2O_5(g)$ is placed in an evacuated container and allowed to decompose at a constant temperature of 300 K. The concentration of $N_2O_5(g)$ in the container is measured over a period of time, and the measurements are recorded in the following table.

Time (hr)	$[N_2O_5]$ (M)
0	0.160
1.67	0.0800
3.33	0.0400
5.00	0.0200

(a) Determine the value of the rate constant, k, for the reaction. Include units in your answer.

$\frac{\ln(.02) - \ln(.16)}{-1.67} = \frac{-k}{1}$ $K = .416\,hr^{-1}$

(b) The following mechanism is proposed for the decomposition of $N_2O_5(g)$.

Step 1: $N_2O_5(g) \rightarrow NO_2(g) + NO_3(g)$
Step 2: $NO_2(g) + NO_3(g) \rightarrow NO_2(g) + NO(g) + O_2(g)$
Step 3: $N_2O_5(g) + NO(g) \rightarrow 3\ NO_2(g)$

Identify which step of the proposed mechanism (1, 2, or 3) is the rate-determining step. Justify your answer in terms of the rate law given.

Step 1 is the rate determining step.

GO ON TO THE NEXT PAGE.

Question 5

Continue your response to **QUESTION 5** on this page.

(c) If this experiment was repeated at the same temperature but with twice the initial concentration of N_2O_5, would the value of k increase, decrease, or remain the same? Explain your reasoning.

K would remain the same.

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

Question 5

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

Overview

Question 5 prompted students to analyze the kinetic properties of the decomposition of N_2O_5.

In part (a) students were to demonstrate their understanding of the relationship between the change in concentration as a function of time by determining the value of the rate constant (Learning Objective TRA-3.B, Science Practice 5.F from the *AP Chemistry Course and Exam Description*). Part (a) was worth 2 points: the first point for the correct determination for the value of the rate constant and the second point for the correct units of the rate constant.

Part (b) provided students with a proposed three-step mechanism for the decomposition of N_2O_5. From this information, students were to determine which step of the mechanism is the rate-determining step, based on the provided rate law equation (TRA-3.B, 5.F).

In part (c) students were asked to predict, and then justify, the dependence of the rate constant on a change in the initial concentration of N_2O_5 at constant temperature (TRA-4.B, 2.F).

Sample: 5A
Score: 4

This response earned 4 points. In part (a) the first point was earned for the correct value of k using the first-order integrated rate law. The second point was earned for the correct units (hr^{-1}). In part (b) the point was earned for selecting step 1 as the rate-determining step because the rate law for this step is consistent with the given rate law. In part (c) the point was earned for indicating that k will remain the same because it is not concentration dependent.

Sample: 5B
Score: 3

This response earned 3 points. In part (a) the first point was earned for the correct value of k using the first-order half-life equation. The second point was earned for the correct units (hr^{-1}). In part (b) the point was earned for selecting step 1 as the rate-determining step because this step has a single reactant (N_2O_5), and the rate law for this step is consistent with the given rate law. In part (c) no point was earned for indicating that k will increase.

Sample: 5C
Score: 2

This response earned 2 points. In part (a) the first point was earned for the correct value of k using the first-order integrated rate law. The second point was earned for the correct units (hr^{-1}). In part (b) no point was earned for selecting step 1 without justification. In part (c) no point was earned for indicating that k will remain the same without explanation.