2024

AP® Chemistry

Sample Student Responses and Scoring Commentary

Inside:

Free-Response Question 6

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

Question 6: Short Answer — 4 points

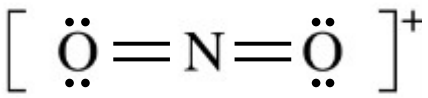
(a) For a correct explanation: **1 point**

The plot of $\frac{1}{[NO_2]}$ *versus time is the most linear, indicating that the reaction is second order with respect to* NO_2.

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

$$6.52 \times 10^{-7}\, M/\text{s} \times \frac{1 \text{ mol } O_2}{2 \text{ mol } NO_2} = 3.26 \times 10^{-7}\, M/\text{s}$$

(c) (i) For the correct Lewis diagram: **1 point**



(ii) For the correct answer and a valid justification, consistent with part (c)(i): **1 point**

Accept one of the following:

- *Agree. The angle of* NO_2^+ *is different from the angle in* NO_2 *because there would no longer be a nonbonding electron on the central atom in* NO_2*, and the* O *atoms would spread farther apart, forming a linear structure with a* 180° *bond angle.*
- *Agree. The hybridization of* N *in* NO_2 *is* sp^2*, which would result in a bond angle of approximately* 120°*. The hybridization of* N *in* NO_2^+ *is* sp*, which would result in a bond angle of* 180°.

Total for part (c) 2 points

Total for question 6 4 points

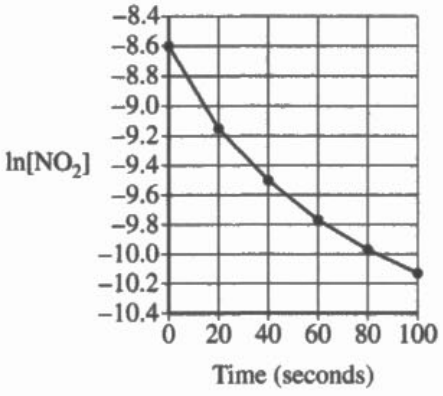
Question 6

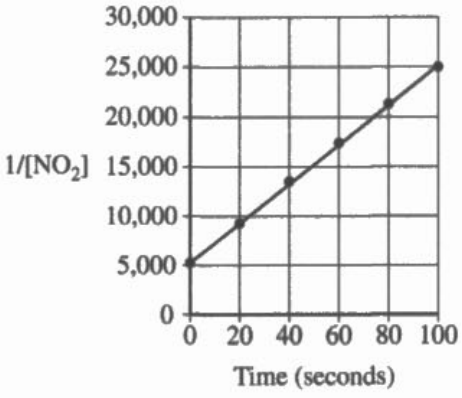
Begin your response to **QUESTION 6** on this page.

6. At elevated temperatures, NO_2 undergoes decomposition in the gas phase, forming NO and O_2 as represented by the following equation.

$$2\,NO_2 \rightarrow 2\,NO + O_2$$

A scientist measures the change in $[NO_2]$ over the first 100. s of the reaction at 546°C. The scientist uses the data collected from the experiment to generate the following two graphs.





Based on these data, the scientist makes the claim that the rate law for the reaction is $rate = k[NO_2]^2$.

(a) Explain how the graphs indicate that the reaction is second order with respect to NO_2.

The graph shows a linear function of $1/[NO_2]$ vs. time which consists with second order graph. Thus, it indicated the reaction is second order.

(b) At a certain point in the reaction, the rate of disappearance of NO_2 is determined to be 6.52×10^{-7} M/s. Determine the rate of appearance, in M/s, of O_2 at this same point in the reaction.

As 2 moles of NO_2 disappear, 1 moles ~~the~~ of O_2 appears. Thus the ratio of disapperance of NO_2 to appearance of O_2 is 2 to 1.

⇒ The rate of apperance of O_2:

$$\frac{6.52 \cdot 10^{-7}\ M/s}{2} = \boxed{3.26 \cdot 10^{-7}\ M/s}$$

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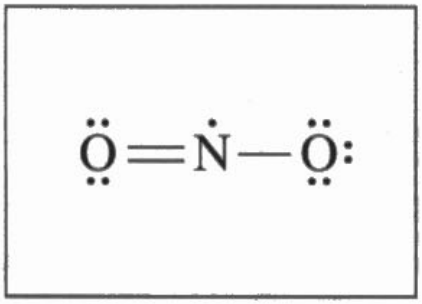
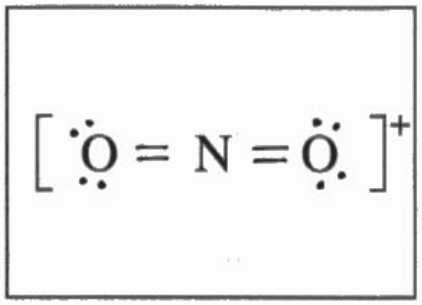
Question 6

Continue your response to **QUESTION 6** on this page.

(c) NO_2 is a molecule that contains an odd number of electrons and can be oxidized to form the NO_2^+ ion. In NO_2, the unpaired electron is presumed to be localized on the nitrogen atom, as shown in the Lewis diagram in the box on the left.





(i) In the box on the right, complete the Lewis diagram for NO_2^+. Be sure to show all bonding and nonbonding electrons.

(ii) A student makes the claim that the bond angles in NO_2 and NO_2^+ are different from each other. Do you agree or disagree with the student's claim? Justify your answer.

I agree with the student's claim. The bond angles in NO_2^+ would be 180° because it is a linear structure. While in NO_2, it contains an unshared electrons, which would push the bonding pairs closer to each other created a bent shape and ~~a~~ bond angles that ~~less~~ less than 180°. Thus, the bond angles in NO_2 and NO_2^+ are different from each other.

Question 6

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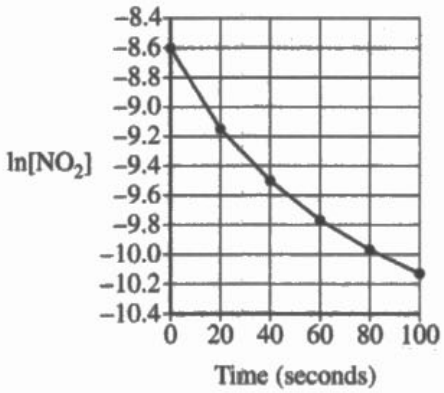
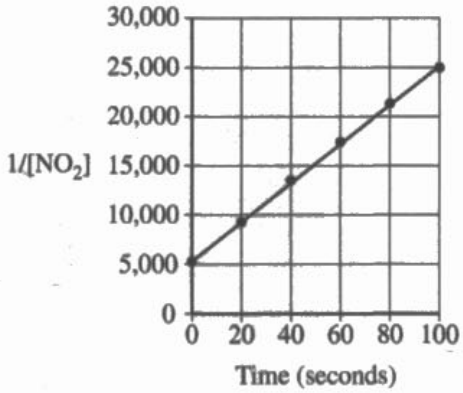
6. At elevated temperatures, NO_2 undergoes decomposition in the gas phase, forming NO and O_2 as represented by the following equation.

$$2\,NO_2 \rightarrow 2\,NO + O_2$$

A scientist measures the change in $[NO_2]$ over the first 100. s of the reaction at 546°C. The scientist uses the data collected from the experiment to generate the following two graphs.





Based on these data, the scientist makes the claim that the rate law for the reaction is $rate = k[NO_2]^2$.

(a) Explain how the graphs indicate that the reaction is second order with respect to NO_2.

The graph which has 1/[NO2] on the y-axis & Time on the x-axis is linear meaning the reaction is second order with respect to NO_2.

(b) At a certain point in the reaction, the rate of disappearance of NO_2 is determined to be 6.52×10^{-7} M/s. Determine the rate of appearance, in M/s, of O_2 at this same point in the reaction.

rate of appearance = 6.52×10^{7} M/s

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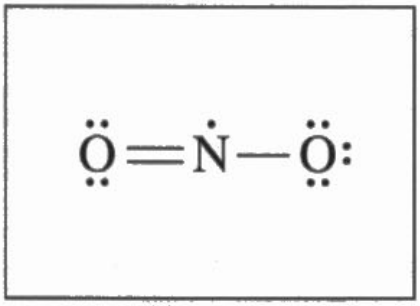
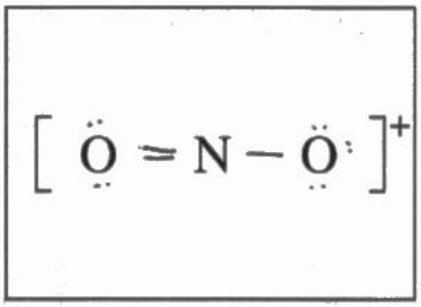
Question 6

Continue your response to **QUESTION 6** on this page.

(c) NO_2 is a molecule that contains an odd number of electrons and can be oxidized to form the NO_2^+ ion. In NO_2, the unpaired electron is presumed to be localized on the nitrogen atom, as shown in the Lewis diagram in the box on the left.





(i) In the box on the right, complete the Lewis diagram for NO_2^+. Be sure to show all bonding and nonbonding electrons.

(ii) A student makes the claim that the bond angles in NO_2 and NO_2^+ are different from each other. Do you agree or disagree with the student's claim? Justify your answer.

Yes I agree the bond angles are different because the unpaired electron would exert force on the bonds, angling them down slightly. However, the NO_2^+ structure is linear without the unpaired electron.

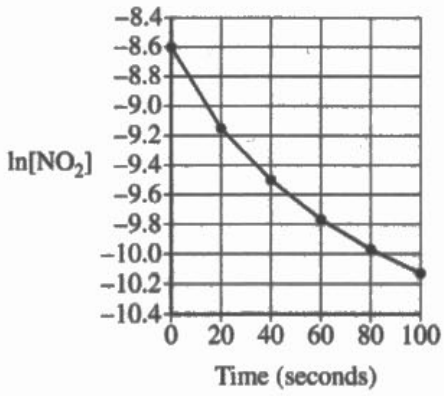
Question 6

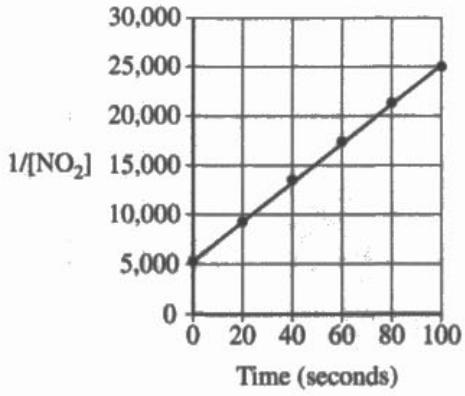
Begin your response to **QUESTION 6** on this page.

6. At elevated temperatures, NO_2 undergoes decomposition in the gas phase, forming NO and O_2 as represented by the following equation.

$$2\,NO_2 \rightarrow 2\,NO + O_2$$

A scientist measures the change in $[NO_2]$ over the first 100. s of the reaction at 546°C. The scientist uses the data collected from the experiment to generate the following two graphs.





Based on these data, the scientist makes the claim that the rate law for the reaction is $rate = k[NO_2]^2$.

(a) Explain how the graphs indicate that the reaction is second order with respect to NO_2.

Because it is decreasing exponentially in the $\ln[NO_2]$ graph meaning it is second order

(b) At a certain point in the reaction, the rate of disappearance of NO_2 is determined to be 6.52×10^{-7} M/s.

Determine the rate of appearance, in M/s, of O_2 at this same point in the reaction.

$4.3\overline{5} \times 10^{-7}$ M/s

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Question 6

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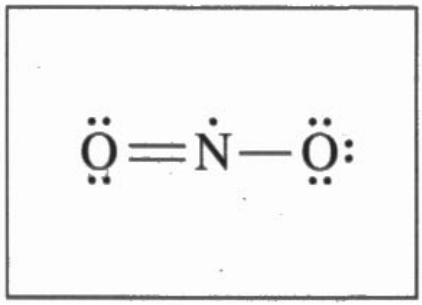

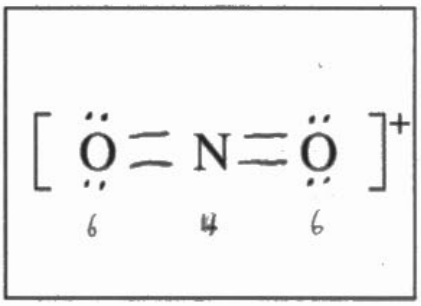

(i) In the box on the right, complete the Lewis diagram for NO_2^+. Be sure to show all bonding and nonbonding electrons.

(ii) A student makes the claim that the bond angles in NO_2 and NO_2^+ are different from each other. Do you agree or disagree with the student's claim? Justify your answer.

I agree, the bond angles in NO_2 would differ due to only one of the O atoms having a double bond, while all the bond angles in NO_2^+ would be the same due to both O atoms being double bonded to N

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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 6

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

Overview

Question 6 presented students with a variety of chemical situations involving nitrogen dioxide.

Part (a) requires students to explain how one of the two provided graphical representations of kinetic data indicates that the reaction is a second-order process. The intent of the question was for students to identify the rate law expression by interpretating graphical information showing how the concentration of a reaction species changes over time (Learning Objective TRA-3.C/5.3.A, Skill 5.D from the *AP Chemistry Course and Exam Description*).

Part (b) requires students to calculate the relative rate of appearance of the O_2 product given the relative rate of disappearance of the NO_2 reactant. The question's intent was for students to use the experimental data and balanced chemical reaction equation to calculate a product's rate of appearance (TRA-3.B/5.2.A, 5.F).

Part (c)(i) requires students to draw the Lewis diagram for the NO_2^+ ion, given a Lewis diagram of the NO_2 molecule and information that the NO_2 can be oxidized to form NO_2^+. The intent of the question was for students to demonstrate an understanding of ion formation and rules for drawing Lewis diagrams (SAP-4.A/2.5.A, 3.B).

Part (c)(ii) requires students to agree or disagree with a student claim that the bond angles of NO_2 and NO_2^+ would be different. The question's intent was for students to support a scientific argument by comparing the two Lewis diagrams (SAP-4.C/2.7.A, 6.C).

Sample: 6A
Score: 4

This response earned 4 points. In part (a) the point was earned for correctly indicating that the $1/[NO_2]$ graph is linear, which corresponds to a second order reaction. In part (b) the point was earned for the correct calculation of the rate of appearance of O_2. In part (c)(i) the point was earned for drawing the correct Lewis diagram of NO_2^+. In part (c)(ii) the point was earned for agreeing with the claim and providing a correct justification that NO_2^+ has a linear shape with a 180° bond angle, while the presence of the odd electron on NO_2 creates a smaller than 180° bond angle.

Sample: 6B
Score: 2

The response earned 2 points. In part (a) the point was earned for correctly indicating that the $1/[NO_2]$ graph is linear, which corresponds to a second order reaction. In part (b) the point was not earned for the statement that the rate of appearance of O_2 is the same as the rate of disappearance of NO_2, which does not take into account the stoichiometry of the reaction. In part (c)(i) the point was not earned for drawing an incorrect Lewis diagram of NO_2^+ where N does not have a complete octet. In part (c)(ii) the point was earned for agreeing with the claim and providing a correct justification.

Question 6 (continued)

Sample: 6C
Score: 1

This response earned 1 point. In part (a) the point was not earned because the explanation is incorrectly based on the exponential decrease in the ln[NO_2] graph rather than the linearity of the 1/[NO_2] graph. In part (b) the point was not earned for an incorrect calculation of the rate of appearance of O_2 with no supporting setup shown. In part (c)(i) the point was earned for drawing the correct Lewis diagram of NO_2^+. In part (c)(ii) the point was not earned for an incorrect justification that the difference in bond angle is due to the difference in bonding rather than the presence of the lone nonbonding electron on N.