2018

AP CollegeBoard

AP Chemistry

Sample Student Responses and Scoring Commentary

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Free Response Question 2

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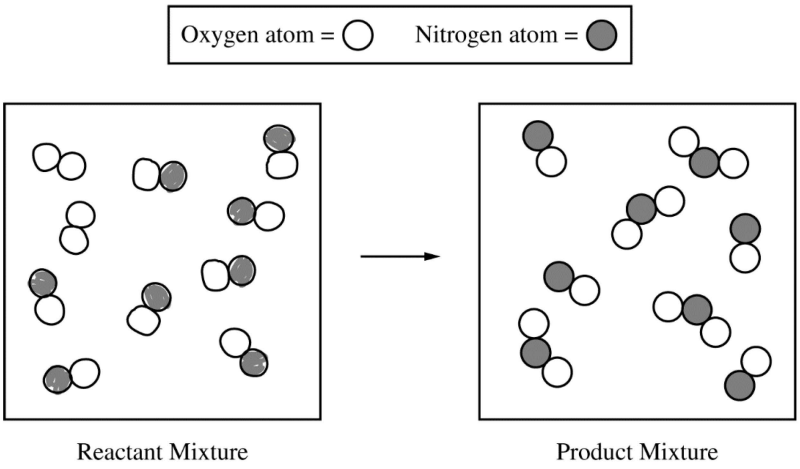
AP® CHEMISTRY
2018 SCORING GUIDELINES

Question 2

$$2\ NO(g) + O_2(g) \qquad 2\ NO_2(g)$$

A student investigates the reactions of nitrogen oxides. One of the reactions in the investigation requires an equimolar mixture of $NO(g)$ and $NO_2(g)$, which the student produces by using the reaction represented above.

a The particle-level representation of the equimolar mixture of $NO(g)$ and $NO_2(g)$ in the flask at the completion of the reaction between $NO(g)$ and $O_2(g)$ is shown below in the box on the right. In the box below on the left, draw the particle-level representation of the reactant mixture of $NO(g)$ and $O_2(g)$ that would yield the product mixture shown in the box on the right. In your drawing, represent oxygen atoms and nitrogen atoms as indicated below.



See sample student response above. (8 molecules of NO and 2 molecules of O_2)	1 point is earned for correctly representing molecules of NO and O_2. 1 point is earned for correctly representing atom conservation.

The student reads in a reference text that $NO(g)$ and $NO_2(g)$ will react as represented by the equation below. Thermodynamic data for the reaction are given in the table below the equation.

$$NO(g) + NO_2(g) \rightleftarrows N_2O_3(g)$$

ΔH°_{298}	ΔS°_{298}	ΔG°_{298}
$-40.4\ kJ/mol_{rxn}$	$-138.5\ J/(K \cdot mol_{rxn})$	$0.87\ kJ/mol_{rxn}$

Question 2 (continued)

(b) The student begins with an equimolar mixture of $NO(g)$ and $NO_2(g)$ in a rigid reaction vessel and the mixture reaches equilibrium at 298 K.

(i) Calculate the value of the equilibrium constant, K, for the reaction at 298 K.

$\Delta G^\circ = -RT\ln K$ $K = e^{-\Delta G^\circ/RT}$ $K = e^{-\frac{870\ \text{J/mol}}{(8.314\ \text{J mol}^{-1}\ \text{K}^{-1})(298\ \text{K})}}$ $K = 0.70$	1 point is earned for a correct calculation of K.

(ii) If both P_{NO} and P_{NO_2} in the vessel are initially 1.0 atm, will $P_{N_2O_3}$ at equilibrium be equal to 1.0 atm? Justify your answer.

No, the pressure will not equal 1.0 atm. $P_{N_2O_3}$ would only equal 1.0 atm if the reaction goes to completion. OR The value of K indicates that a substantial amount of reactants will be present at equilibrium.	1 point is earned for a correct choice and valid justification based on the value of K.

(c) The student hypothesizes that increasing the temperature will increase the amount of $N_2O_3(g)$ in the equilibrium mixture. Indicate whether you agree or disagree with the hypothesis. Justify your answer.

Disagree. Because the reaction is exothermic, increasing the temperature of the reaction will favor the formation of the reactants (according to Le Chatelier's principle).	1 point is earned for the correct choice and a correct justification.

$N_2O_3(g)$ reacts with water to form nitrous acid, $HNO_2(aq)$, a compound involved in the production of acid rain. The reaction is represented below.

$$N_2O_3(g) + H_2O(l) \rightarrow 2\ HNO_2(aq)$$

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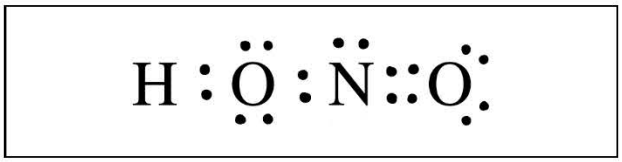
Question 2 (continued)

(d) The skeletal structure of the HNO_2 molecule is shown in the box below.

(i) Complete the Lewis electron-dot diagram of the HNO_2 molecule in the box below, including any lone pairs of electrons.



See sample response above. (Line segments can be used to represent electron pairs.)	1 point is earned for a valid diagram.

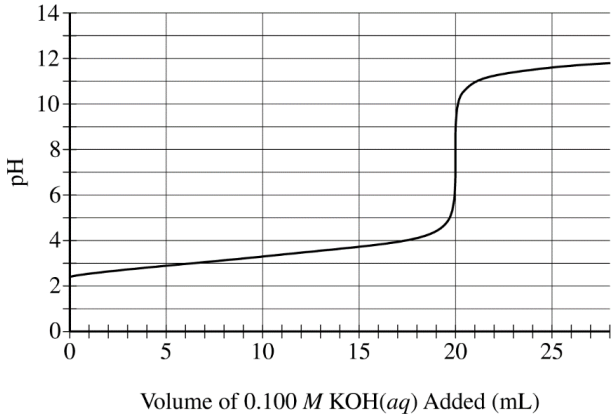
(ii) Based on your completed diagram above, identify the hybridization of the nitrogen atom in the HNO_2 molecule.

sp^2	1 point is earned for the correct answer.

To produce an aqueous solution of HNO_2, the student bubbles $N_2O_3(g)$ into distilled water. Assume that the reaction goes to completion and that HNO_2 is the only species produced. To determine the concentration of $HNO_2(aq)$ in the resulting solution, the student titrates a 100. mL sample of the solution with 0.100 *M* KOH(*aq*). The neutralization reaction is represented below.

$$HNO_2(aq) + OH^-(aq) \rightarrow NO_2^-(aq) + H_2O(l)$$

The following titration curve shows the change in pH of the solution during the titration.



Question 2 (continued)

(e) Use the titration curve and the information above to

(i) determine the initial concentration of the $HNO_2(aq)$ solution

$20.\ \text{mL KOH} \times \frac{0.100\ \text{mol KOH}}{1000\ \text{mL KOH}} = 0.0020\ \text{mol KOH added}$ $\Rightarrow$ 0.0020 mol HNO_2 in 100. mL of solution because the stoichiometry of the neutralization reaction is 1 to 1. $\frac{0.0020\ \text{mol HNO}_2}{0.100\ \text{L}} = 0.020\ M\ \text{HNO}_2$	1 point is earned for the correct calculation of the initial concentration.

(ii) estimate the value of pK_a for $HNO_2(aq)$

The value of pK_a is about 3.4.	1 point is earned for an acceptable estimate for the value of pK_a.

(f) During the titration, after a volume of 15 mL of 0.100 M KOH(aq) has been added, which species, $HNO_2(aq)$ or $NO_2^-(aq)$, is present at a higher concentration in the solution? Justify your answer.

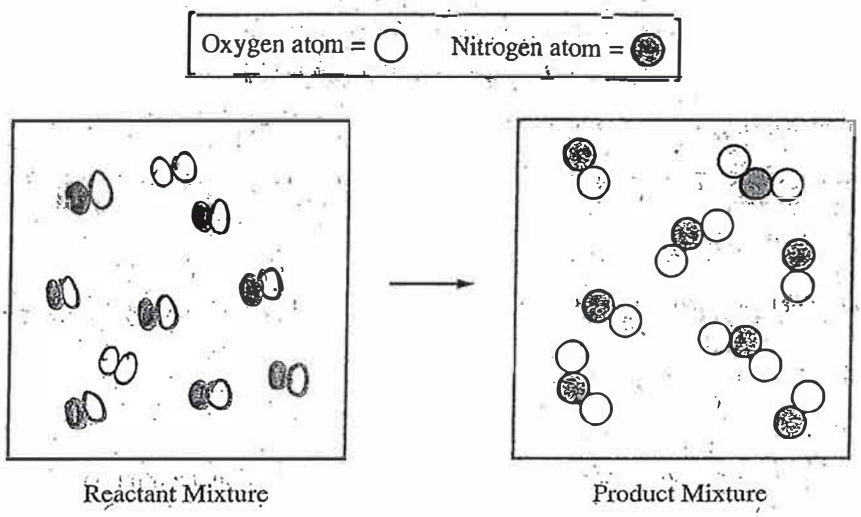
$NO_2^-(aq)$ The titration is past the half-equivalence point; therefore, there will be more conjugate base present than acid.	1 point is earned for the correct choice and a valid justification.

$$2\,NO(g) + O_2(g) \rightarrow 2\,NO_2(g)$$

2A 1 of 3

2. A student investigates the reactions of nitrogen oxides. One of the reactions in the investigation requires an equimolar mixture of $NO(g)$ and $NO_2(g)$, which the student produces by using the reaction represented above.

(a) The particle-level representation of the equimolar mixture of $NO(g)$ and $NO_2(g)$ in the flask at the completion of the reaction between $NO(g)$ and $O_2(g)$ is shown below in the box on the right. In the box below on the left, draw the particle-level representation of the reactant mixture of $NO(g)$ and $O_2(g)$ that would yield the product mixture shown in the box on the right. In your drawing, represent oxygen atoms and nitrogen atoms as indicated below.



The student reads in a reference text that $NO(g)$ and $NO_2(g)$ will react as represented by the equation below. Thermodynamic data for the reaction are given in the table below the equation.

$$NO(g) + NO_2(g) \rightleftarrows N_2O_3(g) + \text{heat}$$

ΔH°_{298}	ΔS°_{298}	ΔG°_{298}
$-40.4\ \text{kJ/mol}_{rxn}$	$-138.5\ \text{J/(K·mol}_{rxn})$	$0.87\ \text{kJ/mol}_{rxn}$

not spontaneous

(b) The student begins with an equimolar mixture of $NO(g)$ and $NO_2(g)$ in a rigid reaction vessel and the mixture reaches equilibrium at 298 K.

(i) Calculate the value of the equilibrium constant, K, for the reaction at 298 K.

(ii) If both P_{NO} and P_{NO_2} in the vessel are initially 1.0 atm, will $P_{N_2O_3}$ at equilibrium be equal to 1.0 atm? Justify your answer.

(c) The student hypothesizes that increasing the temperature will increase the amount of $N_2O_3(g)$ in the equilibrium mixture. Indicate whether you agree or disagree with the hypothesis. Justify your answer.

GO ON TO THE NEXT PAGE.

2A 2 of 3

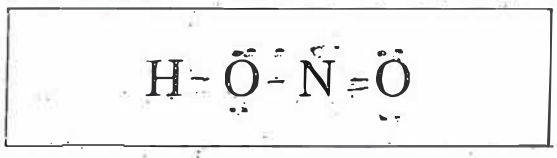
$N_2O_3(g)$ reacts with water to form nitrous acid, $HNO_2(aq)$, a compound involved in the production of acid rain. The reaction is represented below.

$$N_2O_3(g) + H_2O(l) \rightarrow 2\,HNO_2(aq)$$

(d) The skeletal structure of the HNO_2 molecule is shown in the box below.

(i) Complete the Lewis electron-dot diagram of the HNO_2 molecule in the box below, including any lone pairs of electrons.

valence e⁻: 18
wants: 26

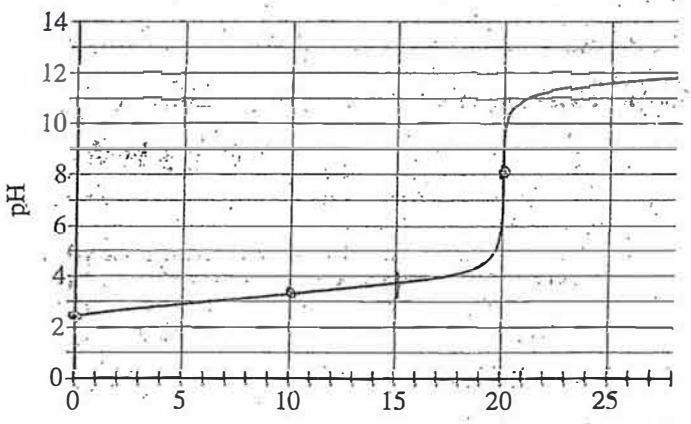


(ii) Based on your completed diagram above, identify the hybridization of the nitrogen atom in the HNO_2 molecule.

To produce an aqueous solution of HNO_2, the student bubbles $N_2O_3(g)$ into distilled water. Assume that the reaction goes to completion and that HNO_2 is the only species produced. To determine the concentration of $HNO_2(aq)$ in the resulting solution, the student titrates a 100. mL sample of the solution with 0.100 *M* KOH(*aq*). The neutralization reaction is represented below.

nitrous acid $HNO_2(aq) + OH^-(aq) \rightarrow NO_2^-(aq) + H_2O(l)$

The following titration curve shows the change in pH of the solution during the titration.



(e) Use the titration curve and the information above to

2 mmol HNO_2 → 2 × M =

(i) determine the initial concentration of the $HNO_2(aq)$ solution

(ii) estimate the value of pK_a for $HNO_2(aq)$

$pK_a \approx 3.4$ $K_a \approx 3.98 \times 10^{-4}$

(f) During the titration, after a volume of 15 mL of 0.100 *M* KOH(*aq*) has been added, which species, $HNO_2(aq)$ or $NO_2^-(aq)$, is present at a higher concentration in the solution? Justify your answer.

GO ON TO THE NEXT PAGE.

2A 3 of 3

a) In box on previous page.

b) i) $\Delta G^\circ = -RT \ln K$

$670\ J/mol\ rxn = -(8.314\ J/mol\ K)(298\ K)(\ln K)$

$\ln K = -0.35$

$K = e^{-0.35}$

$K = 0.70$

ii) No, $P_{N_2O_3}$ at equilibrium will not equal 1.00 atm, because the equilibrium constant K is <1, so the reaction lies mostly to the left, so $P_{N_2O_3}$ won't reach the initial pressures of the reactants.

c) No. By increasing temperature, the reaction shifts left according to LeChatlier's principle. The reaction is exothermic, and an increase in temp will cause the rxn to move left, producing less product to remedy this stress.

d) i) see box on previous page. Also: H–Ö–N=Ö:

ii) The hybridization of N in the above Lewis structure is sp^2.

e) i) @ equivalence pt:

$HNO_2 + OH^- \rightarrow NO_2^- + H_2O$ $\quad$ $x\,M\ HNO_2 = \frac{2\ mmol}{100.\ mL}$

2mmol 2mmol

$x = \boxed{0.0200\ M\ HNO_2}$

ii) The pKa value for $HNO_2 \approx 3.4$

f) NO_2^- (aq) is present in higher concentration, because this is past the halfway point of the titration. 1.5 mmol NO_2^- are present,

$HNO_2 + OH^- \rightarrow NO_2^- + H_2O$ while only 0.5 mmol HNO_2 are present.

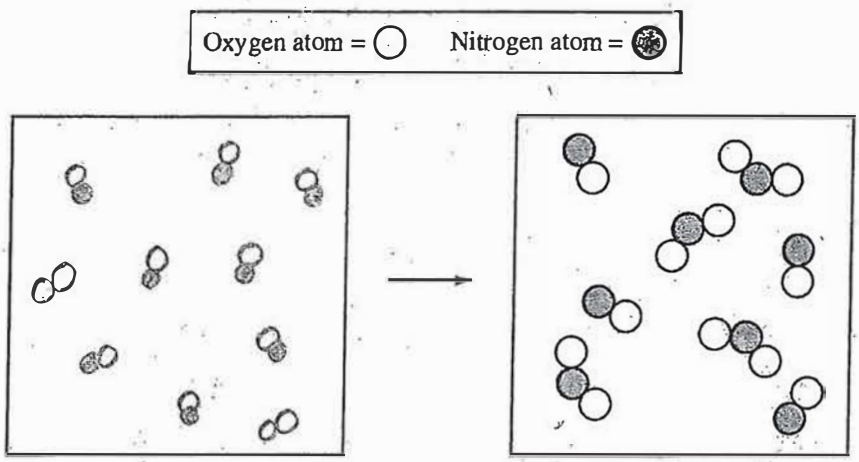
2mmol 1.5mmol

0.5mmol 0 1.5mmol

$$2\,NO(g) + O_2(g) \rightarrow 2\,NO_2(g)$$ 2B 1 of 3

2. A student investigates the reactions of nitrogen oxides. One of the reactions in the investigation requires an equimolar mixture of $NO(g)$ and $NO_2(g)$, which the student produces by using the reaction represented above.

(a) The particle-level representation of the equimolar mixture of $NO(g)$ and $NO_2(g)$ in the flask at the completion of the reaction between $NO(g)$ and $O_2(g)$ is shown below in the box on the right. In the box below on the left, draw the particle-level representation of the reactant mixture of $NO(g)$ and $O_2(g)$ that would yield the product mixture shown in the box on the right. In your drawing, represent oxygen atoms and nitrogen atoms as indicated below.



Reactant Mixture Product Mixture

The student reads in a reference text that $NO(g)$ and $NO_2(g)$ will react as represented by the equation below. Thermodynamic data for the reaction are given in the table below the equation.

$$NO(g) + NO_2(g) \rightleftarrows N_2O_3(g)$$

ΔH°_{298}	ΔS°_{298}	ΔG°_{298}
$-40.4\ kJ/mol_{rxn}$	$-138.5\ J/(K \cdot mol_{rxn})$	$0.87\ kJ/mol_{rxn}$

(b) The student begins with an equimolar mixture of $NO(g)$ and $NO_2(g)$ in a rigid reaction vessel and the mixture reaches equilibrium at 298 K.

(i) Calculate the value of the equilibrium constant, K, for the reaction at 298 K.

(ii) If both P_{NO} and P_{NO_2} in the vessel are initially 1.0 atm, will $P_{N_2O_3}$ at equilibrium be equal to 1.0 atm? Justify your answer.

(c) The student hypothesizes that increasing the temperature will increase the amount of $N_2O_3(g)$ in the equilibrium mixture. Indicate whether you agree or disagree with the hypothesis. Justify your answer.

GO ON TO THE NEXT PAGE.

$N_2O_3(g)$ reacts with water to form nitrous acid, $HNO_2(aq)$, a compound involved in the production of acid rain. The reaction is represented below.

$$N_2O_3(g) + H_2O(l) \rightarrow 2\,HNO_2(aq)$$

(d) The skeletal structure of the HNO_2 molecule is shown in the box below.

(i) Complete the Lewis electron-dot diagram of the HNO_2 molecule in the box below, including any lone pairs of electrons.

1+5+12

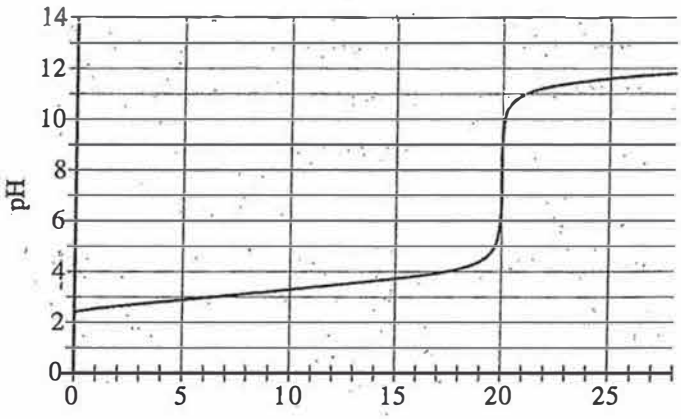
18 e⁻

(ii) Based on your completed diagram above, identify the hybridization of the nitrogen atom in the HNO_2 molecule.

To produce an aqueous solution of HNO_2, the student bubbles $N_2O_3(g)$ into distilled water. Assume that the reaction goes to completion and that HNO_2 is the only species produced. To determine the concentration of $HNO_2(aq)$ in the resulting solution, the student titrates a 100. mL sample of the solution with 0.100 M KOH(aq). The neutralization reaction is represented below.

$$HNO_2(aq) + OH^-(aq) \rightarrow NO_2^-(aq) + H_2O(l)$$

The following titration curve shows the change in pH of the solution during the titration.



H-Ö=N-Ö:

1 6 5 6

1 5 5 7

H-Ö-N=Ö

1 6 5 6

1 6 5 6

(e) Use the titration curve and the information above to

(i) determine the initial concentration of the $HNO_2(aq)$ solution

(ii) estimate the value of pK_a for $HNO_2(aq)$

(f) During the titration, after a volume of 15 mL of 0.100 M KOH(aq) has been added, which species, $HNO_2(aq)$ or $NO_2^-(aq)$, is present at a higher concentration in the solution? Justify your answer.

GO ON TO THE NEXT PAGE.

2B 3 of 3

b.i $\Delta G^\circ = -RT\ln K$ $.87 = -(8.314)(298)\ln K$ $K = 1$

ii Yes. $K_p = \frac{(N_2O_3)}{(NO)(NO_2)}$ $1 = \frac{(N_2O_3)}{(1)(1)}$ $1 = P_{N_2O_3}$

c. Disagree. A negative ΔH shows the reaction is exothermic, so heat is treated as a product and increasing the temp would cause a shift left toward the reactants.

dii sp^2

eii pH = pKa at 10mL $pK_a \approx 3.3$

f. NO_2^- is present in higher concentration after 15mL KOH is added. Halfway to the equivalence point (after 10mL KOH is added) is when HNO_2 and NO_2^- are in equal concentration, so beyond that there is a higher concentration of NO_2^- because the acid is being titrated out.

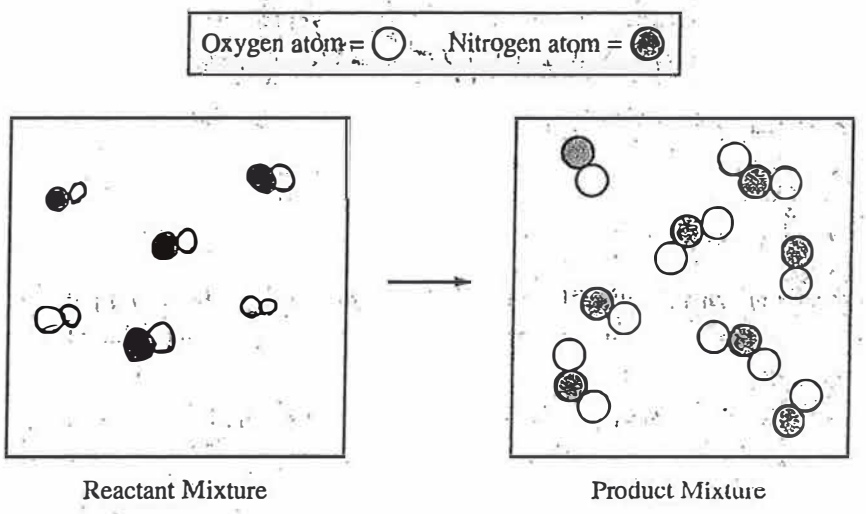
ei $M_AV_A = M_BV_B$ $(M_A)(100mL) = (.1M)(20mL)$ $M_A = .02M\ HNO_2$

GO ON TO THE NEXT PAGE.

$$2\,NO(g) + O_2(g) \rightarrow 2\,NO_2(g)$$ 2C 1 of 4

2. A student investigates the reactions of nitrogen oxides. One of the reactions in the investigation requires an equimolar mixture of $NO(g)$ and $NO_2(g)$, which the student produces by using the reaction represented above.

(a) The particle-level representation of the equimolar mixture of $NO(g)$ and $NO_2(g)$ in the flask at the completion of the reaction between $NO(g)$ and $O_2(g)$ is shown below in the box on the right. In the box below on the left, draw the particle-level representation of the reactant mixture of $NO(g)$ and $O_2(g)$ that would yield the product mixture shown in the box on the right. In your drawing, represent oxygen atoms and nitrogen atoms as indicated below.



Reactant Mixture Product Mixture

The student reads in a reference text that $NO(g)$ and $NO_2(g)$ will react as represented by the equation below. Thermodynamic data for the reaction are given in the table below the equation.

$$NO(g) + NO_2(g) \rightleftarrows N_2O_3(g)$$ +40.4 kJ/mol

ΔH°_{298}	ΔS°_{298}	ΔG°_{298}
-40.4 kJ/mol$_{rxn}$	-138.5 J/(K·mol$_{rxn}$)	0.87 kJ/mol$_{rxn}$

(b) The student begins with an equimolar mixture of $NO(g)$ and $NO_2(g)$ in a rigid reaction vessel and the mixture reaches equilibrium at 298 K.

$\Delta G = -RT \ln K$

(i) Calculate the value of the equilibrium constant, K, for the reaction at 298 K.

(ii) If both P_{NO} and P_{NO_2} in the vessel are initially 1.0 atm, will $P_{N_2O_3}$ at equilibrium be equal to 1.0 atm? Justify your answer.

$\frac{x}{1} = .7$

(c) The student hypothesizes that increasing the temperature will increase the amount of $N_2O_3(g)$ in the equilibrium mixture. Indicate whether you agree or disagree with the hypothesis. Justify your answer.

GO ON TO THE NEXT PAGE.

2C 2.5.4

$N_2O_3(g)$ reacts with water to form nitrous acid, $HNO_2(aq)$, a compound involved in the production of acid rain. The reaction is represented below.

$$N_2O_3(g) + H_2O(l) \rightarrow 2\,HNO_2(aq)$$

(d) The skeletal structure of the HNO_2 molecule is shown in the box below.

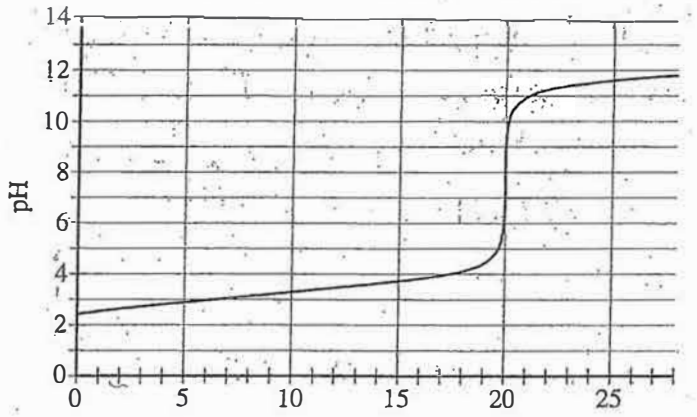
(i) Complete the Lewis electron-dot diagram of the HNO_2 molecule in the box below, including any lone pairs of electrons.

(ii) Based on your completed diagram above, identify the hybridization of the nitrogen atom in the HNO_2 molecule.

To produce an aqueous solution of HNO_2, the student bubbles $N_2O_3(g)$ into distilled water. Assume that the reaction goes to completion and that HNO_2 is the only species produced. To determine the concentration of $HNO_2(aq)$ in the resulting solution, the student titrates a 100. mL sample of the solution with 0.100 *M* KOH(*aq*). The neutralization reaction is represented below.

$$HNO_2(aq) + OH^-(aq) \rightarrow NO_2^-(aq) + H_2O(l)$$

The following titration curve shows the change in pH of the solution during the titration.



(e) Use the titration curve and the information above to

$2.5 = -\log [H^+]$

(i) determine the initial concentration of the $HNO_2(aq)$ solution

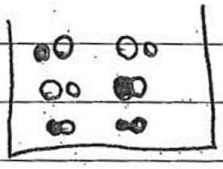
(ii) estimate the value of pK_a for $HNO_2(aq)$

(f) During the titration, after a volume of 15 mL of 0.100 *M* KOH(*aq*) has been added, which species, $HNO_2(aq)$ or $NO_2^-(aq)$, is present at a higher concentration in the solution? Justify your answer.

GO ON TO THE NEXT PAGE.

PAGE FOR ANSWERING QUESTION 2

a) In the drawing, there are twice as many NO as there are O_2.



b) (i) $\Delta G = -RT \ln K$

$0.87\ kJ/mol = -(8.314\ J\ mol^{-1}\ K^{-1})(298\ K) \ln K$

$870\ J/mol = -(8.314\ J\ mol^{-1}\ K^{-1})(298\ K) \ln K$

$K = 0.704$

(ii) No because Since $K = 0.704$ and in the Equilibrium Constant Equation $K = \frac{[products]}{[reactants]}$, $0.704 = \frac{[products]}{[1]^2}$ $P_{product} = 0.704$, this $P_{N_2O_3}$ will not be 1 atm.

c) I disagree with the hypothesis because since ΔH is exothermic, it will lie on the products side. If one were to increase temperature then, by Lechatelier's principle, the reaction will shift to the left creating less product or $N_2O_{3(g)}$.

d) (i) H – Ö – N = Ö: (ii) N, Sp^2

e) (i) $pH = -\log[H^+]$

$2.5 = -\log[H^+]$

$[H^+] = 0.0032\ M$

GO ON TO THE NEXT PAGE.

ADDITIONAL PAGE FOR ANSWERING QUESTION 2

(d.i) At half equivalence point, pH = pK_a
½ eq point is 10 mL, at 10 mL pH ≈ 3.2, therefore
$pK_a \approx 3.2$.

d) HNO_2 is present at a larger concentration when only 15 mL of 0.1 M NaOH(aq) is added because it is still before the equivalence point and thus by Henderson Hasselbach Equation, the concentration of HNO_2 is higher.

AP® CHEMISTRY
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Question 2

Overview

Parts (a) through (f) assessed students' understanding of equilibrium, thermodynamics, Le Chatelier's principle, Lewis electron-dot structures, hybridization, acid-base neutralization, and titration.

In part (a) students were asked to draw a particle-level representation of the mixture of NO and O_2 reactants that would afford the product mixture illustrated in the diagram. Students were required to interpret and use the pictorial symbols, making connections between the balanced chemical equation and the particulate diagram (LO 1.17; SP 1.5). In part (b) students were required to use a table of thermodynamic data to calculate the value of the equilibrium constant for an equimolar mixture of NO and NO_2 that has reached equilibrium at 298 K. Students were expected to recognize the relationship between ΔG° and K (LO 6.25; SP 2.3). They were then asked to determine if the partial pressure of N_2O_3 product at equilibrium will be equal to 1.0 atm if the partial pressures of the reactants (NO and NO_2) in the vessel were initially 1.0 atm. The students should recognize that $K<1$, and thus the partial pressure of N_2O_3 product at equilibrium is greater than 1 atm due to the substantial amount of reactants remaining (LO 6.6; SP 2.2, 6.4). In part (c) students were asked to make and justify a claim about the amount of N_2O_3 product as the temperature is increased. The students should use a qualitative rationale based on the sign of the standard enthalpy change ($\Delta H^\circ<0$) and Le Chatelier's principle (LO 6.8; SP 1.4, 6.4). In part (d) students were asked to draw the Lewis electron-dot diagram of HNO_2 from the skeletal structure. They were then asked to identify the hybridization of the nitrogen atom in the molecule that they drew (LO 2.21; SP 1.4). In part (e) the students were given a neutralization reaction between HNO_2 and KOH and the corresponding titration curve. They were asked to determine the initial concentration of the HNO_2 solution (LO 1.20; SP 4.2, 5.1, 6.4) and to estimate the pK_a of HNO_2 (LO 6.13; SP 5.1, 6.4). In part (f) the students were asked to determine the major species present after a volume of 15 mL of 0.100 M KOH(aq) had been added during the titration experiment (LO 6.17; SP 6.4). This question required students to recognize that 15 mL of KOH solution is past the half-equivalence point, and thus conclude that $NO_2^-(aq)$ is the major species.

Sample: 2A
Score: 10

In part (a) the response earned the full 2 points because the student draws the correct particle-level representation; the correct representation for the reactant molecules NO and O_2 is shown, and the student correctly represents atom conservation. In part (b)(i) the student earned 1 point for correctly calculating K. The student earned 1 point in part (b)(ii) for the correct choice and a valid justification. In part (c) the response earned 1 point for the correct choice and a valid justification. In part (d)(i) the student earned 1 point for drawing the correct Lewis electron-dot diagram. The response earned 1 point in part (d)(ii) for the correct hybridization consistent with the Lewis electron-dot diagram in part (d)(i). In part (e)(i) the student earned 1 point for correctly calculating the initial concentration of HNO_2. The student earned 1 point in part (e)(ii) for correctly estimating the value of pK_a for HNO_2. In part (f) the student earned 1 point for correctly choosing the species present at a higher concentration and giving a valid justification.

Question 2 (continued)

Sample: 2B
Score: 8

In part (a) the response earned the full 2 points because the student draws the correct particle-level representation; the correct representation for the reactant molecules NO and O_2 is shown, and the student correctly represents atom conservation. In part (b)(i) no point was earned because the student calculated K incorrectly. The student did not earn a point in part (b)(ii) because of an incorrect choice. In part (c) the response earned 1 point for the correct choice and a valid justification. In part (d)(i) the student earned 1 point for drawing the correct Lewis electron-dot diagram. The response earned 1 point in part (d)(ii) for the correct hybridization consistent with the Lewis electron-dot diagram in part (d)(i). In part (e)(i) the student earned 1 point for correctly calculating the initial concentration of HNO_2. The student earned 1 point in part (e)(ii) for correctly estimating the value of pK_a for HNO_2. In part (f) the response earned 1 point because the student chooses the species present at a higher concentration and includes a valid justification.

Sample: 2C
Score: 6

In part (a) the response earned 1 point because the student draws the correct particle-level representation for the reactant molecules NO and O_2 but did not earn the second point because atom conservation is not represented. In part (b)(i) the student earned 1 point for correctly calculating K. In part (b)(ii) no point was earned because there is no valid justification. In part (c) the response earned 1 point for the correct choice and a valid justification. In part (d)(i) the student earned 1 point for drawing the correct Lewis electron-dot diagram. In part (d)(ii) the response earned 1 point for the correct hybridization consistent with the Lewis electron-dot diagram in part (d)(i). In part (e)(i) no point was earned because the initial concentration of HNO_2 is calculated incorrectly. In part (e)(ii) the student earned 1 point for correctly estimating the value of pK_a for HNO_2. In part (f) no point was earned because the student chooses the wrong species.