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

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 <u>reactant</u> 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.

Oxygen atom = ○   Nitrogen atom = ●

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.

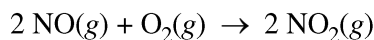$$NO(g) + NO_2(g) \rightleftarrows N_2O_3(g)$$

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.
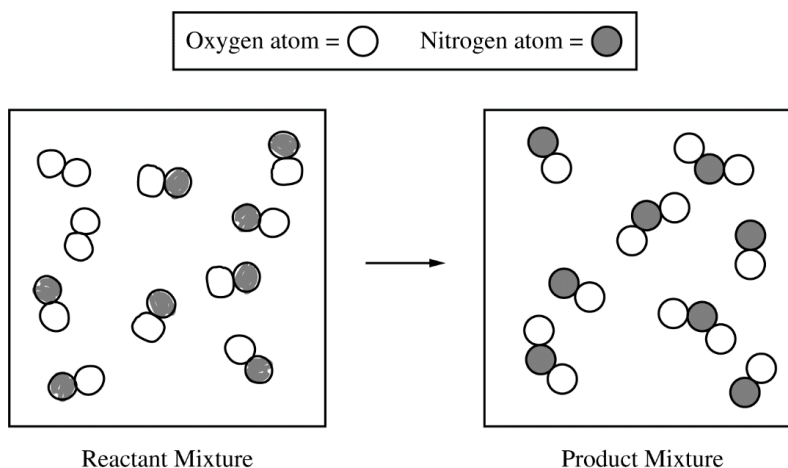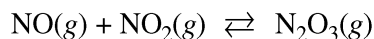
Question 2

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

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 <u>reactant</u> 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}
$-40.4\ \text{kJ/mol}_{rxn}$	$-138.5\ \text{J/(K·mol}_{rxn})$	$0.87\ \text{kJ/mol}_{rxn}$

(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.

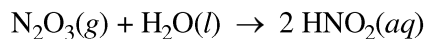|	
$\Delta G° = -RT \ln K$ $K = e^{-\Delta G°/RT}$ $K = e^{-\dfrac{870 \text{ J/mol}}{(8.314 \text{ J mol}^{-1} \text{ K}^{-1})(298 \text{ K})}}$ $K = 0.70$	1 point is earned for a correct calculation of K.

    (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 <u>and</u> 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.

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

(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.
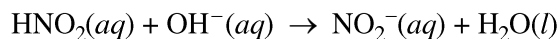
$$H : \overset{\cdot\cdot}{\underset{\cdot\cdot}{O}} : \overset{\cdot\cdot}{N} :: \overset{\cdot\cdot}{\underset{\cdot}{O}} \cdot$$

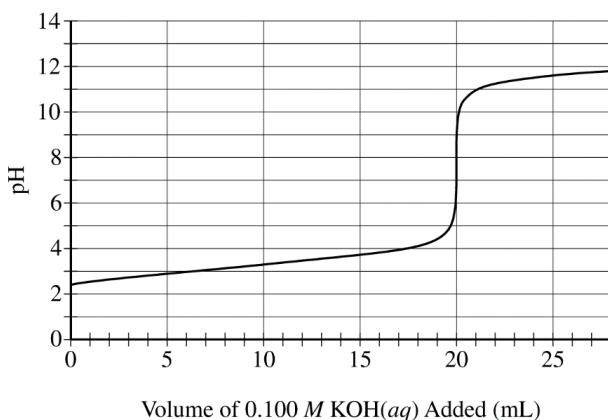| See sample response above. (Line segments can be used to represent electron pairs.)	1 point is earned for a valid diagram.

   (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.

Volume of 0.100 M $KOH(aq)$ Added (mL)

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

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

$20. \text{ mL KOH} \times \dfrac{0.100 \text{ mol KOH}}{1000 \text{ mL KOH}} = 0.0020 \text{ mol KOH added}$ $\Rightarrow \quad 0.0020 \text{ mol HNO}_2 \text{ in } 100. \text{ mL of solution because the stoichiometry}$ of the neutralization reaction is 1 to 1. $\dfrac{0.0020 \text{ mol HNO}_2}{0.100 \text{ L}} = 0.020 \, M \text{ HNO}_2$	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 <u>and</u> a valid justification.