$N_2O_3(g)$ 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.

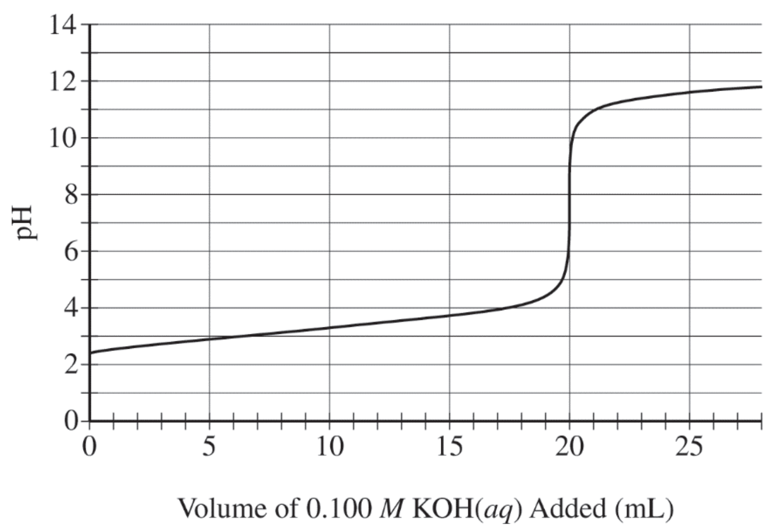
$$\boxed{\text{H O N O}}$$

(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

(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.

3. Answer the following questions relating to Fe and its ions, Fe^{2+} and Fe^{3+}.

   (a) Write the ground-state electron configuration of the Fe^{2+} ion.

Ion	Ionic Radius (pm)
Fe^{2+}	92
Fe^{3+}	79

   (b) The radii of the ions are given in the table above. Using principles of atomic structure, explain why the radius of the Fe^{2+} ion is larger than the radius of the Fe^{3+} ion.

   (c) Fe^{3+} ions interact more strongly with water molecules in aqueous solution than Fe^{2+} ions do. Give one reason for this stronger interaction, and justify your answer using Coulomb's law.

A student obtains a solution that contains an unknown concentration of $Fe^{2+}(aq)$. To determine the concentration of $Fe^{2+}(aq)$ in the solution, the student titrates a sample of the solution with $MnO_4^-(aq)$, which converts $Fe^{2+}(aq)$ to $Fe^{3+}(aq)$, as represented by the following equation.

$$5\ Fe^{2+}(aq) + MnO_4^-(aq) + 8\ H^+(aq) \rightarrow 5\ Fe^{3+}(aq) + Mn^{2+}(aq) + 4\ H_2O(l)$$

   (d) Write the balanced equation for the half-reaction for the oxidation of $Fe^{2+}(aq)$ to $Fe^{3+}(aq)$.

   (e) The student titrates a 10.0 mL sample of the $Fe^{2+}(aq)$ solution. Calculate the value of $[Fe^{2+}]$ in the solution if it takes 17.48 mL of added 0.0350 M $KMnO_4(aq)$ to reach the equivalence point of the titration.

To deliver the 10.0 mL sample of the $Fe^{2+}(aq)$ solution in part (e), the student has the choice of using one of the pieces of glassware listed below.

- 25 mL buret
- 25 mL graduated cylinder
- 25 mL beaker
- 25 mL volumetric flask

   (f) Explain why the 25 mL volumetric flask would be a poor choice to use for delivering the required volume of the $Fe^{2+}(aq)$ solution.

In a separate experiment, the student is given a sample of powdered $Fe(s)$ that contains an inert impurity. The student uses a procedure to oxidize the $Fe(s)$ in the sample to $Fe_2O_3(s)$. The student collects the following data during the experiment.

Mass of $Fe(s)$ with inert impurity	6.724 g
Mass of $Fe_2O_3(s)$ produced	7.531 g

   (g) Calculate the number of moles of Fe in the $Fe_2O_3(s)$ produced.

   (h) Calculate the percent by mass of Fe in the original sample of powdered $Fe(s)$ with the inert impurity.

   (i) If the oxidation of the $Fe(s)$ in the original sample was incomplete so that some of the 7.531 g of product was $FeO(s)$ instead of $Fe_2O_3(s)$, would the calculated mass percent of $Fe(s)$ in the original sample be higher, lower, or the same as the actual mass percent of $Fe(s)$? Justify your answer.

GO ON TO THE NEXT PAGE.

Question 3

Answer the following questions relating to Fe and its ions, Fe^{2+} and Fe^{3+}.

(a) Write the ground-state electron configuration of the Fe^{2+} ion.

$1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 3d^6$ OR [Ar] $3d^6$	1 point is earned for a correct electron configuration.

Ion	Ionic Radius (pm)
Fe^{2+}	92
Fe^{3+}	79

(b) The radii of the ions are given in the table above. Using principles of atomic structure, explain why the radius of the Fe^{2+} ion is larger than the radius of the Fe^{3+} ion.

Both ions have the same nuclear charge; however, the greater number of electrons in the outermost shell of Fe^{2+} results in greater electron-electron repulsion within that shell, leading to a larger radius.	1 point is earned for a valid explanation.

(c) Fe^{3+} ions interact more strongly with water molecules in aqueous solution than Fe^{2+} ions do. Give one reason for this stronger interaction, and justify your answer using Coulomb's law.

Coulomb's law: $F \propto \frac{q_1\, q_2}{r^2}$ (need not be explicitly stated) In comparison to the Fe^{2+} ion, the Fe^{3+} ion has a higher charge. OR The smaller size of Fe^{3+} allows it to get closer to a water molecule.	1 point is earned for a valid explanation.

A student obtains a solution that contains an unknown concentration of $Fe^{2+}(aq)$. To determine the concentration of $Fe^{2+}(aq)$ in the solution, the student titrates a sample of the solution with $MnO_4^-(aq)$, which converts $Fe^{2+}(aq)$ to $Fe^{3+}(aq)$, as represented by the following equation.

$$5\ Fe^{2+}(aq) + MnO_4^-(aq) + 8\ H^+(aq) \rightarrow 5\ Fe^{3+}(aq) + Mn^{2+}(aq) + 4\ H_2O(l)$$

(d) Write the balanced equation for the half-reaction for the oxidation of $Fe^{2+}(aq)$ to $Fe^{3+}(aq)$.

$Fe^{2+}(aq) \rightarrow Fe^{3+}(aq) + e^-$	1 point is earned for the correct half-reaction.

Question 3 (continued)

(e) The student titrates a 10.0 mL sample of the $Fe^{2+}(aq)$ solution. Calculate the value of $[Fe^{2+}]$ in the solution if it takes 17.48 mL of added 0.0350 M $KMnO_4(aq)$ to reach the equivalence point of the titration.

$17.48\ \text{mL} \times \frac{0.0350\ \text{mol KMnO}_4}{1000\ \text{mL}} = 0.000612\ \text{mol KMnO}_4$ $0.000612\ \text{mol KMnO}_4 \times \frac{5\ \text{mol Fe}^{2+}}{1\ \text{mol KMnO}_4} = 0.003059\ \text{mol Fe}^{2+}$ $\frac{0.003059\ \text{mol Fe}^{2+}}{0.0100\ \text{L}} = 0.306\ M\ \text{Fe}^{2+}$	1 point is earned for calculating the number of moles of $KMnO_4$ (may be implicit). 1 point is earned for the correct concentration of $Fe^{2+}(aq)$.

To deliver the 10.0 mL sample of the $Fe^{2+}(aq)$ solution in part (e), the student has the choice of using one of the pieces of glassware listed below.

- 25 mL buret
- 25 mL graduated cylinder
- 25 mL beaker
- 25 mL volumetric flask

(f) Explain why the 25 mL volumetric flask would be a poor choice to use for delivering the required volume of the $Fe^{2+}(aq)$ solution.

The volumetric flask is designed to contain only 25.00 mL precisely.	1 point is earned for a valid explanation.

Question 3 (continued)

In a separate experiment, the student is given a sample of powdered $Fe(s)$ that contains an inert impurity. The student uses a procedure to oxidize the $Fe(s)$ in the sample to $Fe_2O_3(s)$. The student collects the following data during the experiment.

Mass of $Fe(s)$ with inert impurity	6.724 g
Mass of $Fe_2O_3(s)$ produced	7.531 g

(g) Calculate the number of moles of Fe in the $Fe_2O_3(s)$ produced.

$7.531 \text{ g } Fe_2O_3 \times \dfrac{1 \text{ mol } Fe_2O_3}{159.70 \text{ g } Fe_2O_3} = 0.04716 \text{ mol } Fe_2O_3$ $0.04716 \text{ mol } Fe_2O_3 \times \dfrac{2 \text{ mol Fe}}{1 \text{ mol } Fe_2O_3} = 0.09431 \text{ mol Fe}$	1 point is earned for correct calculation.

(h) Calculate the percent by mass of Fe in the original sample of powdered $Fe(s)$ with the inert impurity.

$0.09431 \text{ mol Fe} \times \dfrac{55.85 \text{ g Fe}}{1 \text{ mol}} = 5.267 \text{ g Fe}$ $\dfrac{5.267 \text{ g Fe}}{6.724 \text{ g sample}} \times 100 = 78.33\%$	1 point is earned for correct calculation of the mass percent based on the answer to part (g).

(i) If the oxidation of the $Fe(s)$ in the original sample was incomplete so that some of the 7.531 g of product was $FeO(s)$ instead of $Fe_2O_3(s)$, would the calculated mass percent of $Fe(s)$ in the original sample be higher, lower, or the same as the actual mass percent of $Fe(s)$? Justify your answer.

The calculated mass percent of Fe would be lower than the actual mass percent of Fe. A sample that contains any FeO (rather than Fe_2O_3) will have a higher <u>actual</u> mass percent of Fe than a completely oxidized sample would have. Therefore, when the moles of Fe are calculated (assuming all the mass of the sample is Fe_2O_3) the <u>calculated</u> number of moles of Fe, and hence the <u>calculated</u> mass percent of Fe, will be lower.	1 point is earned for the correct answer and a valid explanation.