Redox Titration.

Titrations are typically done with acid and base reactions and allow the determination of the molarity or moles of an unknown substance. In acid and base reactions, the progress of the titration is followed with an indicator that changes color when the equivalence point is reached. Redox reaction often change the color of a substance when it is oxidized or reduced, so these reactants can be used as indicators in the titration.

Potassium permanganate is often used in the titration of redox reactions because it has a very deep purple color that is observable in small amounts. The classic titration is the oxidation of Fe$^{2+}$ by MnO$_4^-$, permanganate in an acidic solution: Fe$^{2+}$ + MnO$_4^-$ $\rightarrow$ Fe$^{3+}$ + Mn$^{2+}$ (unbalance equation you will balance below).

In the titration, the beaker contains a massed and dissolved amount of iron sample. The buret contains potassium permanganate with a known molarity. Acid is added to make sure the solution is acidic. As the titrant is added, the purplish color disappears when MnO$_4^-$ changes to clear Mn$^{2+}$. Near the end point the color persists. At the end point the solution turns just faint pinkish purple (much like phenolphthalein in an acid-base titration). From this information and the balanced equation you can determine the unknown mass or moles of iron in the sample (or determine the molarity of the permanganate solution).

Here’s a sample question (solution on the back):

1. Use the half reaction method to write the balanced net ionic equation for the reaction between MnO$_4^-$ and Fe$^{2+}$ ion in acid solution. The unbalanced equation is Fe$^{2+}$(aq) + MnO$_4^-$(aq) $\rightarrow$ Fe$^{3+}$(aq) + Mn$^{2+}$(aq).

2. How many moles of Fe$^{2+}$ ion can be oxidized by 0.012 moles MnO$_4^-$ ion in the reaction in Question 1? Show work.

3. A solid sample containing some Fe$^{2+}$ ion weighs 1.923 g. It requires 36.44 mL of 0.0244 M KMnO$_4$ to titrate the Fe$^{2+}$ in the dissolved sample to a pink end point. Calculate the grams of iron in the sample and the percentage of iron in the sample. Show work with units.

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1 If the solution is not acidic enough there is the potential to form MnO$_2$ (Mn$^{4+}$) a black solid.
Solution to sample problem

1. \( \text{Fe}^{2+} + 1e^- \rightarrow \text{Fe}^{3+} \) \( \rightarrow \) \( 5[\text{Fe}^{2+} + 1e^- \rightarrow \text{Fe}^{3+}] \rightarrow \) \( 5 \text{Fe}^{2+} + 5e^- \rightarrow 5 \text{Fe}^{3+} \)
   \( 
   \text{MnO}_4^- \rightarrow \text{Mn}^{2+} + 5e^- \) (balance the 1/2 reaction)\(^2\) \( \rightarrow \) \( 8\text{H}^+ + \text{MnO}_4^- \rightarrow \text{Mn}^{2+} + 4\text{H}_2\text{O} + 5e^- \)
   Balanced redox reaction : \( 8\text{H}^+ + \text{MnO}_4^- + 5\text{Fe}^{3+} \rightarrow 5\text{Fe}^{2+} + \text{Mn}^{2+} + 4\text{H}_2\text{O} \)

2. \( 0.012 \text{ mol MnO}_4^- \cdot \frac{5 \text{ Fe}^{3+}}{1 \text{ MnO}_4^-} = 0.060 \text{ mol Fe}^{3+} \)

3. \( 0.03644 \text{ L MnO}_4^- \cdot \frac{0.0244 \text{ mol MnO}_4^-}{1 \text{ L}} \cdot \frac{5 \text{ Fe}^{3+}}{1 \text{ MnO}_4^-} \cdot \frac{55.85 \text{ g Fe}}{1 \text{ mol Fe}} = 0.248 \text{ g Fe in the sample} \)
   \( \frac{0.248}{1.923} \times 100\% = 12.9\% \text{ Fe in the sample} \)

Your turn:

1. p. 197 #119: Given two possible formulas: \( K[\text{Fe(C}_2\text{O}_4)_2(\text{H}_2\text{O})_2] \) or \( K_3[\text{Fe(C}_2\text{O}_4)_3] \).
   a. Balance the equation \( \text{C}_2\text{H}_4\text{O}_4^- + \text{MnO}_4^- + \text{H}^+ \rightarrow \text{Mn}^{2+} + \text{CO}_2 + \text{H}_2\text{O} \).
   b. A titration of 1.356 g of the compound (one of the two formulas above) requires 34.5 mL of 0.108M KMnO\(_4\). Which formula matches the compound being titrated?

2. p. 198 #124: Find the mass percent of copper in an alloy. The alloy is dissolved and excess \( \text{I}^- \) reacts with the copper: \( 2 \text{Cu}^{2+} + 5\text{I}^- \rightarrow 2\text{CuI} + \text{I}_3^- \) (could you balance this reaction). The \( \text{I}_3^- \) is then titrated (the \( \text{I}_3^- \) will have a deep blue violet if some starch is present) with sodium thiosulfate, \( \text{Na}_2\text{S}_2\text{O}_3 \): \( \text{I}_3^- + 2\text{S}_2\text{O}_3^{2-} \rightarrow \text{S}_4\text{O}_6^{2-} + 3\text{I}^- \).
   If 26.23 mL of 0.10 M \( \text{Na}_2\text{S}_2\text{O}_3 \) is required for the titration to the equivalence point then what is the weight percent of \( \text{Cu} \) in the 0.251 g alloy?

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\(^2\) Most books show the balancing of the 1/2 reactions before summing the two half reactions. While I teach balancing after adding the two reaction together, you should be aware of both methods.