1. The central reaction in the Contact Process for the manufacture of sulphuric acid is

\[ \text{SO}_2 + \frac{1}{2}\text{O}_2 \rightarrow \text{V}_2\text{O}_5 \rightarrow \text{SO}_3 \]

where the vanadium(V) oxide functions as a catalyst. The reaction happens in two steps which depend on the vanadium's ability to vary its oxidation state. Write equations for those two steps.

2. If you warm a solution of ammonium metavanadate with zinc and moderately concentrated hydrochloric acid, the vanadium is reduced through its range of oxidation states. The mixture is warmed in a flask stoppered with cotton wool. The solution goes through these colour changes:

Solution A contains the VO$_2^+$ ion. Other ions which are formed are V(H$_2$O)$_6^{3+}$, V(H$_2$O)$_6^{2+}$ and VO$_2^+$.

a) What are the oxidation states of the vanadium in the ions VO$_2^+$, V(H$_2$O)$_6^{3+}$, V(H$_2$O)$_6^{2+}$ and VO$_2^+$.  

b) Which are the main ions present in the flasks B, C, D, and E?

c) Describe and explain what happens if you pour the liquid contents of flask E into another container.

Don't waste time looking at the rest of the questions unless you are reasonably confident about redox potentials. If you should be confident, but aren't, go and sort out that topic before you continue with this one.

3. The $E^0$ values for the equilibria involved in the reduction of VO$_2^+$ to VO$_2^+$ are

\[ \text{VO}_2^{+}\text{(aq)} + 2\text{H}^+\text{(aq)} + \text{e}^- \leftrightarrow \text{VO}^{2+}\text{(aq)} + \text{H}_2\text{O}\text{(l)} \quad E^0 = +1.00 \text{ v} \]

\[ \text{Zn}^{2+}\text{(aq)} + 2\text{e}^- \leftrightarrow \text{Zn}\text{(s)} \quad E^0 = -0.76 \text{ v} \]

a) Explain how the given $E^0$ values show that you can use zinc as a reducing agent in this reaction.

b) Work out the ionic equation for the overall reaction.
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4. The $E^0$ values for all the stages of the reduction of VO$_2^+$ are as follows.

\[
\begin{align*}
\text{VO}_2^+ (aq) + 2H^+ (aq) + e^- & \rightleftharpoons \text{VO}^{2+} (aq) + H_2O (l) \quad E^0 = +1.00 \text{ v} \\
\text{VO}^{2+} (aq) + 2H^+ (aq) + e^- & \rightleftharpoons \text{V}^3+ (aq) + H_2O (l) \quad E^0 = +0.34 \text{ v} \\
\text{V}^3+ (aq) + e^- & \rightleftharpoons \text{V}^2+ (aq) \quad E^0 = -0.26 \text{ v} \\
\end{align*}
\]

Sulphur dioxide is a reducing agent, and dissolves in water to form sulphurous acid, H$_2$SO$_3$. When it reduces something, it forms sulphate ions. The $E^0$ value for the change is given by

\[
\begin{align*}
\text{SO}_4^{2-} (aq) + 4H^+ (aq) + 2e^- & \rightleftharpoons H_2SO_3(aq) + H_2O (l) \quad E^0 = +0.17 \text{ v} \\
\end{align*}
\]

If you treated VO$_2^+$ ions with sulphur dioxide under acidic conditions, what colour would the final solution be? Explain your answer.