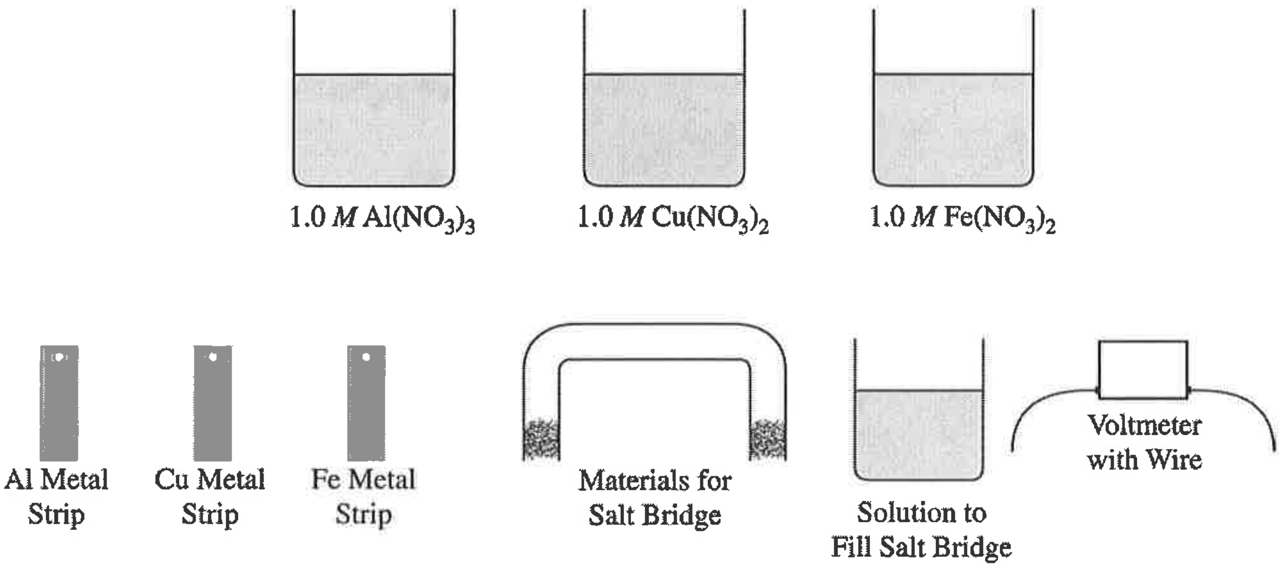
Question 6

Total Score 9 points

6. Answer the following questions about electrochemistry.

   (a) Several different electrochemical cells can be constructed using the materials shown below. Write the balanced net-ionic equation for the reaction that occurs in the cell that would have the greatest positive value of E°_{cell}.



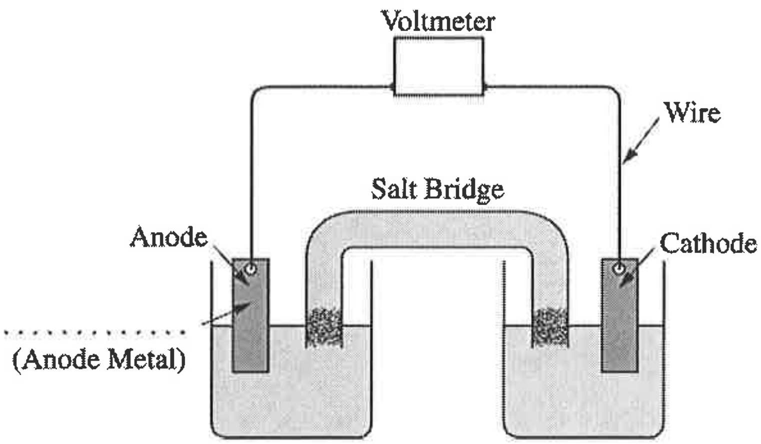
$Al(s) \rightarrow Al^{3+}(aq) + 3\,e^-$ $Cu^{2+}(aq) + 2\,e^- \rightarrow Cu(s)$ $2\,Al(s) + 3\,Cu^{2+}(aq) \rightarrow 2\,Al^{3+}(aq) + 3\,Cu(s)$	1 point for selection of correct two redox couples 1 point for correctly balanced net ionic equation

(b) Calculate the standard cell potential, E°_{cell}, for the reaction written in part (a).

$Al^{3+}(aq) + 3\,e^- \rightarrow Al(s)$ $E^\circ = -1.66$ V $Cu^{2+}(aq) + 2\,e^- \rightarrow Cu(s)$ $E^\circ = +0.34$ V $E^\circ_{cell} = E^\circ_{cathode} - E^\circ_{anode} = +0.34\text{ V} - (-1.66\text{ V}) = +2.00\text{ V}$	1 point for correct E°_{cell} (Must be consistent with part (a))

Question 6 (cont'd.)

(c) A cell is constructed based on the reaction in part (a) above. Label the metal used for the anode on the cell shown in the figure below.



The metal is aluminum solid.	1 point for correct metal (Must be consistent with part (a))

(d) Of the compounds NaOH, CuS, and $NaNO_3$, which one is appropriate to use in a salt bridge? Briefly explain your answer, and for each of the other compounds, include a reason why it is not appropriate.

NaOH is not appropriate. The anion, OH^-, would migrate towards the anode. The OH^- would react with the Al^{3+} ion in solution. CuS is not appropriate. It is insoluble in water, so no ions would be available to migrate to the anode and cathode compartment to balance the charge. $NaNO_3$ is appropriate. It is soluble in water, and neither the cation nor the anion will react with the ions in the anode or cathode compartment.	1 point for correctly indicating whether each compound is appropriate, along with an explanation (3 points total)

Question 6 (cont'd.)

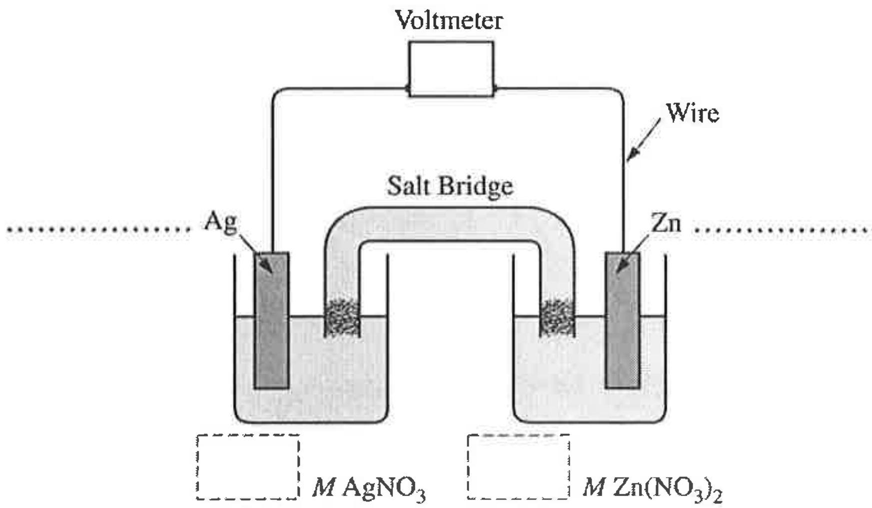
(e) Another standard cell is based on the following reaction.

$$Zn + Pb^{2+} \rightarrow Zn^{2+} + Pb$$

If the concentration of Zn^{2+} is decreased from 1.0 M to 0.25 M, what effect does this have on the cell potential? Justify your answer.

$E_{cell} = E^{\circ}_{cell} - 0.059 \ln\left(\frac{[Zn^{2+}]}{[Pb^{2+}]}\right)$ If $[Zn^{2+}]$ is reduced, then the ratio $\left(\frac{[Zn^{2+}]}{[Pb^{2+}]}\right) < 1$, therefore $\ln\left(\frac{[Zn^{2+}]}{[Pb^{2+}]}\right) < 0$. Thus E_{cell} increases (becomes more positive).	1 point for correctly indicating how E_{cell} is affected 1 point for explanation in terms of Nernst equation and Q

Question 6



6. The following questions refer to the electrochemical cell shown in the diagram above.

(a) Write a balanced net ionic equation for the spontaneous reaction that takes place in the cell.

$Zn^{2+}(aq) + 2e^- \rightarrow Zn(s)$ $Ag^+(aq) + e^- \rightarrow Ag(s)$ $Zn(s) + 2Ag^+(aq) \rightarrow Zn^{2+}(aq) + 2Ag(s)$	1 point for the balanced net-ionic equation 1 point for correct direction (reactants and products)

(b) Calculate the standard cell potential, $E°$, for the reaction in part (a).

$Zn^{2+}(aq) + 2e^- \rightarrow Zn(s)$ $E° = -0.76$ V $Ag^+(aq) + e^- \rightarrow Ag(s)$ $E° = +0.80$ V $E^\circ_{cell} = E^\circ_{cathode} - E^\circ_{anode} = +0.80\text{ V} - (-0.76\text{ V}) = +1.56\text{ V}$	1 point for the correct, positive E°_{cell}

(c) In the diagram above,

(i) label the anode and the cathode on the dotted lines provided, and

The anode is the zinc metal electrode, the cathode is the silver metal electrode.	1 point for the correct metal for anode and cathode

Question 6 (cont'd.)

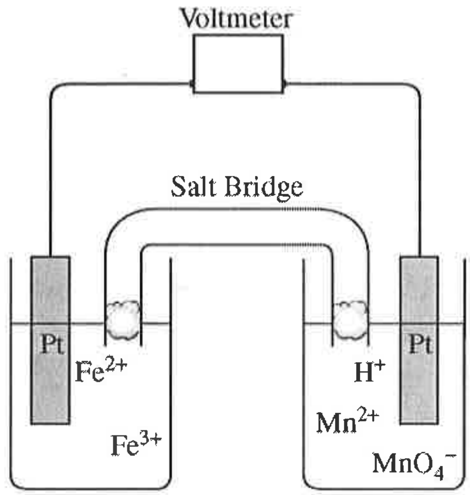
(ii) indicate, in the boxes below the half-cells, the concentration of $AgNO_3$ and the concentration of $Zn(NO_3)_2$ that are needed to generate $E°$

$[AgNO_3] = [Zn(NO_3)_2] = 1\ M$	1 point for the correct concentration for the anodic chamber 1 point for the correct concentration for the cathodic chamber

(d) How will the cell potential be affected if KI is added to the silver half-cell? Justify your answer.

A precipitate will form as I^- ions react with Ag^+ ions in solution in cathode compartment. $[Ag^+]$ will be reduced, causing cell potential to decrease.	1 point for correctly indicating a reaction occurs 1 point for indicating the cell potential decreases

Question 2
(10 points)



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

A galvanic cell and the balanced equation for the spontaneous cell reaction are shown above. The two reduction half-reactions for the overall reaction that occurs in the cell are shown in the table below.

Half-Reaction	$E°$ (V) at 298 K
$Fe^{3+}(aq) + e^- \rightarrow Fe^{2+}(aq)$	+0.77
$MnO_4^-(aq) + 8\ H^+(aq) + 5\ e^- \rightarrow Mn^{2+}(aq) + 4\ H_2O(l)$	+1.49

(a) On the diagram, clearly label the cathode.

The electrode in the beaker on the right should be labeled.	One point is earned for correct identification of the cathode.

(b) Calculate the value of the standard potential, $E°$, for the spontaneous cell reaction.

$E_{cell} = 1.49 - 0.77 = 0.72$ V	One point is earned for the correct numerical answer.

(c) How many moles of electrons are transferred when 1.0 mol of $MnO_4^-(aq)$ is consumed in the overall cell reaction?

5.0 moles of electrons are transferred.	One point is earned for the correct numerical answer.

Question 2 (continued)

(d) Calculate the value of the equilibrium constant, K_{eq}, for the cell reaction at 25°C. Explain what the magnitude of K_{eq} tells you about the extent of the reaction.

$\log K_{eq} = \frac{nE}{0.0592} = \frac{5 \times 0.72}{0.0592} = 61$ $K_{eq} = 6.5 \times 10^{60}$ Because the magnitude of K_{eq} is very large, the extent of the cell reaction is also very large and the reaction goes essentially to completion.	One point is earned for the correct substitution. One point is earned for the correct numerical answer. One point is earned for an explanation.

Three solutions, one containing $Fe^{2+}(aq)$, one containing $MnO_4^-(aq)$, and one containing $H^+(aq)$, are mixed in a beaker and allowed to react. The initial concentrations of the species in the mixture are 0.60 M $Fe^{2+}(aq)$, 0.10 M $MnO_4^-(aq)$, and 1.0 M $H^+(aq)$.

(e) When the reaction mixture has come to equilibrium, which species has the higher concentration, $Mn^{2+}(aq)$ or $MnO_4^-(aq)$? Explain.

$[Mn^{2+}(aq)]$ will be greater than $[MnO_4^-(aq)]$ because: (1) as indicated in part (d), the reaction essentially goes to completion, and (2) there is more than sufficient Fe^{2+} and H^+ to react completely with the MnO_4^-. $[MnO_4^-(aq)]$ at equilibrium is essentially zero.	One point is earned for the choice of Mn^{2+} with the explanation including only item (1). One point is earned for including item (2) in the explanation.

(f) When the reaction mixture has come to equilibrium, what are the molar concentrations of $Fe^{2+}(aq)$ and $Fe^{3+}(aq)$?

At equilibrium, $[Fe^{2+}(aq)] = [Fe^{2+}(aq)]_{initial} - 5[MnO_4^-(aq)]_{reacted}$ $= 0.60 - 5(0.10) = 0.10\ M$ $[Fe^{3+}(aq)] = 5 \times [MnO_4^-(aq)]_{reacted}$ $= 5(0.10) = 0.50\ M$	One point is earned for a correct setup (including a correct setup for an equilibrium calculation). One point is earned for correct numerical answers.

Question 3
(10 points)

A sample of ore containing the mineral tellurite, TeO_2, was dissolved in acid. The resulting solution was then reacted with a solution of $K_2Cr_2O_7$ to form telluric acid, H_2TeO_4. The unbalanced chemical equation for the reaction is given below.

$$\ldots\ TeO_2(s) + \ldots\ Cr_2O_7^{2-}(aq) + \ldots\ H^+(aq) \rightarrow \ldots\ H_2TeO_4(aq) + \ldots\ Cr^{3+}(aq) + \ldots\ H_2O(l)$$

(a) Identify the molecule or ion that is being oxidized in the reaction.

TeO_2 or Te^{4+}	One point is earned for correct identification of molecule or ion.

(b) Give the oxidation number of Cr in the $Cr_2O_7^{2-}(aq)$ ion.

+6	One point is earned for the correct answer.

(c) Balance the chemical equation given above by writing the correct lowest whole-number coefficients on the dotted lines.

$$3\ TeO_2(s) + 1\ Cr_2O_7^{2-}(aq) + 8\ H^+(aq) \rightarrow 3\ H_2TeO_4(aq) + 2\ Cr^{3+}(aq) + 1\ H_2O(l)$$

One point is earned for either

(1) two correct balances among Cr, H, O, charge, and Te vs. $Cr_2O_7^{2-}$ (for balancing by inspection or oxidation number method)

OR

(2) one correct half reaction or use of the correct multiplier to balance the charge (for balancing by half-reaction method).

One additional point is earned for a correctly balanced equation.

In the procedure described above, 46.00 mL of 0.03109 *M* $K_2Cr_2O_7$ was added to the ore sample after it was dissolved in acid. When the chemical reaction had progressed as completely as possible, the amount of unreacted (excess) $Cr_2O_7^{2-}(aq)$ was determined by titrating the solution with 0.110 *M* $Fe(NO_3)_2$. The reaction that occurred during the titration is represented by the following balanced equation.

$$6\ Fe^{2+}(aq) + Cr_2O_7^{2-}(aq) + 14\ H^+(aq) \rightarrow 2\ Cr^{3+}(aq) + 6\ Fe^{3+}(aq) + 7\ H_2O(l)$$

A volume of 9.85 mL of 0.110 *M* $Fe(NO_3)_2$ was required to reach the equivalence point.

Question 3 (continued)

(d) Calculate the number of moles of excess $Cr_2O_7^{2-}(aq)$ that was titrated.

By the stoichiometry of the titration reaction, moles of excess $Cr_2O_7^{2-}$ titrated $= \left(\frac{1}{6}\right)$ mol Fe^{2+} in 9.85 mL of 0.110 M $Fe(NO_3)_2$ $= \left(\frac{1}{6}\right)(0.00985\text{ L})(0.110\text{ mol } Fe(NO_3)_2\text{ L}^{-1})$ $= 0.000181$ mol	One point is earned for either the correct stoichiometric factor *OR* correct use of (0.00985)(0.110) factor. One point is earned for the correct numerical answer with the correct number of significant figures.

(e) Calculate the number of moles of $Cr_2O_7^{2-}(aq)$ that reacted with the tellurite.

moles $Cr_2O_7^{2-}$ that reacted with TeO_2 = total mol $Cr_2O_7^{2-}$ added − excess mol $Cr_2O_7^{2-}$ titrated $= (0.04600\text{ L})(0.03109\text{ mol } Cr_2O_7^{2-}\text{ L}^{-1})$ − excess mol $Cr_2O_7^{2-}$ titrated = 0.001430 mol − 0.000181 mol = 0.001249 mol $Cr_2O_7^{2-}$	One point is earned for correct calculation of initial moles of dichromate ion. One point is earned for correct numerical answer with correct number of significant figures.

(f) Calculate the mass, in grams, of tellurite that was in the ore sample.

mass of TeO_2 in sample $= 0.001249\text{ mol } Cr_2O_7^{2-} \times \frac{3\text{ mol } TeO_2}{1\text{ mol } Cr_2O_7^{2-}} \times \frac{159.6\text{ g } TeO_2}{1\text{ mol } TeO_2}$ = 0.5980 g	One point is earned for appropriate use of the stoichiometric factor *OR* for correct calculation of molar mass of TeO_2. One point is earned for the correct numerical answer.