AP Questions: Electrochemistry

$$I_2 + 2\ S_2O_3^{2-} \rightarrow 2\ I^- + S_4O_6^{2-}$$

(a) How many moles of I_2 was produced during the electrolysis?

(b) The hydrogen gas produced at the cathode during the electrolysis was collected over water at 25°C at a total pressure of 752 millimetres of mercury. Determine the volume of hydrogen collected. (The vapor pressure of water at 25°C is 24 millimetres of mercury.)

(c) Write the equation for the half–reaction that occurs at the anode during the electrolysis.

(d) Calculate the current used during the electrolysis.

1991 D

Explain each of the following.

(a) When an aqueous solution of NaCl is electrolyzed, $Cl_2(g)$ is produced at the anode, but no Na(s) is produced at the cathode.

(b) The mass of Fe(s) produced when 1 faraday is used to reduce a solution of $FeSO_4$ is 1.5 times the mass of Fe(s) produced when 1 faraday is used to reduce a solution of $FeCl_3$.

(c) $Zn + Pb^{2+}$ (1–molar) $\rightarrow Zn^{2+}$ (1–molar) + Pb

The cell that utilizes the reaction above has a higher potential when $[Zn^{2+}]$ is decreased and $[Pb^{2+}]$ is held constant, but a lower potential when $[Pb^{2+}]$ is decreased and $[Zn^{2+}]$ is held constant.

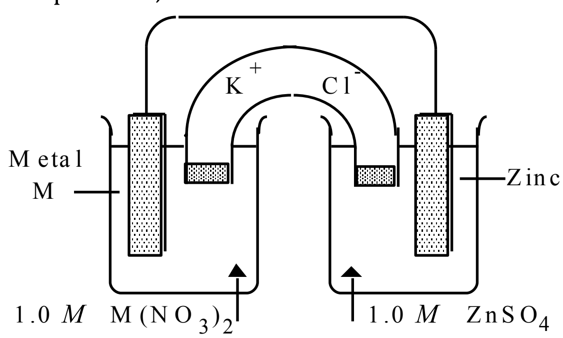
(d) The cell that utilizes the reaction given in (c) has the same cell potential as another cell in which $[Zn^{2+}]$ and $[Pb^{2+}]$ are each 0.1–molar.

1992 B

An unknown metal M forms a soluble compound, $M(NO_3)_2$.

(a) A solution of $M(NO_3)_2$ is electrolyzed. When a constant current of 2.50 amperes is applied for 35.0 minutes, 3.06 grams of the metal M is deposited. Calculate the molar mass of M and identify the metal.

(b) The metal identified in (a) is used with zinc to construct a galvanic cell, as shown below. Write the net ionic equation for the cell reaction and calculate the cell potential, $E°$.



(c) Calculate the value of the standard free energy change, $\Delta G°$, at 25°C for the reaction in (b).

(d) Calculate the potential, E, for the cell shown in (b) if the initial concentration of $ZnSO_4$ is 0.10-molar, but the concentration of the $M(NO_3)_2$ solution remains unchanged.

1980 B

$$M(s) + Cu^{2+}(aq) \rightarrow M^{2+}(aq) + Cu(s)$$

For the reaction above $E°$ = 0.740 volt at 25°C

(a) Determine the standard electrode potential for the reduction half reaction:

$$M^{2+}(aq) + 2e- \rightarrow M(s)$$

(b) A cell is constructed in which the reaction above occurs. All substances are initially in their standard states, and equal volumes of the solutions are used. The cell is then discharged. Calculate the value of the cell potential E, when $[Cu^{2+}]$ has dropped to 0.20 molar.

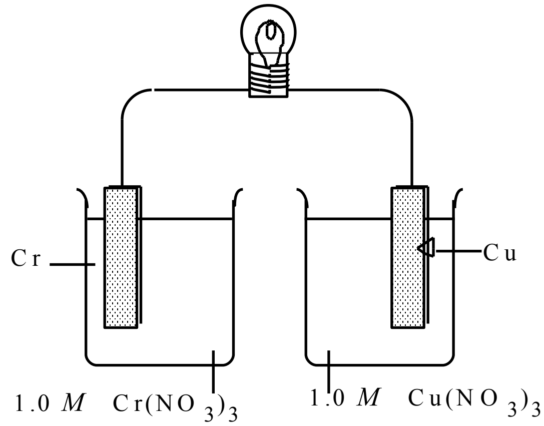
(c) Find the ratio $[M^{2+}]aq/[Cu^{2+}]aq$ when the cell reaction above reaches equilibrium.

1993 D

A galvanic cell is constructed using a chromium electrode in a 1.00-molar solution of $Cr(NO_3)_3$ and a copper electrode in a 1.00-molar solution of $Cu(NO_3)_2$. Both solutions are at 25°C.

(a) Write a balanced net ionic equation for the spontaneous reaction that occurs as the cell operates. Identify the oxidizing agent and the reducing agent.

(b) A partial diagram of the cell is shown below.



(i) Which metal is the cathode?

(ii) What additional component is necessary to make the cell operate?

(iii) What function does the component in (ii) serve?

(c) How does the potential of this cell change if the concentration of $Cr(NO_3)_3$ is changed to 3.00-molar at 25°C? Explain.

1996 D

$$Sr(s) + Mg^{2+} \rightarrow Sr^{2+} + Mg(s)$$

Consider the reaction represented above that occurs at 25°C. All reactants and products are in their standard states. The value of the equilibrium constant, K_{eq}, for the reaction is 4.2×10^{17} at 25°C.

(a) Predict the sign of the standard cell potential, $E°$, for a cell based on the reaction. Explain your prediction.

(b) Identify the oxidizing agent for the spontaneous reaction.

(c) If the reaction were carried out at 60°C instead of 25°C, how would the cell potential change? Justify your answer.

(d) How would the cell potential change if the reaction were carried out at 25°C with a 1.0-molar solution of $Mg(NO_3)_2$ and a 0.10-molar solution of $Sr(NO_3)_2$? Explain.

(e) When the cell reaction in (d) reaches equilibrium, what is the cell potential?

1997 B

In an electrolytic cell, a current of 0.250 ampere is passed through a solution of a chloride of iron, producing $Fe(s)$ and $Cl_2(g)$.

(a) Write the equation for the half-reaction that occurs at the anode.

(b) When the cell operates for 2.00 hours, 0.521 gram of iron is deposited at one electrode. Determine the formula of the chloride of iron in the original solution.

(c) Write the balanced equation for the overall reaction that occurs in the cell.

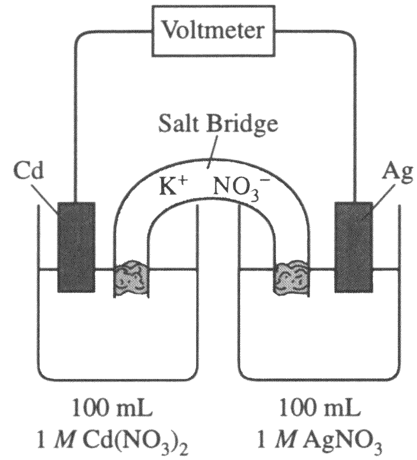
(d) How many liters of $Cl_2(g)$, measured at 25°C and 750 mm Hg, are produced when the cell operates as described in part (b) ?

(e) Calculate the current that would produce chlorine gas from the solution at a rate of 3.00 grams per hour.

1989 B

The electrolysis of an aqueous solution of potassium iodide, KI, results in the formation of hydrogen gas at the cathode and iodine at the anode. A sample of 80.0 millilitres of a 0.150 molar solution of KI was electrolyzed for 3.00 minutes, using a constant current. At the end of this time, the I_2 produced was titrated against a 0.225 molar solution of sodium thiosulfate, which reacts with iodine according to the equation below. The end point of the titration was reached when 37.3 millilitres of the $Na_2S_2O_3$ solution had been added

1998 D



Answer the following questions regarding the electrochemical cell shown.

(a) Write the balanced net-ionic equation for the spontaneous reaction that occurs as the cell operates, and determine the cell voltage.

(b) In which direction do anions flow in the salt bridge as the cell operates? Justify your answer.

(c) If 10.0 mL of 3.0-molar $AgNO_3$ solution is added to the half-cell on the right, what will happen to the cell voltage? Explain.

(d) If 1.0 gram of solid NaCl is added to each half-cell, what will happen to the cell voltage? Explain.

(e) If 20.0 mL of distilled water is added to both half-cells, the cell voltage decreases. Explain.

2000 B

2. Answer the following questions that relate to electrochemical reactions.

(a) Under standard conditions at 25°C, Zn*(s)* reacts with Co^{2+}*(aq)* to produce Co*(s)*.

   (i) Write the balanced equation for the oxidation half reaction.

   (ii) Write the balanced net-ionic equation for the overall reaction.

   (iii) Calculate the standard potential, $E°$, for the overall reaction at 25°C.

(b) At 25°C, H_2O_2 decomposes according to the following equation.

$$2\ H_2O_2(aq) \rightarrow 2\ H_2O(l) + O_2(g) \quad E° = 0.55\ V$$

   (i) Determine the value of the standard free energy change, $\Delta G°$, for the reaction at 25°C.

   (ii) Determine the value of the equilibrium constant, K_{eq}, for the reaction at 25°C.

   (iii) The standard reduction potential, $E°$, for the half reaction $O_2(g) + 4\ H^+(aq) + 4\ e^- \rightarrow 2\ H_2O(l)$ has a value of 1.23 V. Using this information in addition to the information given above, determine the value of the standard reduction potential, $E°$ for the half reaction below.

$$O_2(g) + 2\ H^+(aq) + 2\ e^- \rightarrow H_2O_2(aq)$$

(c) In an electrolytic cell, Cu*(s)* is produced by the electrolysis of $CuSO_4$*(aq)*. Calculate the maximum mass of Cu*(s)* that can be deposited by a direct current of 100. amperes passed through 5.00 L of 2.00 *M* $CuSO_4$*(aq)* for a period of 1.00 hour.

1981 D

A solution of $CuSO_4$ was electrolyzed using platinum electrodes by passing a current through the solution. As a result, there was a decrease in both [Cu^{2+}] and the solution pH; one electrode gained in weight a gas was evolved at the other electrode.

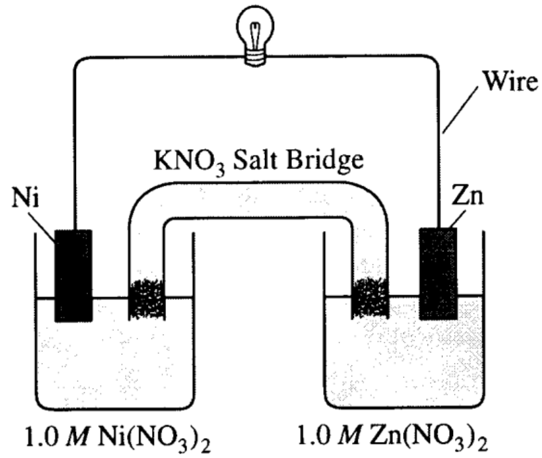
(a) Write the cathode half reaction that is consistent with the observations above.

(b) Write the anode half reaction that is consistent with the observations above.

(c) Sketch an apparatus that can be used for such an experiment and label its necessary components.

(d) List the experimental measurements that would be needed in order to determine from such an experiment the value of the faraday.

2001 D



Answer the following questions that refer to the galvanic cell shown in the diagram above. (A table of standard reduction potentials is printed on the green insert and on page 4 of the booklet with the pink cover.)

(a) Identify the anode of the cell and write the half reaction that occurs there.

(b) Write the net ionic equation for the overall reaction that occurs as the cell operates and calculate the value of the standard cell potential, E°_{cell}.

(c) Indicate how the value of E_{cell} would be affected if the concentration of $Ni(NO_3)_2$*(aq)* was changed from 1.0 *M* to 0.10 *M* and the concentration of $Zn(NO_3)_2$*(aq)* remained at 1.0 *M*. Justify your answer.

(d) Specify whether the value of K_{eq} for the cell reaction is less than 1, greater than 1, or equal to 1. Justify your answer.

2002 B

Answer parts (a) through (e) below, which relate to reactions involving silver ion, Ag^+.

The reaction between silver ion and solid zinc is represented by the following equation.

$$2\ Ag^+(aq) + Zn(s) \rightarrow Zn^{2+}(aq) + 2\ Ag(s)$$

(a) A 1.50 g sample of Zn is combined with 250. mL of 0.110 *M* $AgNO_3$ at 25˚C.

(i) Identify the limiting reactant. Show calculations to support your answer.

(ii) On the basis of the limiting reactant that you identified in part (i), determine the value of $[Zn^{2+}]$ after the reaction is complete. Assume that volume change is negligible.

(b) Determine the value of the standard potential, E°, for a galvanic cell based on the reaction between $AgNO_3$*(aq)* and solid Zn at 25˚C.

Another galvanic cell is based on the reaction between Ag^+*(aq)* and Cu*(s)*, represented by the equation below. At 25˚C, the standard potential, E°, for the cell is 0.46 V.

$$2\ Ag^+(aq) + Cu(s) \rightarrow Cu^{2+}(aq) + 2\ Ag(s)$$

(c) Determine the value of the standard free-energy change, ΔG°, for the reaction between Ag^+*(aq)* and Cu*(s)* at 25˚C.

(d) The cell is constructed so that $[Cu^{2+}]$ is 0.045 *M* and $[Ag^+]$ is 0.010 *M*. Calculate the value of the potential, *E*, for the cell.

(e) Under the conditions specified in part (d), is the reaction in the cell spontaneous? Justify your answer.

1974 B

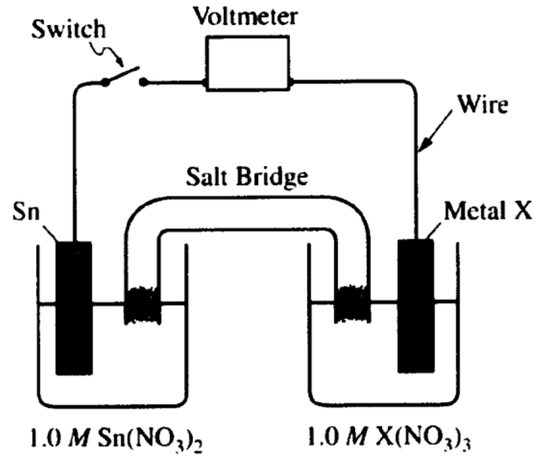
A steady current of 1.00 ampere is passed through an electrolytic cell containing a 1 molar solution of $AgNO_3$ and having a silver anode and a platinum cathode until 1.54 grams of silver is deposited.

(a) How long does the current flow to obtain this deposit?

(b) What weight of chromium would be deposited in a second cell containing 1–molar chromium(III) nitrate and having a chromium anode and a platinum cathode by the same current in the same time as was used in the silver cell?

(c) If both electrodes were platinum in this second cell, what volume of O_2 gas measured at standard temperature and pressure would be released at the anode while the chromium is being deposited at the cathode? The current and the time are the same as in (b)

2004 D Required



An electrochemical cell is constructed with an open switch, as shown in the diagram above. A strip of Sn and a strip of unknown metal, X are used as electrodes. When the switch is closed, the mass of the Sn electrode increases. The half-reactions are shown below.

$Sn^{2+}(aq) + 2e^- \rightarrow Sn(s)$ $\qquad E° = -0.14$ V

$X^{3+}(aq) + 3e^- \rightarrow X(s)$ $\qquad E° = ?$

(a) In the diagram above, label the electrode that is the cathode. Justify your answer.

(b) In the diagram above, draw an arrow indicating the direction of electron flow in the external circuit when the switch is closed.

(c) If the standard cell potential $E°_{cell}$ is +0.60 V, what is the standard potential, in volts for the X^{3+}/X electrode?

(d) Identify metal X.

(e) Write balanced net-ionic equation for the overall chemical reaction occurring in the cell.

(f) In the cell, the concentration of Sn^{2+} is changed from 1.0 *M* to 0.50 *M*, and the concentration of X^{3+} is changed from 1.0 *M* to 0.10 *M*.

(i) Substitute all appropriate values for determining the cell potential, E_{cell}, into the Nernst equation. (Do <u>not</u> do any calculations.)

(ii) On the basis of your response in (f) (i), will the cell potential be greater than, less than, or equal to $E°_{cell}$? Justify your answer.

1972

$$Br_2 + 2\,Fe^{2+}(aq) \rightarrow 2\,Br^-(aq) + 2\,Fe^{3+}(aq)$$

For the reaction above, the following data are available:

$2\,Br^-(aq) \rightarrow Br_2(l) + 2e^-$	$E° =$	-1.07 volts
$Fe^{2+}(aq) \rightarrow Fe^{3+}(aq) + e^-$	$E° =$	-0.77 volts

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$S°$, cal/mole·K

$Br_2(l)$ 58.6	$Fe^{2+}(aq)$ -27.1
$Br^-(aq)$ 19.6	$Fe^{3+}(aq)$ -70.1

(a) Determine $\Delta S°$ (b) Determine $\Delta G°$ (c) Determine $\Delta H°$

1973 B

$$Sn + 2\,Ag^+ \rightarrow Sn^{2+} + 2\,Ag$$

(a) Calculate the standard voltage of a cell involving the system above.

(b) What is the equilibrium constant for the system above?

(c) Calculate the voltage at 25°C of a cell involving the system above when the concentration of Ag^+ is 0.0010 molar and that of Sn^{2+} is 0.20 molar.

2005 D

$$AgNO_3(s) \rightarrow Ag^+(aq) + NO_3^-(aq)$$

The dissolving of $AgNO_3(s)$ in pure water is represented by the equation above..

(a) Is ΔG for the dissolving of $AgNO_3(s)$ positive, negative, or zero? Justify your answer.

(b) Is ΔS for the dissolving of $AgNO_3(s)$ positive, negative, or zero? Justify your answer.

(c) The solubility of $AgNO_3(s)$ increases with increasing temperature.

(i) What is the sign of ΔH for the dissolving process? Justify your answer.

(ii) Is the answer you gave in part (a) consistent with your answers to parts (b) and (c) (i)? Explain.

The compound NaI dissolves in pure water according to the equation $NaI(s) \rightarrow Na^+(aq) + I^-(aq)$. Some of the information in the table of standard reduction potentials given below may be useful in answering the questions that follow.

Half-reaction	E° (V)
$O_2(g) + 4\ H^+ + 4\ e^- \rightarrow 2\ H_2O(l)$	1.23
$I_2(s) + 2\ e^- \rightarrow 2\ I^-$	0.53
$2\ H_2O(l) + 2\ e^- \rightarrow H_2(g) + 2\ OH^-$	-0.83
$Na^+ + e^- \rightarrow Na(s)$	-2.71

(d) An electric current is applied to a 1.0 M NaI solution.

(i) Write the balanced oxidation half reaction for the reaction that takes place.

(ii) Write the balanced reduction half-reaction for the reaction that takes place.

(iii) Which reaction takes place at the anode, the oxidation reaction or the reduction reaction?

(iv) All electrolysis reactions have the same sign for ΔG°. Is the sign positive or negative? Justify your answer.

1988 B

An electrochemical cell consists of a tin electrode in an acidic solution of 1.00 molar Sn^{2+} connected by a salt bridge to a second compartment with a silver electrode in an acidic solution of 1.00 molar Ag^+.

(a) Write the equation for the half–cell reaction occurring at each electrode. Indicate which half–reaction occurs at the anode.

(b) Write the balanced chemical equation for the overall spontaneous cell reaction that occurs when the circuit is complete. Calculate the standard voltage, E°, for this cell reaction.

(c) Calculate the equilibrium constant for this cell reaction at 298K.

(d) A cell similar to the one described above is constructed with solutions that have initial concentrations of 1.00 molar Sn^{2+} and 0.0200 molar Ag^+. Calculate the initial voltage, E°, of this cell.

1985 B

(a) Titanium can be reduced in an acid solution from TiO^{2+} to Ti^{3+} with zinc metal. Write a balanced equation for the reaction of TiO^{2+} with zinc in acid solution.

(b) What mass of zinc metal is required for the reduction of a 50.00 millilitre sample of a 0.115 molar solution of TiO^{2+}?

(c) Alternatively, the reduction of TiO^{2+} to Ti^{3+} can be carried out electrochemically. What is the minimum time, in seconds, required to reduce another 50.000 millilitre sample of the 0.115 molar TiO^{2+} solution with a direct current of 1.06 amperes?

(d) The standard reduction potential, E°, for TiO^{2+} to Ti^{3+} is +0.060 volt. The standard reduction potential, E°, for Zn^{2+} to $Zn_{(s)}$ is -0.763 volt. Calculate the standard cell potential, E°, and the standard free energy change, ΔG°, for the reaction described in part (a).