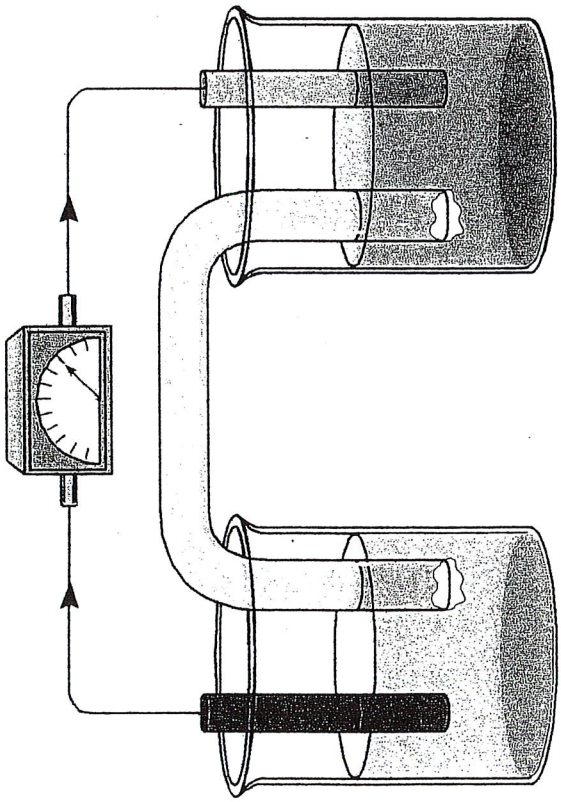
Chapter 18

electrochemistry



AP Chemistry

Name _____

Period ___ Date ___/___/___

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NChO Practice Problems

1998

40. For this reaction, $E°_{cell} = 0.79$ V.

$6I^-(aq) + Cr_2O_7^{2-}(aq) + 14H^+ \rightarrow 3I_2(aq) + 2Cr^{3+}(aq) + 7H_2O(aq)$

Given that the standard reduction potential for $Cr_2O_7^{2-}(aq) \rightarrow 2Cr^{3+}(aq)$ is 1.33 V, what is $E°_{red}$ for $I_2(aq)$?

a) +0.54 V b) -0.54 V
c) +0.18 V d) -0.18 V

41. What is the product formed at the anode in the electrolysis of 1.0 M $NaNO_3$(aq)?

a) $H_2(g)$ b) $NO_2(g)$
c) $O_2(g)$ d) Na(s)

42. Which of these ions is the best reducing agent?

Standard Reduction Potentials, E°	
$Fe^{3+}(aq) + e^- \rightarrow Fe^{2+}(aq)$	+0.77 V
$Cu^{2+}(aq) + e^- \rightarrow Cu^+(aq)$	+0.15 V

a) Fe^{3+} b) Fe^{2+}
c) Cu^{2+} d) Cu^+

43. $Zn(s) + Cl_2(g, 1\ atm) \rightleftharpoons Zn^{2+}(aq, 1\ M) + 2Cl^-(aq, 1\ M)$

An electrochemical cell based on this reaction has a cell voltage, E°, of 2.12 V. Which change could make the cell voltage greater than 2.12 V?

a) add more Zn(s)
b) add more Cl^-(aq) ions
c) decrease the concentration of Zn^{2+}(aq) ions
d) decrease the partial pressure of Cl_2

1997

43. What is the function of H_2O_2 in this reaction?

$6H^+ + 2MnO_4^- + 5H_2O_2 \rightarrow 2Mn^{2+} + 5O_2 + 8H_2O$

a) catalyst b) reducing agent
c) oxidizing agent d) inhibitor

44. How much hydrogen is produced from the electrolysis of water in the same time that 2.2 L of oxygen is formed?

a) 0.14 L b) 1.1 L
c) 2.2 L d) 4.4 L

45. Which of these changes will cause the value of the potential for this half-reaction to be less negative? (E° = -0.28 V for the reaction.)

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

a) increasing the amount of solid Co
b) decreasing the amount of solid Co
c) increasing the concentration of Co^{2+}(aq)
d) decreasing the concentration of Co^{2+}(aq)

1996

43. Use these reduction potentials to determine which one of the reactions below is spontaneous.

Reaction	Reduction Potentials, E°
$Ag^+ + e^- \rightarrow Ag$	0.800 V
$Pb^{2+} + 2e^- \rightarrow Pb$	- 0.126 V
$V^{2+} + 2e^- \rightarrow V$	- 1.18 V

a) $V^{2+} + 2\ Ag \rightarrow V + 2\ Ag^+$
b) $V^{2+} + Pb \rightarrow V + Pb^{2+}$
c) $2\ Ag^+ + Pb^{2+} \rightarrow 2\ Ag + Pb$
d) $2\ Ag^+ + Pb \rightarrow 2\ Ag + Pb^{2+}$

44. It is possible to produce chlorine gas by electrolyzing any of these chlorine-containing compounds under the proper conditions. Which compound will require the smallest number of coulombs to produce one mole of chlorine?

a) $Ca(OCl)_2$ b) $NaClO_2$
c) $KClO_3$ d) $Mg(ClO_4)_2$

1994

46. If solid nickel metal were added to separate aqueous solutions each containing 1M concentrations of Ag^+, Cd^{2+}, and Sn^{2+} ions, how many metals would plate out, based on the given standard reaction potentials?

Standard Reduction Potentials

Ag^+/Ag	0.799 V
Sn^{2+}/Sn	-0.141 V
Ni^{2+}/Ni	-0.236 V
Cd^{2+}/Cd	-0.400 V

a) zero b) one
c) two d) three

48. Solutions of Ag^+, Cu^{2+}, Fe^{3+} and Ti^{4+} are electrolyzed with a constant current until 0.10 mol of metal is deposited. Which will require the greatest length of time?

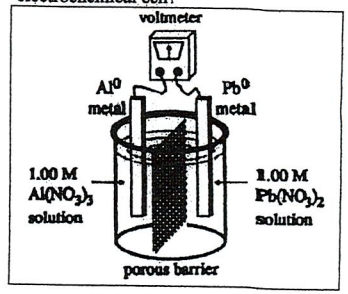
a) Ag^+ b) Cu^{2+}
c) Fe^{3+} d) Ti^{4+}

1993

67. How many grams of cobalt metal will be deposited when a solution of cobalt(II) chloride is electrolyzed with a current of 10. amperes for 109 minutes?

a) 0.66 b) 4.0
c) 20 d) 40

66. What voltage will be produced by the electrochemical cell?



Reduction Potentials

$Pb^{2+} + 2e^- \rightarrow Pb$ -0.13 V

$Al^{3+} + 3e^- \rightarrow Al$ -1.68 V

a) 2.97V b) 1.55V
c) -1.81V d) -2.97V

1992

59. A spoon is made the cathode in an electroplating apparatus containing a $AgNO_3$ solution. How many grams of Ag will be plated on the spoon if a current of 2.00 A is passed through the apparatus for 1.90 min.?

a) 0.255 g b) 0.150 g
c) 0.128 g d) 0.0638 g

60. A cell is set up using the following reactions:

$Zn \mid Zn^{2+}\ (0.5M) \parallel Ni^{2+}\ (0.1\ M) \mid Ni$

$Ni^{2+} + 2e^- \rightarrow Ni \quad E° = -0.250$ V

$Zn^{2+} + 2e^- \rightarrow Zn \quad E° = -0.763$ V

What is the voltage of the cell?

a) -0.513 V b) -1.013 V
c) 0.492 V d) 0.513 V

Answers:

1998	40 a, 41 c, 42 d, 43 c
1997	43 b, 44 d, 45 c
1996	43 d, 44 a
1994	46 c, 48 d
1993	67 c, 66 b
1992	59 a, 60 c

AP Chemistry

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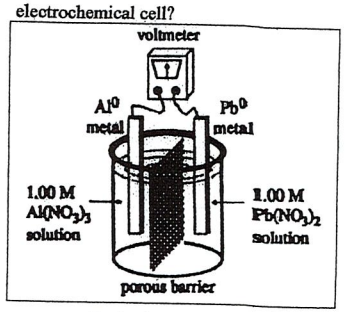

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Electron Transfer Reactions

ELECTROCHEMICAL CELL WORKSHEET

Consider the reduction potential chart. Find and copy the reduction equations for $Ag^+ \rightarrow Ag°$ and $Pb^{2+} \rightarrow Pb°$. Be sure to include their reduction potentials (in volts).

1. Which metal ion has the greater reduction potential? ____
2. If these two metals (and their solutions) were used to create a galvanic cell, which metal would be the anode? ____
3. Write the reaction at the anode: _____
4. Write the reaction at the cathode: _____
5. What is the overall reaction? _____
6. What would be the voltage of the standard electrochemical cell? _____
7. Sketch the cell:

8. Write the cell notation for the cell: _____|_____||_____|_____
9. How many moles of electrons are involved in this reaction? n =_____

10. Find and copy down the Nernst Equation: _____
11. If a new cell is set up with the $[Ag^+] = 0.50$ M and the $[Pb^{2+}] = 2.0$ M, the cell voltage will be _____ (greater / less).
12. Use the Nernst equation to calculate the cell voltage with these new concentrations.

Name _____
Period ___ Date ___/___/___

Electrochemistry

ELECTROLYSIS WORKSHEET

Standard Reduction Potential	E° (volts)
$Cl_2(g) + 2e^- \rightarrow 2Cl^-(aq)$	+1.36
$O_2(g) + 4H^+(aq) + 4e^- \rightarrow 2H_2O(l)$	+1.23
$Ag^+(aq) + e^- \rightarrow Ag(s)$	+0.80
$I_2(s) + 2e^- \rightarrow 2I^-(aq)$	+0.535
$Cu^{2+}(aq) + 2e^- \rightarrow Cu(s)$	+0.337
$SO_4^{2-}(aq) + 4\ H^+(aq) + 2e^- \rightarrow SO_2(g) + 2\ H_2O$	+0.20
$2\ H^+(aq) + 2\ e^- \rightarrow H_2(g)$ (reference electrode)	0.00
$2H_2O(l) + 2e^- \rightarrow H_2(g) + 2OH^-(aq)$	-0.828
$Na^+(aq) + e^- \rightarrow Na(s)$	-2.714
$K^+(aq) + e^- \rightarrow K(s)$	-2.93

1. All of the equations in the chart above are written as _____ (oxidations/reductions).

2. The chemicals at the upper left (Cl_2 and O_2) are the most likely to be _____ (oxidized/reduced) and therefore the best _____ (oxidizing agents/reducing agents).

3. The chemicals at the lower right (Na and K) are the most likely to be _____ (oxidized/reduced) and therefore the best _____ (oxidizing agents/reducing agents).

4. In an electrolytic cell, the (–) electrode is negative because is has _____ (too many/too few) electrons. Chemicals that come into contact with the (–) electrode will _____ (gain/lose) electrons and be _____ (oxidized/reduced). The (–) electrode in electrolysis is called the _____ (cathode/anode).

5. Write the change that water goes through at the (–) electrode. _____

6. In an electrochemical cell, the (+) electrode is positive because is has _____ (too many/too few) electrons. Chemicals that come into contact with the (+) electrode will _____ (gain/lose) electrons and be _____ (oxidized/reduced). The (+) electrode in electrolysis is called the _____ (cathode/anode).

7. Write the change that water goes through at the (+) electrode. _____

8. Add these two reactions together (make certain the electrons cancel) and write the overall reaction for the electrolysis of water. _____

9. We will perform this electrolysis using an aqueous solution of sodium sulfate.
Both the Na^+ and H_2O will be near the (–) electrode. Which chemical is more likely to be reduced? ____

10. Both the SO_4^{2-} and H_2O will be near the (+) electrode. Which chemical will be oxidized? ____

11. In the electrolysis of KI(aq)
Both the K^+ and H_2O will be near the (–) electrode. Which chemical is more likely to be reduced? ____
Both the I^- and H_2O will be near the (+) electrode. Which chemical is more likely to be oxidized? ____
Write the reactions at each electrode and the overall reaction:

Cathode:

Anode:

Overall:

12. In the electrolysis of $CuSO_4$(aq)
Both the Cu^{2+} and H_2O will be near the (–) electrode. Which chemical will be reduced? ____
Both the SO_4^{2-} and H_2O will be near the (+) electrode. Which chemical will be oxidized? ____
Write the reactions at each electrode and the overall reaction:

Cathode:

Anode:

Overall:

13. Silver plating occurs when electrolysis of a Ag_2SO_4 solution is used because silver metal is formed at the _____ (cathode/anode).
This is the (__) (+ / –)electrode. The reaction at this electrode is: _____.

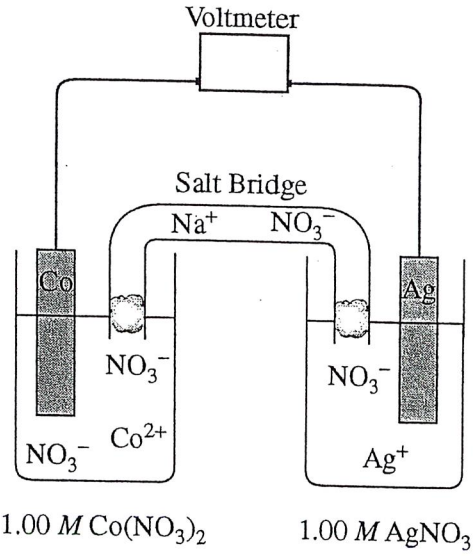
Recall that 1 amp·sec = 1 Coulomb and 96,500 Coulombs = 1 mole e^-'s (Faraday's constant).
If a cell is run for 200. seconds with a current of 0.250 amps, how many grams of Ag° will be deposited?

14. A current of 10.0 amperes flows for 2.00 hours through an electrolytic cell containing a molten salt of metal X. This results in the decomposition of 0.250 mole of metal X at the cathode. The oxidation state of X in the molten salt is ____ (X^+, X^{2+}, X^{3+}, X^{4+})

15. Solutions of Ag^+, Cu^{2+}, Fe^{3+} and Ti^{4+} are electrolyzed with a constant current until 0.10 mol of metal is deposited. Which will require the greatest length of time? _____

Answer Question 5 and Question 6. The Section II score weighting for these questions is 15 percent each.

Your responses to these questions will be graded on the basis of the accuracy and relevance of the information cited. Explanations should be clear and well organized. Examples and equations may be included in your responses where appropriate. Specific answers are preferable to broad, diffuse responses.



5. Answer the following questions relating to the galvanic cell shown in the diagram above.

   (a) Write the balanced equation for the overall cell reaction.

   (b) Calculate the value of $E°$ for the cell.

   (c) Is the value of $\Delta G°$ for the overall cell reaction positive, negative, or 0 ? Justify your answer.

   (d) Consider the cell as it is operating.

      (i) Does E_{cell} increase, decrease, or remain the same? Explain.

      (ii) Does ΔG of the overall cell reaction increase, decrease, or remain the same? Explain.

      (iii) What would happen if the $NaNO_3$ solution in the salt bridge was replaced with distilled water? Explain.

   (e) After a certain amount of time, the mass of the Ag electrode changes by x grams. Given that the molar mass of Ag is 108 g mol^{-1} and the molar mass of Co is 59 g mol^{-1}, write the expression for the change in the mass of the Co electrode in terms of x.

Question 6

Answer each of the following using principles of atomic or molecular structure and/or intermolecular or intramolecular forces.

(a) Explain why the H–O–H bond angle in H_2O is less than the H–N–H bond angles in NH_3, as shown in the table below.

H–O–H Bond Angle in H_2O	H–N–H Bond Angles in NH_3
104.5°	107°

	One point is earned for citing the difference in number of nonbonding pairs of electrons. One point is earned for citing the greater repulsion from nonbonding pairs as compared with bonding pairs.

(b) Explain why the radius of the Br atom is less than the radius of the Br^- ion, as shown in the table below.

Radius of Br	Radius of Br^-
0.111 nm	0.196 nm

	One point is earned for recognition that Br and Br^- have the same nuclear charge. One point is earned for citing increased repulsion among electrons.

Name: _____

Electro Chemistry Review

1. Which of the following is the correct cell notation for the reaction

$Hg_2^{2+} + Cd(s) \rightarrow Cd^{2+} + 2Hg(l)$

a) $Cd^{2+} \mid Cd \mid\mid Hg_2^{2+} \mid Hg$
b) $Cd^{2+} \mid Hg_2^{2+} \mid\mid Cd \mid Hg$
c) $Cd \mid Cd^{2+} \mid\mid Hg_2^{2+} \mid Hg$
d) $Cd^{2+} \mid Hg \mid\mid Hg_2^{2+} \mid Cd$
e) $Hg \mid Cd \mid\mid Hg_2^{2+} \mid Cd^{2+}$

2. Consider an electrochemical cell where the following reaction takes place:

$3Sn^{2+}(aq) + 2Al(s) \rightarrow 3Sn(s) + 2Al^{3+}(aq)$

Which of the following is the correct cell notation for this cell?

a) $Al \mid Al^{3+} \mid\mid Sn^{2+} \mid Sn$
b) $Al^{3+} \mid Al \mid\mid Sn \mid Sn^{2+}$
c) $Sn \mid Sn^{2+} \mid\mid Al^{3+} \mid Al$
d) $Sn \mid Al^{3+} \mid\mid Al \mid Sn^{2+}$
e) $Al \mid Sn^{2+} \mid\mid Sn \mid Al^{3+}$

Standard Reduction Potentials at 25°C	**E° (volts)**
$F_2(g) + 2e^- \rightarrow 2F^-(aq)$	+2.87
$Au^{3+} + 3e^- \rightarrow Au(s)$	+1.50
$Cl_2(g) + 2e^- \rightarrow 2Cl^-(aq)$	+1.36
$O_2(g) + 4H_3O^+(aq) + 4e^- \rightarrow 6H_2O(l)$	+1.23
$Br_2(l) + 2e^- \rightarrow 2Br^-(aq)$	+1.08
$Ag^+(aq) + e^- \rightarrow Ag(s)$	+0.80
$Hg_2^{2+}(aq) + 2e^- \rightarrow 2Hg(l)$	+0.79
$I_2(s) + 2e^- \rightarrow 2I^-(aq)$	+0.535
$Cu^{2+}(aq) + 2e^- \rightarrow Cu(s)$	+0.337
$Sn^{4+}(aq) + 2e^- \rightarrow Sn^{2+}(aq)$	+0.15
$Sn^{2+}(aq) + 2e^- \rightarrow Sn(s)$	-0.14
$Cd^{2+}(aq) + 2e^- \rightarrow Cd(s)$	-0.40
$Zn^{2+}(aq) + 2e^- \rightarrow Zn(s)$	-0.763
$2H_2O(l) + 2e^- \rightarrow H_2(g) + 2OH^-(aq)$	-0.828
$Al^{3+}(aq) + 3e^- \rightarrow Al(s)$	-1.66
$K^+(aq) + e^- \rightarrow K(s)$	-2.93
$Li^+(aq) + e^- \rightarrow Li(s)$	-3.045

3. Given the two half reactions and their potentials, which net reaction is spontaneous?

$Ni^{2+}(aq) + 2e^- \rightarrow Ni(s)$ $\quad E° = -0.25$ V
$Mg^{2+}(aq) + 2e^- \rightarrow Mg(s)$ $\quad E° = -2.37$ V

a) $Ni(s) + Mg^{2+}(aq) \rightarrow Mg(s) + Ni^{2+}(aq)$
b) $Ni^{2+}(aq) + Mg(s) \rightarrow Mg^{2+}(aq) + Ni(s)$
c) $Ni(s) + Mg(s) \rightarrow Mg^{2+}(aq) + Ni^{2+}(aq)$
d) $Mg^{2+}(aq) + Ni^{2+}(aq) \rightarrow Mg(s) + Ni(s)$
e) $Mg^{2+}(aq) + Mg(s) \rightarrow Ni(s) + Ni^{2+}(aq)$

4. Calculate E° for the following reaction:

$Sn^{4+}(aq) + 2K(s) \rightarrow Sn^{2+}(aq) + 2K^+(aq)$

a) +6.00 V
b) -3.08 V
c) +3.08 V
d) +2.78 V
e) -2.78 V

5. Calculate E° for the following reaction:

$2Al^{3+}(aq) + 3Cd(s) \rightarrow 2Al(s) + 3Cd^{2+}(aq)$

a) -2.06 V
b) +4.52 V
c) +2.06 V
d) -4.52 V
e) -1.26 V

6. Using data from the reduction potential table and the reaction

$2Ag(s) + Pt^{2+}(aq) \rightarrow Pt(s) + 2Ag^+(aq)$ $\quad E° = 0.38$ V

calculate the standard reduction potential of the half-reaction

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

a) -1.18 V
b) -0.40 V
c) 0.40 V
d) 1.18 V
e) 2.00 V

7. Using data from the reduction potential table, predict which of the following is the best *oxidizing* agent.

a) F_2
b) Ag
c) Sn^{4+}
d) Ag^+
e) Al^{3+}

8. An electrochemical cell of notation $Pd \mid Pd^{2+} \mid\mid Cu^{2+} \mid Cu$ has an $E° = -0.65$ V. If we know that the standard reduction potential of Cu^{2+}/Cu is $E° = 0.34$ V, what is the standard reduction potential for Pd^{2+}/Pd?

a) -0.99 V
b) -0.31 V
c) +0.31 V
d) 0.62 V
e) +0.99 V

9. The standard cell potential for
$3Sn^{4+}(aq) + 2Al(s) \rightarrow 3Sn^{2+}(aq) + 2Al^{3+}(aq)$
is $E° = 1.81$ V. What is E_{cell} when
$[Sn^{4+}] = 1.0$,
$[Sn^{2+}] = 1.0 \times 10^{-2}$, and
$[Al^{3+}] = 1.5 \times 10^{-3}$ at 298 K.

a) 1.70 V
b) 1.76 V
c) 1.81 V
d) 1.86 V
e) 1.93 V

10. Predict the product at the anode when electric current is passed through a solution of KI.

a) $I_2(l)$
b) $K^+(aq)$
c) $H_2(g)$
d) $K(s)$
e) $O_2(g)$

11. If electric current is passed through aqueous LiBr, the product at the cathode would be _____ and the product at the anode would be _____.

a) $H_2O(l)$, $Li^+(aq)$
b) $Br_2(l)$, $Li(s)$
c) $Li(s)$, $Br_2(l)$
d) $Br_2(l)$, $H_2(g)$
e) $H_2(g)$, $Br_2(l)$

12. How long would it take to deposit 1.36 g of copper from an aqueous solution of copper(II) sulfate by passing a current of two amperes through the solution?

a) 2070 sec
b) 1.11×10^{-5} sec
c) 2570 sec
d) 736 sec
e) 1030 sec

13. If a current of 6.0 amps is passed through a solution of Ag^+ for 1.5 hours, how many grams of silver are produced?

a) 0.60 g
b) 36 g
c) 0.34 g
d) 3.0 g
e) 1.0 g

14. Balance the following redox equation which occurs in acidic solution.

$N_2H_4(g) + BrO_3^-(aq) \rightarrow Br^-(aq) + N_2(g)$

a) $3N_2H_4 + BrO_3^- \rightarrow 3N_2 + Br^- + 3H_2O + 6H^+$
b) $N_2H_4 + BrO_3^- + 2H^+ \rightarrow 2Br^- + N_2 + 3H_2O$
c) $3N_2H_4 + 2BrO_3^- + 12H^+ \rightarrow 3N_2 + 2Br^- + 6H_2O + 12H^+$
d) $N_2H_4 + 2BrO_3^- + 8H^+ \rightarrow 2Br^- + N_2 + 6H_2O$
e) $3N_2H_4 + 2BrO_3^- \rightarrow 3N_2 + 2Br^- + 6H_2O$

15. Which of the following reactions is NOT a redox reaction?

a) $2HgO(s) \rightarrow 2\ Hg(l) + O_2(g)$
b) $H_2(g) + Br_2(g) \rightarrow 2HBr(g)$
c) $2HCl(aq) + Zn(s) \rightarrow H_2(g) + ZnCl_2(aq)$
d) $H_2CO_3(aq) \rightarrow H_2O(l) + CO_2(g)$
e) $2KClO_3 \rightarrow 2KCl(s) + 3\ O_2(g)$

Push Problems