Name _____ Date _____ Class _____

CHAPTER 21 STUDY GUIDE FOR CONTENT MASTERY

Electrochemistry

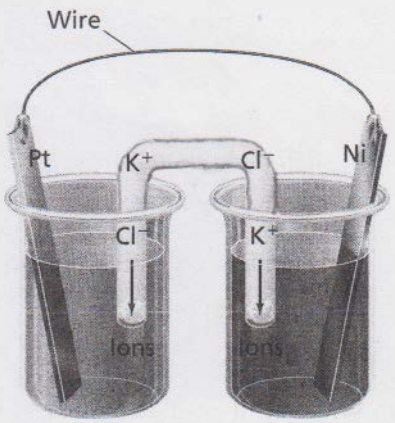
Section 21.1 Voltaic Cells

In your textbook, read about redox in electrochemistry.

Use each of the terms below just once to complete the passage.

voltaic	electrochemical cell	electric current	salt bridge	battery

Oxidation and reduction reactions can occur in separate solutions, as long as there are two connections between the solutions. One connection is a(n) **(1)** _____ through which ions can flow. The other connection is a metal wire through which electrons can flow. The flow of ions or electrons is known as a(n) **(2)** _____. The complete setup, called a(n) **(3)** _____, can convert chemical energy into electrical energy or electrical energy into chemical energy. Cells that convert chemical energy to electrical energy by a spontaneous redox reaction are called **(4)** _____ cells. Several electrochemical cells in a single package are called a **(5)** _____.



Use the diagram of an electrochemical cell to answer the following questions.

6. The equation at the bottom of each beaker shows the half-reaction that is occurring in that beaker. What kind of reaction (oxidation or reduction) is occurring in each beaker?

   Left beaker _____

   Right beaker _____

7. Write the net ionic equation for this electrochemical cell.

   _____

8. In which direction do electrons move through the wire?

   _____

9. What kind of ions (positive or negative) move from the ∩-shaped tube into each beaker?

   Left beaker _____ Right beaker _____

In your textbook, read about the chemistry of voltaic cells.

For each item in Column A, write the letter of the matching item in Column B.

Column A	Column B
_____ **10.** One of the two parts of an electrochemical cell, where either oxidation or reduction takes place	**a.** battery
_____ **11.** An electrode where oxidation takes place	**b.** electrical potential
_____ **12.** An electrode where reduction takes place	**c.** half-cell
_____ **13.** One or more electrochemical cells in a single package that generates electrical current	**d.** cathode
_____ **14.** A measure of the amount of current that can be generated from an electrochemical cell to do work	**e.** anode

In your textbook, read about calculating cell electrochemical potential.

Circle the letter of the choice that best completes the statement or answers the question.

15. The tendency of an electrode to gain electrons is called

a. electron potential.
b. gravitational potential.
c. reduction potential.
d. oxidation potential.

16. A sheet of platinum covered with finely divided platinum particles is immersed in a 1*M* HCl solution containing hydrogen gas at a pressure of 1 atm and a temperature of 25°C. The platinum sheet is known as a

a. standard platinum electrode.
b. standard hydrogen electrode.
c. hydrogen chloride electrode.
d. platinum chloride electrode.

17. The standard reduction potential of a half-cell is a measure of

a. concentration.
b. pressure.
c. temperature.
d. voltage.

18. Which of the following is the correct way to represent the equation, $H_2(g) + Cu^{2+}(aq) \rightarrow 2H^+(aq) + Cu(s)$?

a. $H_2|H^+\|Cu^{2+}|Cu$
b. $H^+|H_2\|Cu|Cu^{2+}$
c. $Cu^{2+}|Cu\|H_2|H^+$
d. $Cu|Cu^{2+}\|H^+|H_2$

19. When connected to a hydrogen electrode, an electrode with a negative standard reduction potential will carry out

a. reduction.
b. oxidation.
c. both oxidation and reduction.
d. neither oxidation nor reduction.

Section *continued*

In your textbook, read about calculating cell electrochemical potential.

Use the table of standard reduction potentials below to answer the following questions.

Half-reaction	E^0 (volts)
$Al^{3+} + 3e^- \rightarrow Al$	−1.662
$Ga^{3+} + 3e^- \rightarrow Ga$	−0.549
$Tl^{3+} + 3e^- \rightarrow Tl$	+0.741

20. Suppose you have two voltaic cells whose half-cells are represented by the following pairs of reduction half-reactions. For each voltaic cell, identify which half-reaction will proceed in the forward direction as a reduction and which will proceed in the reverse direction as an oxidation.

Voltaic Cell #1		Voltaic Cell #2	
$Al^{3+}(aq) + 3e^- \rightarrow Al(s)$	_____	$Tl^{3+}(aq) + 3e^- \rightarrow Tl(s)$	_____
$Ga^{3+}(aq) + 3e^- \rightarrow Ga(s)$	_____	$Ga^{3+}(aq) + 3e^- \rightarrow Ga(s)$	_____

21. Calculate the cell standard potential, E^0_{cell}, of each voltaic cell in question 20.

Voltaic Cell #1: _____

Voltaic Cell #2: _____

In your textbook, read about using standard reduction potentials.

Use the table of standard reduction potentials at the top of this page to answer the following questions.

22. Write the reduction and oxidation half-reactions for the following reaction:

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

reduction half-reaction: _____

oxidation half-reaction: _____

23. What is the standard reduction potential, E^0, for each half-reaction in question 22?

$E^0_{reduction}$: _____ $E^0_{oxidation}$: _____

24. Calculate the cell standard potential, E^0_{cell}, for the reaction in question 22.

_____

25. Will the reaction in question 22 occur spontaneously as written? Explain why or why not.

_____

26. Will the reverse reaction, $Tl^{3+}(aq) + Al(s) \rightarrow Tl(s) + Al^{3+}(aq)$, occur spontaneously? Explain why or why not.

_____

Understanding Main Ideas (Part B)

Answer the following question.

1. Suppose you are given the two half-reactions that are involved in an electrochemical cell. How do you decide which half-reaction will proceed as a reduction and which will proceed as an oxidation?

_____

_____

_____

Use the table of standard reduction potentials below to answer the following questions.

Half-reaction	E^0 (volts)
$Cr^{2+} + 2e^- \rightarrow Cr$	−0.913
$Fe^{2+} + 2e^- \rightarrow Fe$	−0.447
$Cd^{2+} + 2e^- \rightarrow Cd$	−0.4030
$Br_2 + 2e^- \rightarrow 2Br^-$	+1.06

2. For each of these pairs of half-reactions, write a balanced equation for the overall cell reaction and calculate the standard cell potential, E^0_{cell}.

   a. Half-reactions: $Cd^{2+}(aq) + 2e^- \rightarrow Cd(s)$ $Cr^{2+}(aq) + 2e^- \rightarrow Cr(s)$

   Cell reaction: _____

   E^0_{cell}: _____

   _____

   b. Half-reactions: $Fe^{2+}(aq) + 2e^- \rightarrow Fe(s)$ $Br_2(g) + 2e^- \rightarrow 2Br^-(aq)$

   Cell reaction: _____

   E^0_{cell}: _____

   _____

3. Calculate E^0_{cell} for $Cr + Br_2 \rightarrow Cr^{2+} + 2Br^-$. Will this reaction occur spontaneously as written?

_____

_____

Applying Scientific Methods, *continued*

The first battery, made by Alessandro Volta in 1800, consisted of a series of alternating zinc and sliver plates separated by layers of cloth soaked with salt solution. The plates served as electrodes, and the cloth layers served as salt bridges. Volta's battery is diagrammed in the figure (below left). Use the table of standard reduction potentials (below right) to answer the following questions about Volta's battery.

Half-reaction	E^0 (volts)
$Zn^{2+} + 2e^- \rightarrow Zn$	−0.7618
$Sn^{2+} + 2e^- \rightarrow Sn$	−0.1375
$Cu^{2+} + 2e^- \rightarrow Cu$	+0.3419
$Ag^+ + e^- \rightarrow Ag$	+0.7996

1. Write the half-reaction that occurs at each zinc electrode. Is this reaction an oxidation or a reduction?

2. Write the halfreaction that occurs at each silver electrode. Is this reaction an oxidation or a reduction?

3. What voltage, E^0_{cell}, would each cell in the battery produce under standard conditions?

4. Some of the batteries Volta made had as many as 60 cells. What voltage, $E^0_{battery}$, would a zinc–silver battery with 60 cells produce under standard conditions?

5. Volta also made copper–zinc, copper–silver, copper–tin, tin–zinc, and tin–silver batteries. Of all of Volta's batteries, which would produce the largest voltage under standard conditions? Assume that all batteries have the same number of cells. Explain your reasoning.

Section 21.3 Electrolysis

In your textbook, read about reversing redox reactions and electrolysis.

In the space at the left, write the word or phrase in parentheses that correctly completes the statement.

_____ **1.** When a battery is being recharged, its redox reaction is reversed and energy is (absorbed, released) by the battery.

_____ **2.** The use of electrical energy to cause a chemical reaction is called (combustion, electrolysis).

_____ **3.** An electrochemical cell in which electrolysis is occurring is called an (electrolytic, exothermic) cell.

_____ **4.** In a Down's cell, sodium metal and chlorine gas are produced from (molten, solid) sodium chloride.

_____ **5.** The electrolysis of brine involves applying current to an aqueous solution of (hydrochloric acid, sodium chloride).

_____ **6.** The commercially important products of the electrolysis of brine are hydrogen gas, chlorine gas, and (oxygen gas, sodium hydroxide).

In your textbook, read about the purification of metallic ores, electroplating, and aluminum manufacture.

Answer the following questions.

7. Copper can be produced by heating Cu_2S in the presence of oxygen. Why must the copper then be subjected to electrolysis?

_____

_____

8. When an object is electroplated with silver, what is the anode and what is the cathode?

anode _____

cathode _____

9. The manufacture of aluminum begins with the electrolysis of aluminum oxide, Al_2O_3. What half-reaction occurs at the cathode?

_____

10. Why are plants that produce aluminum often built close to large hydroelectric power stations?

_____

_____

Electrochemistry

Use data from Table 21.1 as needed in the following problems. Assume that all half-cells are under standard conditions.

1. For each of these pairs of half-reactions, write a balanced equation for the overall cell reaction and calculate the standard cell potential, E^0_{cell}.

a. $Cs^+(aq) + e^- \rightarrow Cs(s)$
$Cu^+(aq) + e^- \rightarrow Cu(s)$

Cell reaction:

$E^0_{cell} =$

b. $Hg^{2+}(aq) + 2e^- \rightarrow Hg(l)$
$Mn^{2+}(aq) + 2e^- \rightarrow Mn(s)$

Cell reaction:

$E^0_{cell} =$

c. $Fe^{3+}(aq) + 3e^- \rightarrow Fe(s)$
$Cr^{3+}(aq) + 3e^- \rightarrow Cr(s)$

Cell reaction:

$E^0_{cell} =$

d. $Br_2(g) + 2e^- \rightarrow 2Br^-(aq)$
$Au^+(aq) + e^- \rightarrow Au(s)$ $E^\circ = +1.69$ V

Cell reaction:

$E^0_{cell} =$

e. $Be^{2+}(aq) + 2e^- \rightarrow Be(s)$ $E^\circ = -1.85$
$Tl^{3+}(aq) + 3e^- \rightarrow Tl(s)$ $E^\circ = +0.74$

Cell reaction:

$E^0_{cell} =$

$NO_3^-(aq) + 4H^+(aq) + 3e^- \rightarrow NO(g) + 2H_2O(l)$
$In^{3+}(aq) + 3e^- \rightarrow In(s)$

Cell reaction:

$E^0_{cell} =$

$H_3PO_4(aq) + 2H^+(aq) + 2e^- \rightarrow H_3PO_3(aq) + H_2O(l)$
$SeO_4^{2-}(aq) + 4H^+(aq) + 2e^- \rightarrow H_2SeO_3(aq) + H_2O(l)$

Cell reaction:

$E^0_{cell} =$

$MnO_4^-(aq) + 8H^+(aq) + 5e^- \rightarrow Mn^{2+}(aq) + 4H_2O(l)$
$2CO_2(g) + 2H^+(aq) + 2e^- \rightarrow H_2C_2O_4(aq)$

Cell reaction:

$E^0_{cell} =$

2. Calculate the standard cell potential, E^0_{cell}, for a cell composed of a $Sn|Sn^{2+}$ half-cell and each of these half-cells.

Pd|Pd^{2+}

$E^0_{cell} =$

Hf|Hf^{4+}

$E^0_{cell} =$

c. $Cl_2|Cl^-$

$E^0_{cell} =$

d. Pb|Pb^{2+}

$E^0_{cell} =$

3. Which of the following cells will produce the highest voltage?

$Mn|Mn^{2+}\|Zn^{2+}|Zn$

$Zn|Zn^{2+}\|Ni^{2+}|Ni$

$Ni|Ni^{2+}\|Cu^{2+}|Cu$

4. For each of these overall cell reactions, write the oxidation and reduction half-reactions, calculate the standard cell potential, E^0_{cell}, and determine if the reaction is spontaneous or not.

a. $Fe^{3+}(aq) + Co^{2+}(aq) \rightarrow Fe^{2+}(aq) + Co^{3+}(aq)$

Oxidation half-reaction:

Reduction half-reaction:

$E^0_{cell} =$

Spontaneous?

b. $Fe^{3+}(aq) + Cu^{+}(aq) \rightarrow Fe^{2+}(aq) + Cu^{2+}(aq)$

Oxidation half-reaction:

Reduction half-reaction:

$E^0_{cell} =$

Spontaneous?

c. $3Ni^{2+}(aq) + 2Rh(s) \rightarrow 3Ni(s) + 2Rh^{3+}(aq)$

Oxidation half-reaction:

Reduction half-reaction:

$E^0_{cell} =$

Spontaneous?

$2Na^{+}(aq) + 2Hg(l) + 2I^{-}(aq) \rightarrow 2Na(s) + Hg_2I_2(s)$

Oxidation half-reaction:

Reduction halfreaction:

$E^0_{cell} =$

Spontaneous?

$O_2(g) + 2H_2SO_3(aq) \rightarrow 2SO_4^{2-}(aq) + 4H^{+}(aq)$

Oxidation half-reaction:

Reduction half-reaction:

$E^0_{cell} =$

Spontaneous?

Suppose a battery-powered device requires a minimum voltage of 9.0 V to run. How many lead–acid cells would be needed to run the device? (Remember that a standard automobile battery contains six lead–acid cells connected in one package.) The overall reaction of a lead–acid cell is

$Pb(s) + PbO_2(s) + 4H^{+}(aq) + 2SO_4^{2-}(aq) \rightarrow 2PbSO_4(s) + 2H_2O(l)$

6. What is the minimum voltage that must be applied to a Down's cell to cause the electrolysis of molten sodium chloride? The net cell reaction is

$2Na^{+}(l) + 2Cl^{-}(l) \rightarrow 2Na(l) + Cl_2(g)$

One way to determine the metallic composition of an alloy is to use electroplating. Suppose an electrolytic cell is set up with solution of nickel ions obtained from a 6.753-g sample of a nickel alloy. The cell also contains a platinum electrode that has a mass of 10.533 g. Electric current is used to reduce the nickel ions to nickel metal, which is deposited on the platinum electrode. After being plated with nickel, the platinum electrode has a mass of 15.042 g. What is the percentage of nickel in the alloy?

$Co^{3+} + e^- \rightarrow Co^{2+} \quad E^\circ = +1.92\,v$

$Cu^{2+} + e^- \rightarrow Cu^{+} \quad E^\circ = +0.15\,v$

$Rh^{3+} + 3e^- \rightarrow Rh \quad E^\circ = +0.76$