23 ELECTROCHEMISTRY
PLANNING GUIDE

SECTION	STUDENT ACTIVITIES/FEATURES	TEACHER'S RESOURCE GUIDE
23.1 Electrochemical Cells **Objectives** ▸ Describe how redox reactions interconvert electrical energy and chemical energy ▸ Explain the structure of a dry cell and identify the substances that are oxidized and reduced	**Discover It!** *A Lemon Battery,* p. 676	**Review Module** (Chapters 21–24) ▸ Section Review 23.1 ▸ Quizzes **Small-Scale Chemistry Lab Manual,** Experiment 33: *Small-Scale Voltaic Cells*
23.2 Half-Cells and Cell Potentials **Objectives** ▸ Define standard cell potential and standard reduction potential ▸ Use standard reduction potential to calculate standard cell potential	**Sample Problems** 23-1 through 23-2	**Review Module** ▸ Section Review 23.2 ▸ Practice Problems ▸ Quizzes **Laboratory Manual,** Experiment 45: *Corrosion*
23.3 Electrolytic Cells **Objectives** ▸ Distinguish between electrolytic and voltaic cells, and list some possible uses of electrolytic cells ▸ Identify the products of the electrolysis of brine, molten sodium chloride, and water.	**Link to Metallurgy** *Anodizing,* p. 695 **Mini Lab** *Tarnish Removal,* p. 676 **Small-Scale Lab** *Electrolysis of Water,* p. 698 **Chemistry Serving . . . the Environment** *How Many Miles Per Charge?,* p. 699 **Chemistry in Careers** *Automotive Design Engineer,* p. 699	**Review Module** ▸ Section Review 23.3 ▸ Vocabulary Review 23 ▸ Interpreting Graphics ▸ Chapter 23 Tests and Quizzes **Laboratory Recordsheets** 23-1 and 23-2 **Laboratory Manual,** Experiment 46: *Electrochemistry* **Laboratory Practical** 23-1 **Solutions Manual for Chapter Reviews**

TECHNOLOGY RESOURCES

Internet Connections
Within this chapter, you will see the chemSURF logo. If you and your students have access to the Internet, the following URL address will provide various Internet connections that are related to topics and features presented in this chapter.

http://www.chemsurf.com

You can also find relevant chapter material at
The Chemistry Place address:
http://www.chemplace.com

CD-ROMs

Chem ASAP! CD-ROM
- Chapter 23

ResourcePro CD-ROM
- Chapter 23

ActivChemistry CD-ROM
- Electrochemistry

Assessment Resources CD-ROM

Videodiscs and Videotapes

Small-Scale Lab Video and Videodisc
- #4: Redox Reactions
- #5: Small-Scale Voltaic Cells
- #6: Electrolysis of Solutions

Overhead Transparencies
- #71: Voltaic Cell
- #72: Voltaic and Electrolytic Cells

ASSESSMENT

Student Edition
- Section Reviews 23.1–23.3
- Chapter 23 Review, pp. 700–702
- Alternative Assessment, p. 703

Teacher's Resource Package
Review Module (Chap. 21–24)
- Vocabulary Review
- Chapter 23 Test A and Test B
- Chapter 23 Quizzes

Technology
Chem ASAP! CD-ROM
- Assessment 23.1–23.3

Assessment Resources CD-ROM
- Chapter 23 Tests

PLANNING FOR ACTIVITIES

STUDENT EDITION

Discover It! p. 676
- whole lemon
- copper strip
- zinc strip
- sandpaper
- voltmeter

Mini Lab p. 697
- baking soda
- water
- hot plate
- saucepan
- tablespoon
- shallow dish
- aluminum foil
- tarnished silver utensil

Small-Scale Lab, p. 698
- pencil
- paper
- ruler
- reaction surface
- electrolysis device
- H_2O
- Na_2SO_4
- Na_2SO_4 + BTB

TEACHER'S EDITION

Teacher Demo, p. 677
- radio that works with cord or batteries

Teacher Demo, p. 678
- 200 mL of 0.1*M* silver nitrate ($AgNO_3$)
- 250-mL beaker
- glass stirring rod
- polished copper strip
- 50% molar excess of NaCl
- plastic container

Teacher Demo, p. 681
- dry cell
- hacksaw
- zinc electrode
- carbon electrode
- saturated ammonium chloride
- powdered manganese dioxide
- voltmeter

Teacher Demo, p. 682
- two lead strips
- wooden rod
- 250-mL beaker
- sulfuric acid
- 6-V DC power supply
- wire
- bell

Teacher Demo, p. 687
- pennies
- metal wires from twist ties
- table salt
- tap water

Teacher Demo, p. 693
- Hoffman apparatus
  or
  iron nails and two test tubes
- 6*M* NaOH solution for each test tube
- beaker
- sodium hydroxide solution
- matches
- wire

Name _____ Class _____ Date _____

23.1 ELECTROCHEMICAL CELLS
SECTION REVIEW

Objectives

- Describe how redox reactions interconvert electrical energy and chemical energy
- Explain the structure of a dry cell and identify the substances that are oxidized and reduced

Key Terms

- electrochemical process
- half-cell
- cathode
- salt bridge
- electrochemical cell
- electrode
- battery
- dry cell
- voltaic cells
- anode
- fuel cells

Part A Completion

Use this completion exercise to check your understanding of the concepts and terms that are introduced in this section. Each blank can be completed with a term, short phrase, or number.

Chemical processes can release or absorb energy. Any conversion between chemical energy and electrical is known as an ___1___. These processes always involve spontaneous redox reactions in which a transfer of ___2___ occur. Electrochemical cells that generate electrical energy are known as ___3___.

The half-reactions associated with redox reactions take place in half-cells. The half-cells are separated by a porous plate or ___4___. This barrier prevents the contents of the two half-cells from mixing, but permits the passage of ___5___ between the half-cells. Electrons are transferred through an external circuit from the ___6___, the electrode where oxidation occurs, to the ___7___, the electrode where reduction occurs.

1. _____
2. _____
3. _____
4. _____
5. _____
6. _____
7. _____

Name _____ Class _____ Date _____

Part B True-False

Classify each of these statements as always true, AT; sometimes true, ST; or never true, NT.

_____ **8.** Nickel is below mercury in the activity series of metals.

_____ **9.** The reduction half-reaction in a voltaic cell occurs at the cathode.

_____ **10.** In a flashlight battery, the anode is the graphite rod.

_____ **11.** A salt bridge is part of a voltaic cell.

Part C Matching

Match each description in Column B to the correct term in Column A.

Column A	Column B
_____ **12.** dry cell	**a.** the electrode at which oxidation occurs
_____ **13.** voltaic cells	**b.** a group of voltaic cells that are connected together
_____ **14.** cathode	**c.** a voltaic cell in which a fuel substance undergoes oxidation to produce electrical energy
_____ **15.** battery	**d.** the electrode at which reduction occurs
_____ **16.** fuel cell	**e.** any device that converts chemical energy into electrical energy or electrical energy into chemical energy
_____ **17.** electrochemical cell	**f.** electrochemical cells used to convert chemical energy into electrical energy
_____ **18.** anode	**g.** a commercial voltaic cell in which the electrolyte is a moist paste

Part D Questions and Problems

Answer the following in the space provided.

19. Describe the voltaic cell represented as:

$Mg(s) \mid MgSO_4(aq) \parallel PbSO_4(aq) \mid Pb(s)$

Sketch a diagram of the cell similar to the one shown in Figure 23.3 of your textbook. Label the cathode and anode, and indicate the direction of electron flow.

Name _____ Class _____ Date _____

23.2 HALF-CELLS AND CELL POTENTIALS
SECTION REVIEW

Objectives

- Define standard cell potential and standard reduction potential
- Use standard reduction potentials to calculate standard cell potential

Key Terms

- electrical potential
- reduction potential
- cell potential
- standard cell potential
- standard hydrogen electrode

Key Equation

$E^0_{cell} = E^0_{red} - E^0_{oxid}$

Part A Completion

Use this completion exercise to check your understanding of the concepts and terms that are introduced in this section. Each blank can be completed with a term, short phrase, or number.

The measure of a voltaic cell's ability to produce an electric current is called its __1__, which is usually measured in volts. The electrical potential of a cell results from a competition for __2__ between the two half-cells. The half-cell with the greatest reduction potential is the half-cell with the greatest tendency to acquire __3__; it will be the half-cell where __4__ occurs. The difference between the reduction potentials of the two half-cells is called the __5__.

In comparing standard cell potentials for half-reactions, the __6__ serves as a reference and is assigned a value of __7__. A negative value for the standard reduction potential means that the tendency for this half-cell to be reduced is __8__ than the tendency for hydrogen ions to be reduced. If the calculated standard cell potential for a given redox reaction is positive, then the reaction is __9__.

1. _____
2. _____
3. _____
4. _____
5. _____
6. _____
7. _____
8. _____
9. _____

Name _____ Class _____ Date _____

Part B True-False

Classify each of these statements as always true, AT; sometimes true, ST; or never true, NT.

_____ **10.** The half-cell that has a greater tendency to acquire electrons will be the one in which oxidation occurs.

_____ **11.** In an electrochemical cell, the hydrogen half-cell is the reduction half-cell.

_____ **12.** A positive value for a standard reduction potential means hydrogen ions have a greater tendency to be reduced than the ions in this half-cell.

_____ **13.** If the cell potential for a given redox reaction is negative, the reaction is spontaneous.

Part C Matching

Match each description in Column B to the correct term in Column A.

Column A	Column B
_____ **14.** electrical potential	**a.** the difference between the reduction potentials of the two half-cells
_____ **15.** reduction potential	**b.** the measure of a cell's ability to produce an electric current
_____ **16.** spontaneous reaction	**c.** the standard reduction potential of the hydrogen electrode
_____ **17.** 0.00 V	**d.** the tendency of a given half-reaction to occur as a reduction
_____ **18.** cell potential	**e.** standard reduction potential for the oxidation half-cell
_____ **19.** E^0_{oxid}	**f.** a reaction known to give the products as written in the balanced equation

Part D Questions and Problems

Answer the following in the space provided.

20. Compute the standard cell potential of a $Mg \mid Mg^{2+} \parallel Cl_2 \mid Cl^-$ cell using standard electrode potentials.

Name _____ Class _____ Date _____

23.3 ELECTROLYTIC CELLS
SECTION REVIEW

Objectives

- Distinguish between electrolytic and voltaic cells, and list some possible uses of electrolytic cells
- Identify the products of the electrolysis of brine, molten sodium chloride, and water

Key Terms

- electrolysis
- electrolytic cell

Part A Completion

Use this completion exercise to check your understanding of the concepts and terms that are introduced in this section. Each blank can be completed with a term, short phrase, or number.

The process in which electrical energy is used to make a nonspontaneous redox reaction go forward is called __1__. The apparatus in which this process is carried out is called an __2__. In this type of cell, as in voltaic cells, __3__ flow from the anode to the cathode through an external circuit. In an electrolytic cell, electrons are driven by an outside power source such as a __4__.

In the electrolysis of water, a small amount of __5__ must be added to enable the water to conduct electricity. The products of the electrolysis of water are __6__ and __7__. During the electrolysis of molten sodium chloride , chloride ions are oxidized to produce chlorine gas at the anode and sodium ions are reduced to produce __8__ at the cathode.

1. _____
2. _____
3. _____
4. _____
5. _____
6. _____
7. _____
8. _____

Part B True-False

Classify each of these statements as always true, AT; sometimes true, ST; or never true, NT.

_____ **9.** During the electrolysis of brine, sodium metal is produced at the cathode.

_____ **10.** An electrolytic cell drives a nonspontaneous reaction to completion.

_____ **11.** When a current is applied via two electrodes in water oxygen and hydrogen are produced.

_____ **12.** An object that is to be electroplated needs to be the cathode of the electrolytic cell.

Part C Matching

Match each description in Column B to the correct term in Column A.

Column A	Column B
_____ **13.** electrolysis	**a.** an electrolytic method for obtaining ultrapure metals
_____ **14.** electrolytic cell	**b.** the process in which electrical energy is used to make a nonspontaneous reaction go forward
_____ **15.** brine	**c.** the deposition of a thin layer of metal on an object in an electrolytic cell
_____ **16.** electroplating	**d.** an electrochemical cell used to cause a chemical change through the application of electrical energy
_____ **17.** electrorefining	**e.** a concentrated solution of sodium chloride

Part D Questions and Problems

Answer the following in the space provided.

18. Distinguish between electrolytic and voltaic cells and list some applications of each.

19. Sketch an electrolytic cell that could be used to silverplate a teaspoon. Label the anode, cathode, and the direction of electron flow. Write the anode and cathode reactions that occur.

Name _____ Class _____ Date _____

23 ELECTROCHEMISTRY
PRACTICE PROBLEMS

Use Table 23.2 to solve the following problems in your notebook.

SECTION 23.2 HALF-CELLS AND CELL POTENTIALS

1. Determine the cell reaction, the standard cell potential (E^0_{cell}) and the half-cell that acts as the cathode for the voltaic cells composed of the following half-cells.

   a. $Mg^{2+}(aq) + 2e^- \rightarrow Mg(s)$

   $Cl_2(g) + 2e^- \rightarrow 2Cl^-(aq)$

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

   $Ag^+(aq) + e^- \rightarrow Ag(s)$

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

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

   d. $Br_2(l) + 2e^- \rightarrow 2Br^-(aq)$

   $Na^+(aq) + e^- \rightarrow Na(s)$

   e. $2H^+(aq) + 2e^- \rightarrow H_2(g)$

   $MnO_2(s) + 4H^+(aq) + 2e^- \rightarrow Mn^{2+}(aq) + 2H_2O(l)$

2. Calculate E^0_{cell} to determine whether the following redox reactions are spontaneous as written.

   a. $Sn^{2+}(aq) + Ba(s) \rightarrow Sn(s) + Ba^{2+}(aq)$

   b. $2Ag^+(aq) + 2Cl^-(aq) \rightarrow 2Ag(s) + Cl_2(g)$

   c. $Zn(s) + F_2(g) \rightarrow 2F^-(aq) + Zn^{2+}(aq)$

   d. $2Li(s) + Co^{2+}(aq) \rightarrow 2Li^+(aq) + Co(s)$

   e. $2I^-(aq) + K^+(aq) \rightarrow I_2(s) + K(s)$

Name _____ Class _____ Date _____

23 INTERPRETING GRAPHICS

USE WITH SECTION 23.3

Electrolysis is sometimes used to purify metals from mixtures. In this process, a slab or bar of impure metal, containing many types of metallic elements, is made the anode of an electrolytic cell. When external electrical energy is supplied to the cell, metallic elements in the anode are oxidized to cations which dissolve in solution. Then the cations are reduced to the pure metal at the surface of the cathode. A schematic diagram of an electrolytic cell used to purify copper is shown below. If the voltage supply is carefully regulated, less reactive metals are not oxidized at the anode, but instead collect as "mud" at the bottom of the cell below the anode. Metals more reactive than copper are oxidized at the anode, but are not reduced at the cathode; therefore, they remain dissolved as ions in the electrolyte solution ($CuSO_4$).

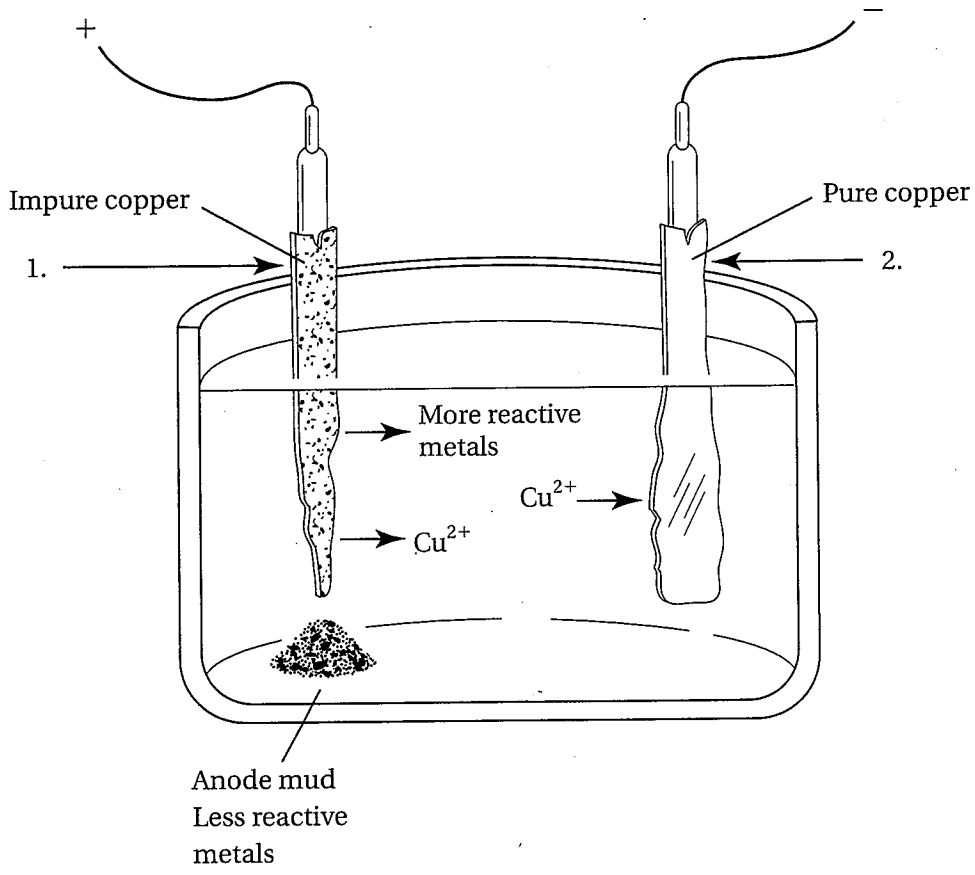

Figure 1 Purification of copper by electrolysis at 25 °C, 101.3 kPa, in 1*M* $CuSO_4$.

Identify the anode and cathode in the diagram. Write your answers on the lines provided.

1. _____ **2.** _____

3. What name is given to the technique used to obtain pure copper by electrolysis?

_____

Name _____ Class _____ Date _____

4. The apparatus depicted in Figure 1 is not complete, the electrolytic cell must be connected to a DC source (a battery).
   a. To which electrodes of the battery, positive (+) or negative (−), should the anode and cathode of the electrolytic cell be connected?

   b. Describe the connections in terms of the anode and cathode of the battery.

5. At which of the electrodes, numbered 1 and 2 in Figure 1, is oxidation occurring? Reduction? Label the electrodes in the diagram.

6. Using arrows, annotate the diagram in Figure 1 to show the flow of electrons out of or into the electrodes.

The E^0_{red} values for several metals are shown below.

$E^0_{Zn^{2+}} = -0.76\,V$	$E^0_{Cu^{2+}} = +0.34\,V$	$E^0_{Au^{3+}} = +1.50\,V$
$E^0_{Fe^{2+}} = -0.44\,V$	$E^0_{Ag^{+}} = +0.80\,V$	$E^0_{Pt^{2+}} = +1.18\,V$

Assume that all of these metals are present in the impure metal anode. Use these data to answer the following questions.

7. What voltage should be applied to the electrolytic cell to purify copper in the manner described above?

8. If the voltage from the DC source is maintained at 0.40 V:
   a. Which metals will be found in the anode mud when the electrolysis is complete?

   b. Which cations will be found dissolved in the electrolyte solution?

   c. Which metal(s) will plate out at the cathode?

Name _____ Class _____ Date _____

23 VOCABULARY REVIEW

Each clue describes a vocabulary term. Read the clues and write the letters of each term on the lines provided.

1. Clue: an electrochemical cell used to convert chemical energy into electrical energy.

   ___ ___ ___ ___ ___ ◯ ___ ___ ___ ___ ◯

2. Clue: cell in which a fuel undergoes oxidation to produce electrical energy.

   ___ ◯ ___ ___ ___ ___ ___ ___

3. Clue: any device that converts chemical energy into electrical energy or electrical energy into chemical energy.

   ___ ___ ___ ___ ___ ___ ___ ___ ___ ___ ◯ ___ ___ ___ ___

   ___ ___ ___ ___

4. Clue: the interconversion of chemical energy and electrical energy.

   ___ ___ ___ ___ ___ ___ ___ ___ ___ ___ ◯ ___ ___ ___ ___

   ___ ___ ___ ___ ___ ___ ___

5. Clue: the electrode at which reduction occurs.

   ___ ◯ ___ ___ ___ ___ ___

6. Clue: a measure of the tendency of a given half-reaction to occur as a reduction in an electrochemical cell.

   ___ ___ ___ ◯ ___ ___ ___ ___ ___

   ___ ___ ___ ___ ◯ ___ ___ ___ ___

Write the letters found inside the circles on the lines below. Then unscramble them to find the name of one metal commercially produced by electrolysis.

Scrambled letters:

___ ___ ___ ___ ___ ___ ___ ___

Solution:

___ ___ ___ ___ ___ ___ ___ ___

Name _____ Class _____ Date _____

23 ELECTROCHEMISTRY

Quiz for CHAPTER 23

Classify each of these statements as always true, AT; sometimes true, ST; or never true, NT.

_____ **1.** In a lead storage battery, the sulfuric acid concentration increases during discharge. *23.1*

_____ **2.** The oxidation half-reaction in a voltaic cell occurs at the anode. *23.1*

_____ **3.** In a flashlight battery, the zinc metal case is the cathode. *23.1*

_____ **4.** A strip of zinc metal, when dipped into a solution of copper sulfate, becomes copper plated. (Zinc is more easily oxidized than copper.) *23.1*

_____ **5.** Batteries can be recharged. *23.1*

_____ **6.** Voltaic cells were named for electromotive force (emf), which is measured in volts. *23.1*

_____ **7.** A salt bridge allows for the passage of electrons from one half-cell to another half-cell. *23.1*

_____ **8.** In a voltaic cell, a wire carries the electrons in the external circuit from the anode to the cathode. *23.1*

_____ **9.** In a voltaic cell, the anode is the negative electrode. *23.1*

_____ **10.** Fuel cells use methane as fuel. *23.1*

_____ **11.** The standard hydrogen electrode is assigned a reduction potential of 1.00 V. *23.2*

_____ **12.** The anode in an electrolytic cell is the positive electrode. *23.3*

_____ **13.** The electrolysis of brine produces chlorine gas at the cathode. *23.3*

_____ **14.** The standard cell potential is the measured cell potential when the ion concentrations are 1*M*, any gases are at a pressure of 101 kPa, and the temperature is 25 °C. *23.2*

_____ **15.** $E^0_{cell} = E^0_{red} + E^0_{oxid}$ *23.2*

_____ **16.** A standard reduction potential for a half-cell is negative if the tendency for reduction to occur is less than the tendency of hydrogen ions to be reduced to hydrogen gas. *23.2*

_____ **17.** A redox reaction is spontaneous if the standard cell potential is positive. *23.2*

_____ **18.** Electroplating is the deposition of a thin layer of a metal on an object in a voltaic cell. *23.3*

Name _____ Class _____ Date _____

23 ELECTROCHEMISTRY
CHAPTER TEST A

A. Matching

Match each term in Column B with the correct description in Column A.

	Column A	Column B
_____ 1.	a conductor in a circuit that carries electrons to or from a substance other than a metal	**a.** anode
_____ 2.	one part of a voltaic cell, in which either oxidation or reduction occurs	**b.** electrode
_____ 3.	a voltaic cell in which the electrolyte is a paste	**c.** cathode
_____ 4.	the electrode at which reduction occurs	**d.** dry cell
_____ 5.	a voltaic cell in which a fuel undergoes oxidation and from which electrical energy is obtained continuously	**e.** battery
_____ 6.	an electrochemical cell that is used to convert chemical energy into electrical energy	**f.** electrolysis
_____ 7.	a tube containing a conducting solution	**g.** voltaic cell
_____ 8.	a group of cells that are connected together	**h.** half-cell
_____ 9.	the process in which electrical energy is used to bring about a chemical change	**i.** salt bridge
_____ 10.	the electrode at which oxidation occurs	**j.** fuel cell

B. Multiple Choice

Write the letter of the best answer in the blank.

_____ **11.** In the electrolysis of brine, the substance produced at the cathode is:
- **a.** chlorine.
- **b.** oxygen.
- **c.** sodium.
- **d.** hydrogen.

_____ **12.** Which of the following describes a dry cell?
- **a.** It can be recharged many times.
- **b.** The graphite rod does not undergo reduction, even though it is the cathode.
- **c.** It contains concentrated sulfuric acid.
- **d.** all of these

Name _____ Class _____ Date _____

_____ **13.** A clean strip of copper is dipped into a solution of magnesium sulfate. Magnesium is above the copper in the activity series of metals. Predict what you will observe.
a. The copper strip becomes magnesium-plated.
b. Copper dissolves and the solution turns blue.
c. No reaction occurs.
d. Bubbles of hydrogen gas appear on the copper.

_____ **14.** A clean iron nail is dipped into a solution of silver nitrate. Iron is above silver in the activity series of metals. Predict what you will observe.
a. The iron will be reduced.
b. Bubbles of nitrogen gas will form on the iron nail.
c. The iron nail will become silver-plated.
d. No reaction occurs.

_____ **15.** In a fully charged lead storage battery, the cathode grid is packed with:
a. spongy lead.
b. lead sulfate.
c. lead(IV) oxide.
d. sulfuric acid.

_____ **16.** Which of the following is true about fuel cells?
a. They can be designed so that they emit no pollutants.
b. They are inexpensive.
c. They have never been built or used.
d. They produce energy in short bursts only.

_____ **17.** Which of the following is true for an electrolytic cell?
a. It changes electrical energy into chemical energy.
b. It is the type of cell used in electroplating.
c. It uses an electric current to make a nonspontaneous reaction go.
d. all of these

_____ **18.** When a lead storage battery discharges:
a. the concentration of lead sulfate in the battery decreases.
b. the concentration of sulfuric acid increases.
c. the concentration of sulfuric acid decreases.
d. none of these

_____ **19.** A zinc-copper cell is constructed:

$$Zn \mid Zn^{2+}\ (1M) \parallel Cu^{2+}\ (1M) \mid Cu$$

What occurs to the mass of the copper electrode as the reaction proceeds? (Zinc is above copper in the activity series of metals.)
a. It increases.
b. It remains the same.
c. It decreases.

_____ **20.** In the cell reaction described in question 19, the negative electrode is:
a. $Zn(s)$.
b. $Cu^{2+}(aq)$.
c. $Zn^{2+}(aq)$.
d. $Cu(s)$.

_____ **21.** Which half-reaction occurs at the negative electrode in an electrolytic cell in which an object is being plated with silver?
a. $Ag + 1e^- \rightarrow Ag^+$
b. $Ag \rightarrow Ag^+ + 1e^-$
c. $Ag^+ + 1e^- \rightarrow Ag$
d. $Ag^+ \rightarrow Ag + 1e^-$

Name _____ Class _____ Date _____

_____ **22.** Which metal will react spontaneously with $Cu^{2+}(aq)$ at 25 °C?
a. Ag **c.** Mg
b. Au **d.** Hg

_____ **23.** Which reaction occurs when bromine is added to an aqueous solution of iodide ions?
a. $2I^- + Br_2 \rightarrow I_2 + 2Br^-$ **c.** $2I^- + 2Br^- \rightarrow I_2 + Br_2$
b. $I_2 + 2Br \rightarrow Br_2 + 2I^-$ **d.** $I_2 + Br_2 \rightarrow 2I^- + 2Br^-$

_____ **24.** Which ion can be most easily reduced?
a. Cu^{2+} **c.** Fe^{2+}
b. Zn^{2+} **d.** Ca^{2+}

_____ **25.** Oxygen and copper are produced during the electrolysis of a CuO solution. Which reaction occurs at the negative electrode?
a. Oxygen ions are reduced. **c.** Copper ions are reduced.
b. Oxygen atoms are oxidized. **d.** Copper atoms are oxidized.

C. True–False

Classify each of these statements as always true, AT; sometimes true, ST; or never true, NT.

_____ **26.** During the electrolysis of brine, chlorine gas is produced at the cathode.

_____ **27.** Copper is above gold in the activity series of metals because copper is less reactive and less easily oxidized.

_____ **28.** The oxidation half-reaction in a voltaic cell occurs at the anode.

_____ **29.** Cell potential is the sum of the reduction potential of the half-cell where reduction occurs and the reduction potential of the half-cell where oxidation occurs.

_____ **30.** In an electrolytic cell, oxidation occurs at the cathode and reduction occurs at the anode.

D. Questions

Answer the following question in the space provided.

31. Draw a voltaic cell. Label the cathode, anode, salt bridge, and direction of the flow of electrons.

Name _____ Class _____ Date _____

E. Essay

Write a short essay for the following.

32. State the sign of the electrodes and the reaction that occurs at each electrode for both voltaic and electrolytic cells.

F. Additional Questions

Answer the following questions in the space provided.

33. The standard reduction potential for the cobalt half-cell is −0.28 V. What is the significance of the negative value? (Refer to the standard hydrogen half-cell in your answer.)

34. What is meant by the reduction potential of a half-cell?

35. Are the following redox reactions spontaneous as written? (Use the information in the Reference Section. Show your work.)

a. $Ni(s) + Zn^{2+}(aq) \rightarrow Ni^{2+}(aq) + Zn(s)$

b. $3Co(s) + 2Al^{3+}(aq) \rightarrow 3Co^{2+}(aq) + 2Al(s)$

Reference Section

Reduction Potentials at 25 °C		
Electrode	**Half-Reaction**	**E°(V)**
Al^{3+}/Al	$Al^{3+} + 3e^- \rightarrow Al$	−1.66
Zn^{2+}/Zn	$Zn^{2+} + 2e^- \rightarrow Zn$	−0.76
Co^{2+}/Co	$Co^{2+} + 2e^- \rightarrow Zn$	−0.28
Ni^{2+}/Ni	$Ni^{2+} + 2e^- \rightarrow Ni$	−0.25

Name _____ Class _____ Date _____

23 ELECTROCHEMISTRY
CHAPTER TEST B

A. Matching

Match each term in Column B with the correct description in Column A.

	Column A	Column B
_____ 1.	the ability of a voltaic cell to produce an electric current	**a.** fuel cells
_____ 2.	any device that converts chemical energy into electrical energy or electrical energy into chemical energy	**b.** salt bridge
_____ 3.	the process in which electrical energy in used to bring about a chemical change	**c.** battery
_____ 4.	the electrode at which oxidation occurs	**d.** electrochemical cell
_____ 5.	a group of voltaic cells that are connected together	**e.** cathode
_____ 6.	electrochemical cells that are used to convert chemical energy into electrical energy	**f.** electrolysis
_____ 7.	a voltaic cell in which the electrolyte is a paste	**g.** voltaic cells
_____ 8.	the electrode at which reduction occurs	**h.** electrical potential
_____ 9.	a tube containing a conducting solution that lets ions pass from one compartment of a voltaic cell to another	**i.** anode
_____ 10.	voltaic cells in which a fuel undergoes oxidation and from which electrical energy is obtained continuously	**j.** dry cell

B. Multiple Choice

Write the letter of the best answer in the blank. Refer to the Reference Section on p. 71 for the reduction potentials as needed.

_____ **11.** Which of the following is true concerning the reaction given below?

$$Zn(s) + 2H^+(aq) \rightarrow Zn^{2+}(aq) + H_2(g)$$

a. $Zn(s)$ is being reduced.
b. $H^+(aq)$ is being oxidized.
c. Electrons are being transferred from $Zn(s)$ to $H^+(aq)$.
d. all of these

_____ **12.** If Al is above Co in the activity series of metals, which of the following will occur if a strip of Al is dipped into a solution of $Co(NO_3)_2$?
a. A redox reaction takes place.
b. The Al strip dissolves.
c. The Al strip becomes coated with Co.
d. all of these

Name _____ Class _____ Date _____

_____ **13.** In an electrochemical cell, the anode is:
- **a.** the electrode at which reduction occurs.
- **b.** the electrode at which electrons are produced.
- **c.** the positive electrode.
- **d.** all of these

_____ **14.** If Mg is above Ni in the activity series of metals, which of the following will occur if a strip of Mg is dipped into a solution of $Ni(NO_3)_2$?
- **a.** No reaction occurs.
- **b.** The Ni^{2+} loses electrons.
- **c.** The Mg is oxidized.
- **d.** none of these

_____ **15.** Which of the following is true concerning the electrochemical cell represented by the following?

$$Mn(s) \mid Mn(NO_3)_2(aq) \parallel PbSO_4(aq) \mid Pb(s)$$

- **a.** Pb is oxidized.
- **b.** Mn is reduced.
- **c.** A strip of Pb is dipped into a solution of $Mn(NO_3)_2$.
- **d.** Electrons are lost at the Mn electrode.

_____ **16.** Which of the following is true about a dry cell?
- **a.** It is a voltaic cell in which the electrolyte is a paste.
- **b.** Zn serves as the cathode.
- **c.** Graphite serves as the anode.
- **d.** all of these

_____ **17.** In a lead storage battery:
- **a.** the anode is packed with spongy lead and the cathode is packed with lead(IV) oxide.
- **b.** the electrodes are immersed in sulfuric acid.
- **c.** the system can be recharged by the passage of electric current through the cell.
- **d.** all of these

_____ **18.** If the metals Ca, Zn, Fe, and Cu are listed in that order in the activity series of metals, the one that would be most readily oxidized is:
- **a.** Ca.
- **b.** Zn.
- **c.** Fe.
- **d.** Cu.

_____ **19.** Among the metals listed in question 18, the one that would be most readily reduced is:
- **a.** Ca.
- **b.** Zn.
- **c.** Fe.
- **d.** Cu.

_____ **20.** In a hydrogen-oxygen fuel cell:
- **a.** oxygen is fed into the anode compartment.
- **b.** hydrogen is fed into the cathode compartment.
- **c.** the net reaction is the oxidation of hydrogen to form water.
- **d.** all of these

_____ **21.** The standard reference electrode that is used with other electrodes to measure their reduction potentials consists of:
- **a.** Zn.
- **b.** H_2.
- **c.** Cu.
- **d.** Ag.

Name _____ Class _____ Date _____

_____ **22.** Which of the following is true concerning standard reduction potentials?
- **a.** A positive value indicates that the tendency for a specified substance to be reduced is less than that of H^+.
- **b.** A negative value indicates that the tendency for a specified substance to be reduced is more than that of H^+.
- **c.** The half-reactions at the top of the standard reduction potential table have the greatest tendency to occur as oxidations.
- **d.** all of these

_____ **23.** The standard cell potential of a cell composed of the half-cells

$$Zn \mid Zn^{2+} \parallel Pb^{2+} \mid Pb$$ is:

- **a.** +0.89 V.
- **b.** +0.63 V.
- **c.** −0.89 V.
- **d.** −0.63 V.

_____ **24.** In the voltaic cell described in question 23, the anode is:
- **a.** Zn.
- **b.** Zn^{2+}.
- **c.** Pb^{2+}.
- **d.** Pb.

_____ **25.** Among the following reactions, which would be expected to occur spontaneously?
- **a.** $Cu(s) + Mg^{2+}(aq) \rightarrow Cu^{2+}(aq) + Mg(s)$
- **b.** $2Na(s) + Pb^{2+}(aq) \rightarrow 2Na^{+}(aq) + Pb(s)$
- **c.** $2Ag(s) + Zn^{2+}(aq) \rightarrow 2Ag^{+}(aq) + Zn(s)$
- **d.** all of these

_____ **26.** Which of the following is true about an electrolytic cell?
- **a.** Electrons flow from the cathode to the anode in the external circuit.
- **b.** Oxidation occurs at the cathode.
- **c.** The redox reaction involved in such a cell is nonspontaneous.
- **d.** all of these

_____ **27.** The net products that result from the electrolysis of water are:
- **a.** H_2 and OH^-.
- **b.** O_2 and H^+.
- **c.** H^+ and OH^-.
- **d.** H_2 and O_2.

C. True–False

Classify each of these statements as always true, AT; sometimes true, ST; or never true, NT.

_____ **28.** Given any two elements in the activity series of metals, the one that appears above the other undergoes reduction.

_____ **29.** The salt bridge in a voltaic cell provides a pathway for the electrons to flow from one electrode to the other.

_____ **30.** A flashlight battery is an example of a dry cell.

_____ **31.** The specific gravity of the sulfuric acid contained in a lead storage battery is an indication of the condition of that battery.

_____ **32.** Half-cell potentials cannot be measured.

_____ **33.** The standard cell potential for a voltaic cell consisting of some combination of Zn, Zn^{2+}, F_2 and F^- would be a positive value.

Name _____ Class _____ Date _____

D. Questions

Answer the following questions in the space provided.

34. Given the following voltaic cell, draw the cell and label the cathode, anode, salt bridge, and direction of flow of the electrons.

$$Cu(s) \mid Cu(NO_3)_2(aq) \parallel AgNO_3(aq) \mid Ag(s)$$

35. Based on the information given in question 34, write the two half-reactions, as well as the final net reaction for the Cu-Ag voltaic cell. Use the information provided in the Reference Section to calculate the standard cell potential for this voltaic cell.

E. Essay

Write a short essay for the following.

36. Give at least three similarities and three differences between voltaic and electrolytic cells.

Reference Section

Reduction Potentials at 25 °C	
Electrode	**E^0 (V)**
N^+/Na	−2.71 V
Mg^{2+}/Mg	−2.37 V
Al^{3+}/Al	−1.66 V
Zn^{2+}/Zn	−0.76 V
Pb^{2+}/Pb	−0.13 V
Cu^{2+}/Cu	+0.34 V
Ag^+/Ag	+0.80 V
F_2/F	+2.87 V

Name _____ Class _____ Date _____

F. Additional Questions

Answer the following questions in the space provided.

37. Write the half-cell reactions and the net reaction for the following voltaic cell. Calculate the standard cell potential for the cell.

$$Al(s) \mid Al^{3+}(aq) \parallel Pb^{2+}(aq) \mid Pb(s)$$

38. Determine which of the following redox reactions will occur spontaneously and calculate the standard cell potential in each case.

a. $2Na(s) + Cu^{2+}(aq) \rightarrow 2Na^{+}(aq) + Cu(s)$

b. $2Ag(s) + Mg^{2+}(aq) \rightarrow 2Ag^{+}(aq) + Mg(s)$

c. $2Al(s) + 3Zn^{2+}(aq) \rightarrow 2Al^{3+}(aq) + 3Zn(s)$

39. Given the hypothetical elements W, X, Y, and Z, along with their corresponding ions W^{2+}, X^{2+}, Y^{2+}, and Z^{2+}, use the information provided below to determine the order in which these elements should be listed in the activity series of metals.

Reaction 1: $X^{2+} + Z \rightarrow X + Z^{2+}$	(reacts spontaneously)
Reaction 2: $W + X^{2+} \rightarrow$	(does not react)
Reaction 3: $Y + Z^{2+} \rightarrow Y^{2+} + Z$	(reacts spontaneously)

23 ELECTROCHEMISTRY
PLANNING GUIDE

SECTION	STUDENT ACTIVITIES/FEATURES	TEACHER'S RESOURCE GUIDE
23.1 Electrochemical Cells **Objectives** ▸ Describe how redox reactions interconvert electrical energy and chemical energy ▸ Explain the structure of a dry cell and identify the substances that are oxidized and reduced	**Discover It!** *A Lemon Battery,* p. 676	**Review Module** (Chapters 21–24) ▸ Section Review 23.1 ▸ Quizzes **Small-Scale Chemistry Lab Manual,** Experiment 33: *Small-Scale Voltaic Cells*
23.2 Half-Cells and Cell Potentials **Objectives** ▸ Define standard cell potential and standard reduction potential ▸ Use standard reduction potential to calculate standard cell potential	**Sample Problems** 23-1 through 23-2	**Review Module** ▸ Section Review 23.2 ▸ Practice Problems ▸ Quizzes **Laboratory Manual,** Experiment 45: *Corrosion*
23.3 Electrolytic Cells **Objectives** ▸ Distinguish between electrolytic and voltaic cells, and list some possible uses of electrolytic cells ▸ Identify the products of the electrolysis of brine, molten sodium chloride, and water.	**Link to Metallurgy** *Anodizing,* p. 695 **Mini Lab** *Tarnish Removal,* p. 676 **Small-Scale Lab** *Electrolysis of Water,* p. 698 **Chemistry Serving . . . the Environment** *How Many Miles Per Charge?,* p. 699 **Chemistry in Careers** *Automotive Design Engineer,* p. 699	**Review Module** ▸ Section Review 23.3 ▸ Vocabulary Review 23 ▸ Interpreting Graphics ▸ Chapter 23 Tests and Quizzes **Laboratory Recordsheets** 23-1 and 23-2 **Laboratory Manual,** Experiment 46: *Electrochemistry* **Laboratory Practical** 23-1 **Solutions Manual for Chapter Reviews**

TECHNOLOGY RESOURCES

Internet Connections
Within this chapter, you will see the chemSURF logo. If you and your students have access to the Internet, the following URL address will provide various Internet connections that are related to topics and features presented in this chapter.

http://www.chemsurf.com

You can also find relevant chapter material at
The Chemistry Place address:
http://www.chemplace.com

CD-ROMs

Chem ASAP! CD-ROM
- Chapter 23

ResourcePro CD-ROM
- Chapter 23

ActivChemistry CD-ROM
- Electrochemistry

Assessment Resources CD-ROM

Videodiscs and Videotapes

Small-Scale Lab Video and Videodisc
- #4: Redox Reactions
- #5: Small-Scale Voltaic Cells
- #6: Electrolysis of Solutions

Overhead Transparencies
- #71: Voltaic Cell
- #72: Voltaic and Electrolytic Cells

ASSESSMENT

Student Edition
- Section Reviews 23.1–23.3
- Chapter 23 Review, pp. 700–702
- Alternative Assessment, p. 703

Technology
Chem ASAP! CD-ROM
- Assessment 23.1–23.3

Assessment Resources CD-ROM
- Chapter 23 Tests

Teacher's Resource Package
Review Module (Chap. 21–24)
- Vocabulary Review
- Chapter 23 Test A and Test B
- Chapter 23 Quizzes

PLANNING FOR ACTIVITIES

STUDENT EDITION

Discover It! p. 676
- whole lemon
- copper strip
- zinc strip
- sandpaper
- voltmeter

Mini Lab p. 697
- baking soda
- water
- hot plate
- saucepan
- tablespoon
- shallow dish
- aluminum foil
- tarnished silver utensil

Small-Scale Lab, p. 698
- pencil
- paper
- ruler
- reaction surface
- electrolysis device
- H_2O
- Na_2SO_4
- Na_2SO_4 + BTB

TEACHER'S EDITION

Teacher Demo, p. 677
- radio that works with cord or batteries

Teacher Demo, p. 678
- 200 mL of 0.1*M* silver nitrate ($AgNO_3$)
- 250-mL beaker
- glass stirring rod
- polished copper strip
- 50% molar excess of NaCl
- plastic container

Teacher Demo, p. 681
- dry cell
- hacksaw
- zinc electrode
- carbon electrode
- saturated ammonium chloride
- powdered manganese dioxide
- voltmeter

Teacher Demo, p. 682
- two lead strips
- wooden rod
- 250-mL beaker
- sulfuric acid
- 6-V DC power supply
- wire
- bell

Teacher Demo, p. 687
- pennies
- metal wires from twist ties
- table salt
- tap water

Teacher Demo, p. 693
- Hoffman apparatus
  or
  iron nails and two test tubes
- 6*M* NaOH solution for each test tube
- beaker
- sodium hydroxide solution
- matches
- wire

Name _____ Class _____ Date _____

23.1 ELECTROCHEMICAL CELLS
SECTION REVIEW

Objectives

- Describe how redox reactions interconvert electrical energy and chemical energy
- Explain the structure of a dry cell and identify the substances that are oxidized and reduced

Key Terms

- electrochemical process
- half-cell
- cathode
- salt bridge
- electrochemical cell
- electrode
- battery
- dry cell
- voltaic cells
- anode
- fuel cells

Part A Completion

Use this completion exercise to check your understanding of the concepts and terms that are introduced in this section. Each blank can be completed with a term, short phrase, or number.

Chemical processes can release or absorb energy. Any conversion between chemical energy and electrical is known as an __1__. These processes always involve spontaneous redox reactions in which a transfer of __2__ occur. Electrochemical cells that generate electrical energy are known as __3__.

The half-reactions associated with redox reactions take place in half-cells. The half-cells are separated by a porous plate or __4__. This barrier prevents the contents of the two half-cells from mixing, but permits the passage of __5__ between the half-cells. Electrons are transferred through an external circuit from the __6__, the electrode where oxidation occurs, to the __7__, the electrode where reduction occurs.

1. _____
2. _____
3. _____
4. _____
5. _____
6. _____
7. _____

Name _____ Class _____ Date _____

Part B True-False

Classify each of these statements as always true, AT; sometimes true, ST; or never true, NT.

_____ **8.** Nickel is below mercury in the activity series of metals.

_____ **9.** The reduction half-reaction in a voltaic cell occurs at the cathode.

_____ **10.** In a flashlight battery, the anode is the graphite rod.

_____ **11.** A salt bridge is part of a voltaic cell.

Part C Matching

Match each description in Column B to the correct term in Column A.

Column A	Column B
_____ **12.** dry cell	**a.** the electrode at which oxidation occurs
_____ **13.** voltaic cells	**b.** a group of voltaic cells that are connected together
_____ **14.** cathode	**c.** a voltaic cell in which a fuel substance undergoes oxidation to produce electrical energy
_____ **15.** battery	**d.** the electrode at which reduction occurs
_____ **16.** fuel cell	**e.** any device that converts chemical energy into electrical energy or electrical energy into chemical energy
_____ **17.** electrochemical cell	**f.** electrochemical cells used to convert chemical energy into electrical energy
_____ **18.** anode	**g.** a commercial voltaic cell in which the electrolyte is a moist paste

Part D Questions and Problems

Answer the following in the space provided.

19. Describe the voltaic cell represented as:

$Mg(s) \mid MgSO_4(aq) \parallel PbSO_4(aq) \mid Pb(s)$

Sketch a diagram of the cell similar to the one shown in Figure 23.3 of your textbook. Label the cathode and anode, and indicate the direction of electron flow.

Name _____ Class _____ Date _____

23.2 HALF-CELLS AND CELL POTENTIALS

SECTION REVIEW

Objectives

- Define standard cell potential and standard reduction potential
- Use standard reduction potentials to calculate standard cell potential

Key Terms

- electrical potential
- reduction potential
- cell potential
- standard cell potential
- standard hydrogen electrode

Key Equation

$E^0_{cell} = E^0_{red} - E^0_{oxid}$

Part A Completion

Use this completion exercise to check your understanding of the concepts and terms that are introduced in this section. Each blank can be completed with a term, short phrase, or number.

The measure of a voltaic cell's ability to produce an electric current is called its __1__, which is usually measured in volts. The electrical potential of a cell results from a competition for __2__ between the two half-cells. The half-cell with the greatest reduction potential is the half-cell with the greatest tendency to acquire __3__; it will be the half-cell where __4__ occurs. The difference between the reduction potentials of the two half-cells is called the __5__.

In comparing standard cell potentials for half-reactions, the __6__ serves as a reference and is assigned a value of __7__. A negative value for the standard reduction potential means that the tendency for this half-cell to be reduced is __8__ than the tendency for hydrogen ions to be reduced. If the calculated standard cell potential for a given redox reaction is positive, then the reaction is __9__.

1. _____
2. _____
3. _____
4. _____
5. _____
6. _____
7. _____
8. _____
9. _____

Name _____ Class _____ Date _____

Part B True-False

Classify each of these statements as always true, AT; sometimes true, ST; or never true, NT.

_____ **10.** The half-cell that has a greater tendency to acquire electrons will be the one in which oxidation occurs.

_____ **11.** In an electrochemical cell, the hydrogen half-cell is the reduction half-cell.

_____ **12.** A positive value for a standard reduction potential means hydrogen ions have a greater tendency to be reduced than the ions in this half-cell.

_____ **13.** If the cell potential for a given redox reaction is negative, the reaction is spontaneous.

Part C Matching

Match each description in Column B to the correct term in Column A.

Column A	Column B
_____ **14.** electrical potential	**a.** the difference between the reduction potentials of the two half-cells
_____ **15.** reduction potential	**b.** the measure of a cell's ability to produce an electric current
_____ **16.** spontaneous reaction	**c.** the standard reduction potential of the hydrogen electrode
_____ **17.** 0.00 V	**d.** the tendency of a given half-reaction to occur as a reduction
_____ **18.** cell potential	**e.** standard reduction potential for the oxidation half-cell
_____ **19.** E^0_{oxid}	**f.** a reaction known to give the products as written in the balanced equation

Part D Questions and Problems

Answer the following in the space provided.

20. Compute the standard cell potential of a $Mg \mid Mg^{2+} \parallel Cl_2 \mid Cl^-$ cell using standard electrode potentials.

Name _____ Class _____ Date _____

23.3 ELECTROLYTIC CELLS
SECTION REVIEW

Objectives

- Distinguish between electrolytic and voltaic cells, and list some possible uses of electrolytic cells
- Identify the products of the electrolysis of brine, molten sodium chloride, and water

Key Terms

- electrolysis
- electrolytic cell

Part A Completion

Use this completion exercise to check your understanding of the concepts and terms that are introduced in this section. Each blank can be completed with a term, short phrase, or number.

The process in which electrical energy is used to make a nonspontaneous redox reaction go forward is called __1__. The apparatus in which this process is carried out is called an __2__. In this type of cell, as in voltaic cells, __3__ flow from the anode to the cathode through an external circuit. In an electrolytic cell, electrons are driven by an outside power source such as a __4__.

In the electrolysis of water, a small amount of __5__ must be added to enable the water to conduct electricity. The products of the electrolysis of water are __6__ and __7__. During the electrolysis of molten sodium chloride , chloride ions are oxidized to produce chlorine gas at the anode and sodium ions are reduced to produce __8__ at the cathode.

1. _____
2. _____
3. _____
4. _____
5. _____
6. _____
7. _____
8. _____

Part B True-False

Classify each of these statements as always true, AT; sometimes true, ST; or never true, NT.

_____ **9.** During the electrolysis of brine, sodium metal is produced at the cathode.

_____ **10.** An electrolytic cell drives a nonspontaneous reaction to completion.

_____ **11.** When a current is applied via two electrodes in water oxygen and hydrogen are produced.

_____ **12.** An object that is to be electroplated needs to be the cathode of the electrolytic cell.

Part C Matching

Match each description in Column B to the correct term in Column A.

	Column A	Column B
_____ **13.**	electrolysis	**a.** an electrolytic method for obtaining ultrapure metals
_____ **14.**	electrolytic cell	**b.** the process in which electrical energy is used to make a nonspontaneous reaction go forward
_____ **15.**	brine	**c.** the deposition of a thin layer of metal on an object in an electrolytic cell
_____ **16.**	electroplating	**d.** an electrochemical cell used to cause a chemical change through the application of electrical energy
_____ **17.**	electrorefining	**e.** a concentrated solution of sodium chloride

Part D Questions and Problems

Answer the following in the space provided.

18. Distinguish between electrolytic and voltaic cells and list some applications of each.

19. Sketch an electrolytic cell that could be used to silverplate a teaspoon. Label the anode, cathode, and the direction of electron flow. Write the anode and cathode reactions that occur.

Name _____ Class _____ Date _____

23 ELECTROCHEMISTRY
PRACTICE PROBLEMS

Use Table 23.2 to solve the following problems in your notebook.

SECTION 23.2 HALF-CELLS AND CELL POTENTIALS

1. Determine the cell reaction, the standard cell potential (E^0_{cell}) and the half-cell that acts as the cathode for the voltaic cells composed of the following half-cells.

   a. $Mg^{2+}(aq) + 2e^- \rightarrow Mg(s)$

   $Cl_2(g) + 2e^- \rightarrow 2Cl^-(aq)$

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

   $Ag^+(aq) + e^- \rightarrow Ag(s)$

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

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

   d. $Br_2(l) + 2e^- \rightarrow 2Br^-(aq)$

   $Na^+(aq) + e^- \rightarrow Na(s)$

   e. $2H^+(aq) + 2e^- \rightarrow H_2(g)$

   $MnO_2(s) + 4H^+(aq) + 2e^- \rightarrow Mn^{2+}(aq) + 2H_2O(l)$

2. Calculate E^0_{cell} to determine whether the following redox reactions are spontaneous as written.

   a. $Sn^{2+}(aq) + Ba(s) \rightarrow Sn(s) + Ba^{2+}(aq)$

   b. $2Ag^+(aq) + 2Cl^-(aq) \rightarrow 2Ag(s) + Cl_2(g)$

   c. $Zn(s) + F_2(g) \rightarrow 2F^-(aq) + Zn^{2+}(aq)$

   d. $2Li(s) + Co^{2+}(aq) \rightarrow 2Li^+(aq) + Co(s)$

   e. $2I^-(aq) + K^+(aq) \rightarrow I_2(s) + K(s)$

Name _____ Class _____ Date _____

23 INTERPRETING GRAPHICS

USE WITH SECTION 23.3

Electrolysis is sometimes used to purify metals from mixtures. In this process, a slab or bar of impure metal, containing many types of metallic elements, is made the anode of an electrolytic cell. When external electrical energy is supplied to the cell, metallic elements in the anode are oxidized to cations which dissolve in solution. Then the cations are reduced to the pure metal at the surface of the cathode. A schematic diagram of an electrolytic cell used to purify copper is shown below. If the voltage supply is carefully regulated, less reactive metals are not oxidized at the anode, but instead collect as "mud" at the bottom of the cell below the anode. Metals more reactive than copper are oxidized at the anode, but are not reduced at the cathode; therefore, they remain dissolved as ions in the electrolyte solution ($CuSO_4$).

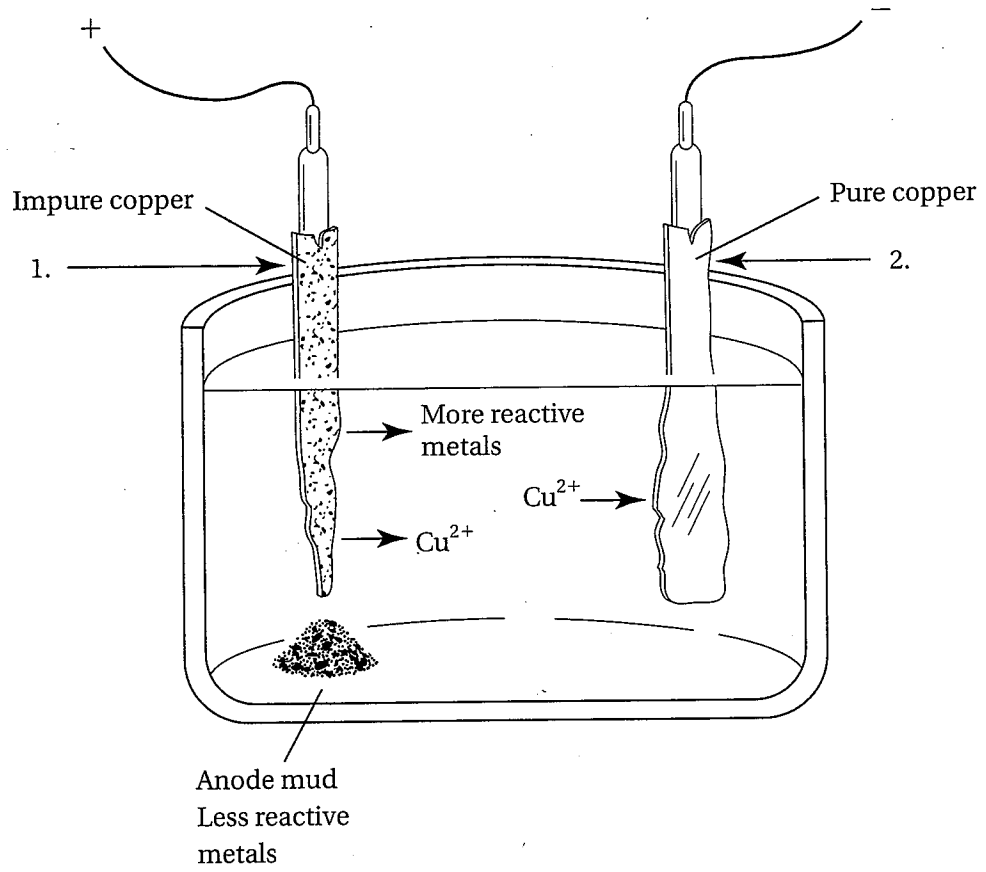

Figure 1 Purification of copper by electrolysis at 25 °C, 101.3 kPa, in 1*M* $CuSO_4$.

Identify the anode and cathode in the diagram. Write your answers on the lines provided.

1. _____ **2.** _____

3. What name is given to the technique used to obtain pure copper by electrolysis?

_____

Name _____ Class _____ Date _____

4. The apparatus depicted in Figure 1 is not complete, the electrolytic cell must be connected to a DC source (a battery).
   a. To which electrodes of the battery, positive (+) or negative (−), should the anode and cathode of the electrolytic cell be connected?

   b. Describe the connections in terms of the anode and cathode of the battery.

5. At which of the electrodes, numbered 1 and 2 in Figure 1, is oxidation occurring? Reduction? Label the electrodes in the diagram.

6. Using arrows, annotate the diagram in Figure 1 to show the flow of electrons out of or into the electrodes.

The E^0_{red} values for several metals are shown below.

$E^0_{Zn^{2+}} = -0.76\,V$ $E^0_{Cu^{2+}} = +0.34\,V$ $E^0_{Au^{3+}} = +1.50\,V$
$E^0_{Fe^{2+}} = -0.44\,V$ $E^0_{Ag^{+}} = +0.80\,V$ $E^0_{Pt^{2+}} = +1.18\,V$

Assume that all of these metals are present in the impure metal anode. Use these data to answer the following questions.

7. What voltage should be applied to the electrolytic cell to purify copper in the manner described above?

8. If the voltage from the DC source is maintained at 0.40 V:
   a. Which metals will be found in the anode mud when the electrolysis is complete?

   b. Which cations will be found dissolved in the electrolyte solution?

   c. Which metal(s) will plate out at the cathode?

Name _____ Class _____ Date _____

23 VOCABULARY REVIEW

Each clue describes a vocabulary term. Read the clues and write the letters of each term on the lines provided.

1. Clue: an electrochemical cell used to convert chemical energy into electrical energy.

   ___ ___ ___ ___ ___ ◯ ___ ___ ___ ___ ◯

2. Clue: cell in which a fuel undergoes oxidation to produce electrical energy.

   ___ ◯ ___ ___ ___ ___ ___ ___

3. Clue: any device that converts chemical energy into electrical energy or electrical energy into chemical energy.

   ___ ___ ___ ___ ___ ___ ___ ___ ___ ___ ◯ ___ ___ ___ ___

   ___ ___ ___ ___

4. Clue: the interconversion of chemical energy and electrical energy.

   ___ ___ ___ ___ ___ ___ ___ ___ ___ ___ ◯ ___ ___ ___ ___

   ___ ___ ___ ___ ___ ___ ___

5. Clue: the electrode at which reduction occurs.

   ___ ◯ ___ ___ ___ ___ ___

6. Clue: a measure of the tendency of a given half-reaction to occur as a reduction in an electrochemical cell.

   ___ ___ ___ ◯ ___ ___ ___ ___ ___

   ___ ___ ___ ___ ◯ ___ ___ ___ ___

Write the letters found inside the circles on the lines below. Then unscramble them to find the name of one metal commercially produced by electrolysis.

Scrambled letters:

___ ___ ___ ___ ___ ___ ___ ___

Solution:

___ ___ ___ ___ ___ ___ ___ ___

Name _____ Class _____ Date _____

23 ELECTROCHEMISTRY

Quiz for CHAPTER 23

Classify each of these statements as always true, AT; sometimes true, ST; or never true, NT.

_____ **1.** In a lead storage battery, the sulfuric acid concentration increases during discharge. *23.1*

_____ **2.** The oxidation half-reaction in a voltaic cell occurs at the anode. *23.1*

_____ **3.** In a flashlight battery, the zinc metal case is the cathode. *23.1*

_____ **4.** A strip of zinc metal, when dipped into a solution of copper sulfate, becomes copper plated. (Zinc is more easily oxidized than copper.) *23.1*

_____ **5.** Batteries can be recharged. *23.1*

_____ **6.** Voltaic cells were named for electromotive force (emf), which is measured in volts. *23.1*

_____ **7.** A salt bridge allows for the passage of electrons from one half-cell to another half-cell. *23.1*

_____ **8.** In a voltaic cell, a wire carries the electrons in the external circuit from the anode to the cathode. *23.1*

_____ **9.** In a voltaic cell, the anode is the negative electrode. *23.1*

_____ **10.** Fuel cells use methane as fuel. *23.1*

_____ **11.** The standard hydrogen electrode is assigned a reduction potential of 1.00 V. *23.2*

_____ **12.** The anode in an electrolytic cell is the positive electrode. *23.3*

_____ **13.** The electrolysis of brine produces chlorine gas at the cathode. *23.3*

_____ **14.** The standard cell potential is the measured cell potential when the ion concentrations are 1*M*, any gases are at a pressure of 101 kPa, and the temperature is 25 °C. *23.2*

_____ **15.** $E^0_{cell} = E^0_{red} + E^0_{oxid}$ *23.2*

_____ **16.** A standard reduction potential for a half-cell is negative if the tendency for reduction to occur is less than the tendency of hydrogen ions to be reduced to hydrogen gas. *23.2*

_____ **17.** A redox reaction is spontaneous if the standard cell potential is positive. *23.2*

_____ **18.** Electroplating is the deposition of a thin layer of a metal on an object in a voltaic cell. *23.3*

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23 ELECTROCHEMISTRY
CHAPTER TEST A

A. Matching

Match each term in Column B with the correct description in Column A.

Column A		Column B
_____	**1.** a conductor in a circuit that carries electrons to or from a substance other than a metal	**a.** anode
_____	**2.** one part of a voltaic cell, in which either oxidation or reduction occurs	**b.** electrode
_____	**3.** a voltaic cell in which the electrolyte is a paste	**c.** cathode
_____	**4.** the electrode at which reduction occurs	**d.** dry cell
_____	**5.** a voltaic cell in which a fuel undergoes oxidation and from which electrical energy is obtained continuously	**e.** battery
_____	**6.** an electrochemical cell that is used to convert chemical energy into electrical energy	**f.** electrolysis
_____	**7.** a tube containing a conducting solution	**g.** voltaic cell
_____	**8.** a group of cells that are connected together	**h.** half-cell
_____	**9.** the process in which electrical energy is used to bring about a chemical change	**i.** salt bridge
_____	**10.** the electrode at which oxidation occurs	**j.** fuel cell

B. Multiple Choice

Write the letter of the best answer in the blank.

_____ **11.** In the electrolysis of brine, the substance produced at the cathode is:
- **a.** chlorine.
- **b.** oxygen.
- **c.** sodium.
- **d.** hydrogen.

_____ **12.** Which of the following describes a dry cell?
- **a.** It can be recharged many times.
- **b.** The graphite rod does not undergo reduction, even though it is the cathode.
- **c.** It contains concentrated sulfuric acid.
- **d.** all of these

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_____ **13.** A clean strip of copper is dipped into a solution of magnesium sulfate. Magnesium is above the copper in the activity series of metals. Predict what you will observe.
a. The copper strip becomes magnesium-plated.
b. Copper dissolves and the solution turns blue.
c. No reaction occurs.
d. Bubbles of hydrogen gas appear on the copper.

_____ **14.** A clean iron nail is dipped into a solution of silver nitrate. Iron is above silver in the activity series of metals. Predict what you will observe.
a. The iron will be reduced.
b. Bubbles of nitrogen gas will form on the iron nail.
c. The iron nail will become silver-plated.
d. No reaction occurs.

_____ **15.** In a fully charged lead storage battery, the cathode grid is packed with:
a. spongy lead.
b. lead sulfate.
c. lead(IV) oxide.
d. sulfuric acid.

_____ **16.** Which of the following is true about fuel cells?
a. They can be designed so that they emit no pollutants.
b. They are inexpensive.
c. They have never been built or used.
d. They produce energy in short bursts only.

_____ **17.** Which of the following is true for an electrolytic cell?
a. It changes electrical energy into chemical energy.
b. It is the type of cell used in electroplating.
c. It uses an electric current to make a nonspontaneous reaction go.
d. all of these

_____ **18.** When a lead storage battery discharges:
a. the concentration of lead sulfate in the battery decreases.
b. the concentration of sulfuric acid increases.
c. the concentration of sulfuric acid decreases.
d. none of these

_____ **19.** A zinc-copper cell is constructed:

$$Zn \mid Zn^{2+}\ (1M) \parallel Cu^{2+}\ (1M) \mid Cu$$

What occurs to the mass of the copper electrode as the reaction proceeds? (Zinc is above copper in the activity series of metals.)
a. It increases.
b. It remains the same.
c. It decreases.

_____ **20.** In the cell reaction described in question 19, the negative electrode is:
a. $Zn(s)$.
b. $Cu^{2+}(aq)$.
c. $Zn^{2+}(aq)$.
d. $Cu(s)$.

_____ **21.** Which half-reaction occurs at the negative electrode in an electrolytic cell in which an object is being plated with silver?
a. $Ag + 1e^- \rightarrow Ag^+$
b. $Ag \rightarrow Ag^+ + 1e^-$
c. $Ag^+ + 1e^- \rightarrow Ag$
d. $Ag^+ \rightarrow Ag + 1e^-$

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_____ **22.** Which metal will react spontaneously with $Cu^{2+}(aq)$ at 25 °C?
a. Ag **c.** Mg
b. Au **d.** Hg

_____ **23.** Which reaction occurs when bromine is added to an aqueous solution of iodide ions?
a. $2I^- + Br_2 \rightarrow I_2 + 2Br^-$ **c.** $2I^- + 2Br^- \rightarrow I_2 + Br_2$
b. $I_2 + 2Br \rightarrow Br_2 + 2I^-$ **d.** $I_2 + Br_2 \rightarrow 2I^- + 2Br^-$

_____ **24.** Which ion can be most easily reduced?
a. Cu^{2+} **c.** Fe^{2+}
b. Zn^{2+} **d.** Ca^{2+}

_____ **25.** Oxygen and copper are produced during the electrolysis of a CuO solution. Which reaction occurs at the negative electrode?
a. Oxygen ions are reduced. **c.** Copper ions are reduced.
b. Oxygen atoms are oxidized. **d.** Copper atoms are oxidized.

C. True-False

Classify each of these statements as always true, AT; sometimes true, ST; or never true, NT.

_____ **26.** During the electrolysis of brine, chlorine gas is produced at the cathode.

_____ **27.** Copper is above gold in the activity series of metals because copper is less reactive and less easily oxidized.

_____ **28.** The oxidation half-reaction in a voltaic cell occurs at the anode.

_____ **29.** Cell potential is the sum of the reduction potential of the half-cell where reduction occurs and the reduction potential of the half-cell where oxidation occurs.

_____ **30.** In an electrolytic cell, oxidation occurs at the cathode and reduction occurs at the anode.

D. Questions

Answer the following question in the space provided.

31. Draw a voltaic cell. Label the cathode, anode, salt bridge, and direction of the flow of electrons.

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E. Essay

Write a short essay for the following.

32. State the sign of the electrodes and the reaction that occurs at each electrode for both voltaic and electrolytic cells.

F. Additional Questions

Answer the following questions in the space provided.

33. The standard reduction potential for the cobalt half-cell is −0.28 V. What is the significance of the negative value? (Refer to the standard hydrogen half-cell in your answer.)

34. What is meant by the reduction potential of a half-cell?

35. Are the following redox reactions spontaneous as written? (Use the information in the Reference Section. Show your work.)

a. $Ni(s) + Zn^{2+}(aq) \rightarrow Ni^{2+}(aq) + Zn(s)$

b. $3Co(s) + 2Al^{3+}(aq) \rightarrow 3Co^{2+}(aq) + 2Al(s)$

Reference Section

Reduction Potentials at 25 °C		
Electrode	**Half-Reaction**	**E°(V)**
Al^{3+}/Al	$Al^{3+} + 3e^- \rightarrow Al$	−1.66
Zn^{2+}/Zn	$Zn^{2+} + 2e^- \rightarrow Zn$	−0.76
Co^{2+}/Co	$Co^{2+} + 2e^- \rightarrow Zn$	−0.28
Ni^{2+}/Ni	$Ni^{2+} + 2e^- \rightarrow Ni$	−0.25

Name _____ Class _____ Date _____

23 ELECTROCHEMISTRY
CHAPTER TEST B

A. Matching

Match each term in Column B with the correct description in Column A.

	Column A	Column B
_____ 1.	the ability of a voltaic cell to produce an electric current	**a.** fuel cells
_____ 2.	any device that converts chemical energy into electrical energy or electrical energy into chemical energy	**b.** salt bridge
_____ 3.	the process in which electrical energy in used to bring about a chemical change	**c.** battery
_____ 4.	the electrode at which oxidation occurs	**d.** electrochemical cell
_____ 5.	a group of voltaic cells that are connected together	**e.** cathode
_____ 6.	electrochemical cells that are used to convert chemical energy into electrical energy	**f.** electrolysis
_____ 7.	a voltaic cell in which the electrolyte is a paste	**g.** voltaic cells
_____ 8.	the electrode at which reduction occurs	**h.** electrical potential
_____ 9.	a tube containing a conducting solution that lets ions pass from one compartment of a voltaic cell to another	**i.** anode
_____ 10.	voltaic cells in which a fuel undergoes oxidation and from which electrical energy is obtained continuously	**j.** dry cell

B. Multiple Choice

Write the letter of the best answer in the blank. Refer to the Reference Section on p. 71 for the reduction potentials as needed.

_____ **11.** Which of the following is true concerning the reaction given below?

$$Zn(s) + 2H^+(aq) \rightarrow Zn^{2+}(aq) + H_2(g)$$

a. $Zn(s)$ is being reduced.
b. $H^+(aq)$ is being oxidized.
c. Electrons are being transferred from $Zn(s)$ to $H^+(aq)$.
d. all of these

_____ **12.** If Al is above Co in the activity series of metals, which of the following will occur if a strip of Al is dipped into a solution of $Co(NO_3)_2$?
a. A redox reaction takes place.
b. The Al strip dissolves.
c. The Al strip becomes coated with Co.
d. all of these

Name _____ Class _____ Date _____

_____ **13.** In an electrochemical cell, the anode is:
- **a.** the electrode at which reduction occurs.
- **b.** the electrode at which electrons are produced.
- **c.** the positive electrode.
- **d.** all of these

_____ **14.** If Mg is above Ni in the activity series of metals, which of the following will occur if a strip of Mg is dipped into a solution of $Ni(NO_3)_2$?
- **a.** No reaction occurs.
- **b.** The Ni^{2+} loses electrons.
- **c.** The Mg is oxidized.
- **d.** none of these

_____ **15.** Which of the following is true concerning the electrochemical cell represented by the following?

$$Mn(s) \mid Mn(NO_3)_2(aq) \parallel PbSO_4(aq) \mid Pb(s)$$

- **a.** Pb is oxidized.
- **b.** Mn is reduced.
- **c.** A strip of Pb is dipped into a solution of $Mn(NO_3)_2$.
- **d.** Electrons are lost at the Mn electrode.

_____ **16.** Which of the following is true about a dry cell?
- **a.** It is a voltaic cell in which the electrolyte is a paste.
- **b.** Zn serves as the cathode.
- **c.** Graphite serves as the anode.
- **d.** all of these

_____ **17.** In a lead storage battery:
- **a.** the anode is packed with spongy lead and the cathode is packed with lead(IV) oxide.
- **b.** the electrodes are immersed in sulfuric acid.
- **c.** the system can be recharged by the passage of electric current through the cell.
- **d.** all of these

_____ **18.** If the metals Ca, Zn, Fe, and Cu are listed in that order in the activity series of metals, the one that would be most readily oxidized is:
- **a.** Ca.
- **b.** Zn.
- **c.** Fe.
- **d.** Cu.

_____ **19.** Among the metals listed in question 18, the one that would be most readily reduced is:
- **a.** Ca.
- **b.** Zn.
- **c.** Fe.
- **d.** Cu.

_____ **20.** In a hydrogen-oxygen fuel cell:
- **a.** oxygen is fed into the anode compartment.
- **b.** hydrogen is fed into the cathode compartment.
- **c.** the net reaction is the oxidation of hydrogen to form water.
- **d.** all of these

_____ **21.** The standard reference electrode that is used with other electrodes to measure their reduction potentials consists of:
- **a.** Zn.
- **b.** H_2.
- **c.** Cu.
- **d.** Ag.

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_____ **22.** Which of the following is true concerning standard reduction potentials?
- **a.** A positive value indicates that the tendency for a specified substance to be reduced is less than that of H^+.
- **b.** A negative value indicates that the tendency for a specified substance to be reduced is more than that of H^+.
- **c.** The half-reactions at the top of the standard reduction potential table have the greatest tendency to occur as oxidations.
- **d.** all of these

_____ **23.** The standard cell potential of a cell composed of the half-cells

$$Zn \mid Zn^{2+} \parallel Pb^{2+} \mid Pb$$ is:

- **a.** +0.89 V.
- **b.** +0.63 V.
- **c.** −0.89 V.
- **d.** −0.63 V.

_____ **24.** In the voltaic cell described in question 23, the anode is:
- **a.** Zn.
- **b.** Zn^{2+}.
- **c.** Pb^{2+}.
- **d.** Pb.

_____ **25.** Among the following reactions, which would be expected to occur spontaneously?
- **a.** $Cu(s) + Mg^{2+}(aq) \rightarrow Cu^{2+}(aq) + Mg(s)$
- **b.** $2Na(s) + Pb^{2+}(aq) \rightarrow 2Na^{+}(aq) + Pb(s)$
- **c.** $2Ag(s) + Zn^{2+}(aq) \rightarrow 2Ag^{+}(aq) + Zn(s)$
- **d.** all of these

_____ **26.** Which of the following is true about an electrolytic cell?
- **a.** Electrons flow from the cathode to the anode in the external circuit.
- **b.** Oxidation occurs at the cathode.
- **c.** The redox reaction involved in such a cell is nonspontaneous.
- **d.** all of these

_____ **27.** The net products that result from the electrolysis of water are:
- **a.** H_2 and OH^-.
- **b.** O_2 and H^+.
- **c.** H^+ and OH^-.
- **d.** H_2 and O_2.

C. True-False

Classify each of these statements as always true, AT; sometimes true, ST; or never true, NT.

_____ **28.** Given any two elements in the activity series of metals, the one that appears above the other undergoes reduction.

_____ **29.** The salt bridge in a voltaic cell provides a pathway for the electrons to flow from one electrode to the other.

_____ **30.** A flashlight battery is an example of a dry cell.

_____ **31.** The specific gravity of the sulfuric acid contained in a lead storage battery is an indication of the condition of that battery.

_____ **32.** Half-cell potentials cannot be measured.

_____ **33.** The standard cell potential for a voltaic cell consisting of some combination of Zn, Zn^{2+}, F_2 and F^- would be a positive value.

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D. Questions

Answer the following questions in the space provided.

34. Given the following voltaic cell, draw the cell and label the cathode, anode, salt bridge, and direction of flow of the electrons.

$$Cu(s) \mid Cu(NO_3)_2(aq) \parallel AgNO_3(aq) \mid Ag(s)$$

35. Based on the information given in question 34, write the two half-reactions, as well as the final net reaction for the Cu-Ag voltaic cell. Use the information provided in the Reference Section to calculate the standard cell potential for this voltaic cell.

E. Essay

Write a short essay for the following.

36. Give at least three similarities and three differences between voltaic and electrolytic cells.

Reference Section

Reduction Potentials at 25 °C	
Electrode	**E^0 (V)**
N^+/Na	−2.71 V
Mg^{2+}/Mg	−2.37 V
Al^{3+}/Al	−1.66 V
Zn^{2+}/Zn	−0.76 V
Pb^{2+}/Pb	−0.13 V
Cu^{2+}/Cu	+0.34 V
Ag^+/Ag	+0.80 V
F_2/F	+2.87 V

Name _____ Class _____ Date _____

F. Additional Questions

Answer the following questions in the space provided.

37. Write the half-cell reactions and the net reaction for the following voltaic cell. Calculate the standard cell potential for the cell.

$$Al(s) \mid Al^{3+}(aq) \parallel Pb^{2+}(aq) \mid Pb(s)$$

38. Determine which of the following redox reactions will occur spontaneously and calculate the standard cell potential in each case.

a. $2Na(s) + Cu^{2+}(aq) \rightarrow 2Na^{+}(aq) + Cu(s)$

b. $2Ag(s) + Mg^{2+}(aq) \rightarrow 2Ag^{+}(aq) + Mg(s)$

c. $2Al(s) + 3Zn^{2+}(aq) \rightarrow 2Al^{3+}(aq) + 3Zn(s)$

39. Given the hypothetical elements W, X, Y, and Z, along with their corresponding ions W^{2+}, X^{2+}, Y^{2+}, and Z^{2+}, use the information provided below to determine the order in which these elements should be listed in the activity series of metals.

Reaction 1: $X^{2+} + Z \rightarrow X + Z^{2+}$	(reacts spontaneously)
Reaction 2: $W + X^{2+} \rightarrow$	(does not react)
Reaction 3: $Y + Z^{2+} \rightarrow Y^{2+} + Z$	(reacts spontaneously)