Lesson 42 Spontaneous Redox Reactions

Key Words

electrochemical cell: redox system that produces electricity
half-cell: metal placed in a solution of a salt of that metal
salt bridge: tube of salt connecting two half-cells
spontaneous reaction: reaction that takes place without the use of outside energy
voltage: measure of electric force

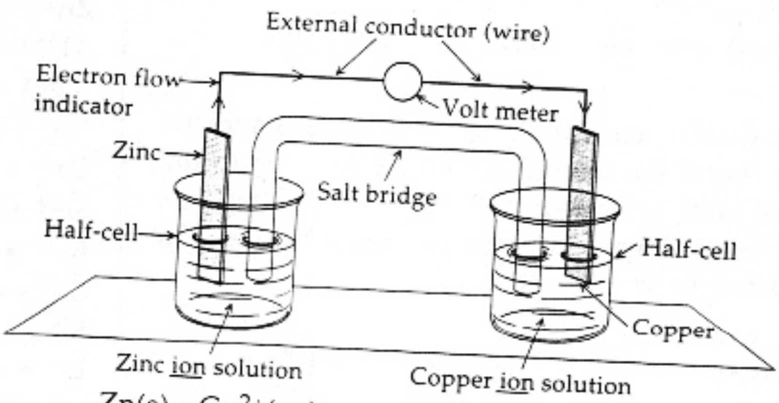
KEY IDEAS

In an electrochemical cell, oxidation and reduction take place in two different half-cells. This reaction is spontaneous, and it produces electricity.

Auto mechanics work with batteries, and batteries are made of electrochemical cells. The reactions inside these cells produce the electricity that starts a car's engine. This electricity also makes the car's lights work and runs the car's other electrical parts.

Redox and Electricity. An **electrochemical cell** (ee-LEHK-troh-KEHM-ih-kuhl) is made of two half-cells, an external conductor, and a salt bridge. These parts are shown in Fig. 42-1.

Fig. 42-1



$$Zn(s) + Cu^{2+}(aq) \longrightarrow Zn^{2+}(aq) + Cu^{\circ}(s)$$

A **half-cell** is made of a metal strip in contact with a solution of its ions. As you can see in the zinc half-cell, the zinc loses electrons. Thus oxidation takes place in the zinc half-cell. Now look at the copper half-cell. Here electrons are gained, so reduction takes place in the copper half-cell.

In Fig. 42-1, the arrows show the path of the electrons. The electrons lost by the zinc metal move into the external conductor, or wire. The electrons then move through the voltmeter and the wire into the copper metal. The copper ions in solution gain the electrons and become copper metal.

The **salt bridge** is a tube that allows ions to move from one solution to another. This bridge completes the circuit. A **spontaneous reaction** (spahn-TAY-nee-uhs) takes place without outside energy. In the cell shown in Fig. 42-1, the reaction goes on until the zinc metal strip wears out. Then the cell no longer works.

Metals and Electrons. Recall that **GER** stands for Gain of Electrons is **R**eduction. Thus, a substance with a strong reduction potential is one that has a strong tendency to gain electrons. The table of standard reduction potentials shown in Fig. 42-2 lists substances in order of their tendency to be reduced, or gain electrons.

Voltage (VOHL-tihj) is a measure of electric force. The voltages of reactions taking place in half-cells, or half-reactions, are listed in the table. For example, in a zinc half-reaction, zinc ions (Zn^{2+}) gain electrons to become zinc metal (Zn°). The voltage (E°) for this half-reaction is –0.76 v. In a copper half-reaction, copper ions (Cu^{2+}) gain electrons to become copper metal (Cu°). The voltage for this half-reaction is +0.34 v.

All the reactions in the table show reduction, which is a gain of electrons. To find the voltage for oxidation, which is a loss of electrons, turn the equation around. Then reverse the sign of the voltage, as shown below.

reduction: $Zn^{2+} + 2e^- \longrightarrow Zn(s)$ $E^{\circ} = -0.76$ v

oxidation: $Zn(s) \longrightarrow Zn^{2+} + 2e^-$ $E^{\circ} = +0.76$ v

Look again at the Cu-Zn cell shown in Fig. 42-1 on page 206. You have already found the oxidation voltage for zinc in this cell. Now use the table to look up the reduction voltage for copper. Add the two voltages together as shown below. The sum is the voltage for the whole cell.

oxidation: $Zn(s) \longrightarrow Zn^{2+} + 2e^-$ $E^{\circ} = +0.76$ v

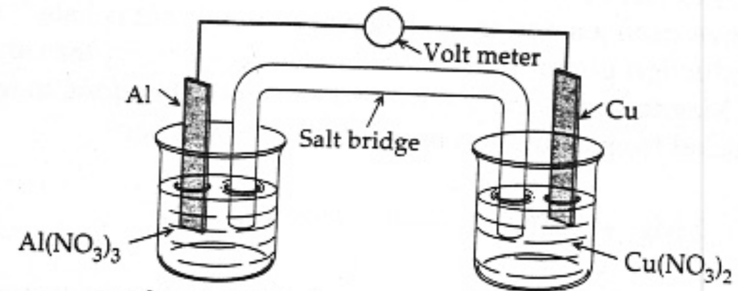
reduction: $Cu^{2+} + 2e^- \longrightarrow Cu(s)$ $E^{\circ} = +0.34$ v

Sum = +1.10 v

Fig. 42-2

STANDARD REDUCTION POTENTIALS	
Solutions are 1 M (ag)	
Half-cell Reaction	E° (volts)
$Au^{3+} + 3e^- \rightarrow Au(s)$	+1.50
$Hg^{2+} + 2e^- \rightarrow Hg(\ell)$	+0.85
$Ag^+ + e^- \rightarrow Ag(s)$	+0.80
$Fe^{3+} + e^- \rightarrow Fe^{2+}$	+0.77
$Cu^+ + e^- \rightarrow Cu(s)$	+0.52
$Cu^{2+} + 2e^- \rightarrow Cu(s)$	+0.34
$2H^+ + 2e^- \rightarrow Cu(s)$	0.00
$Pb^{2+} + 2e^- \rightarrow Pb(s)$	–0.13
$Sn^{2+} + 2e^- \rightarrow Sn(s)$	–0.14
$Ni^{2+} + 2e^- \rightarrow Ni(s)$	–0.26
$Co^{2+} + 2e^- \rightarrow Co(s)$	–0.28
$Fe^{2+} + 2e^- \rightarrow Fe(s)$	–0.45
$Cr^{3+} + 3e^- \rightarrow Cr(s)$	–0.74
$Zn^{2+} + 2e^- \rightarrow Zn(s)$	–0.76
$Al^{3+} + 3e^- \rightarrow Al(s)$	–1.66
$Mg^{2+} + 2e^- \rightarrow Mg(s)$	–2.37
$Na^+ + e^- \rightarrow Na(s)$	–2.71
$Ca^{2+} + 2e^- \rightarrow Ca(s)$	–2.87
$Sr^{2+} + 2e^- \rightarrow Sr(s)$	–2.89
$Ba^{2+} + 2e^- \rightarrow Ba(s)$	–2.91
$Cs^+ + e^- \rightarrow Cs(s)$	–2.92
$K^+ + e^- \rightarrow K(s)$	–2.93
$Li^+ + e^- \rightarrow Li(s)$	–3.04

Fig. 42-3



$$2Al^0(s) + 3Cu^{2+}(aq) \longrightarrow 2Al^{3+}(aq) + 3Cu^0(s)$$

Use the table on page 207 to find the voltages for each half-cell of the aluminum-copper cell shown in Fig. 42-3. The reduction voltage for the Al half-cell is –1.66 v. However, the Al will lose electrons because it is listed lower in the table than Cu. The loss of electrons from Al is oxidation.

The voltage for the Cu half-cell is listed as +0.34 v. To find the voltage for this Al-Cu cell, first change the reduction voltage to oxidation for the Al half-cell. Then add the two voltages together as shown below.

oxidation: $Al(s) \longrightarrow Al^{3+} + 3e^-$ $E° = +1.66$ v

reduction: $Cu^{2+} + 2e^- \longrightarrow Cu(s)$ $E° = +0.34$ v

Sum = +2.00 v

✓ **1. In a copper half-cell connected to a zinc half-cell, which metal loses electrons?** ____________________

✓ **2. In a copper half-cell connected to an aluminum half-cell, which metal gains electrons?** ____________________

✓ **3. What is the voltage of a zinc-silver cell in which the oxidation voltage (for zinc) is +0.76 v and the reduction voltage (for silver) is +0.80 v?**

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Metal Activity. The table on page 207 can be used to predict replacement reactions between metals and the ions of other metals. The most active metal, lithium (Li), has the lowest tendency to gain electrons, or to be reduced (**GER**). Thus Li is at the bottom of the table. Lithium also has the strongest tendency of the metals listed to lose electrons, or to be oxidized (**LEO**). The least active metal, gold (Au), is at the top of the table, so it has the greatest tendency to be reduced (**GER**). Gold also has the lowest tendency to lose electrons, or to be oxidized (**LEO**).

In a replacement reaction (see Lesson 27), a more active metal replaces one that is less active from a solution of its ions. A metal that is listed lower in the table of reduction potentials is more active, so it can replace any metal that is higher. Magnesium is more active than nickel. Therefore, magnesium will replace nickel from a solution of its ions as shown here.

$$2\,Mg + Ni(NO_3)_2 \longrightarrow 2\,MgNO_3 + Ni$$

Study the equation below and the table of standard reduction potentials on page 207. Notice that zinc is lower in the table and will replace the copper from solution.

$$Zn + CuSO_4 \longrightarrow ZnSO_4 + Cu$$

✓ **4. If an iron nail is placed in a copper sulfate solution, will a reaction take place? Use the table to find out.** ______________________________

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Look at the equation below.

$$Ag + CuSO_4 \longrightarrow \text{no reaction}$$

Silver is above copper in the table. Thus silver is less active than copper. A spontaneous reaction will not take place.

Reactions with Acids. Solutions of acids produce hydrogen ions (H^+). All the reduction potentials listed in the table are determined by comparison with the H^+ half-cell, which has a voltage (E°) of 0.00 v. Thus the table can be used to predict which metals will react with acids such as sulfuric acid (H_2SO_4) and hydrochloric acid (HCl). Metals listed in the table below hydrogen react spontaneously with these acids. For example, aluminum is listed in the table below hydrogen, so aluminum will react with hydrochloric acid.

Look at the equation below.

$$2Al + 6HCl \longrightarrow 2AlCl_3 + 3H_2$$

Find iron in the table. Notice that iron will also react with HCl. Gold is in the table above hydrogen, so gold will not react with H_2SO_4.

✓ **5. Will silver (Ag) react with H_2SO_4?** ______________________________

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TAKE ANOTHER LOOK

Look at Fig. 42-4 which shows a strip of zinc placed into a copper sulfate solution. Copper forms a coating on the zinc. The zinc replaces the copper from solution because zinc is more active than the copper. Thus, a spontaneous redox reaction is taking place.

Look at Fig. 42-5 which shows a strip of magnesium placed into hydrochloric acid. The acid gives off bubbles of hydrogen gas. Magnesium is an active metal listed in the table on page 207 below hydrogen. Thus, magnesium replaces the hydrogen from the acid.

Fig. 42-4

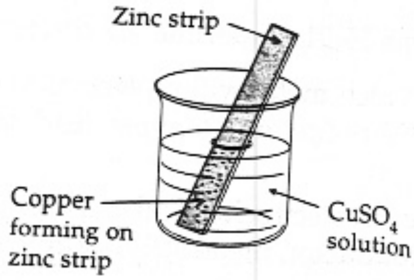
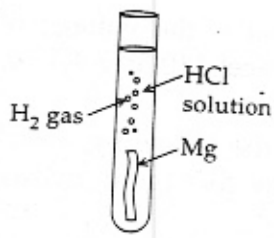


Fig. 42-5



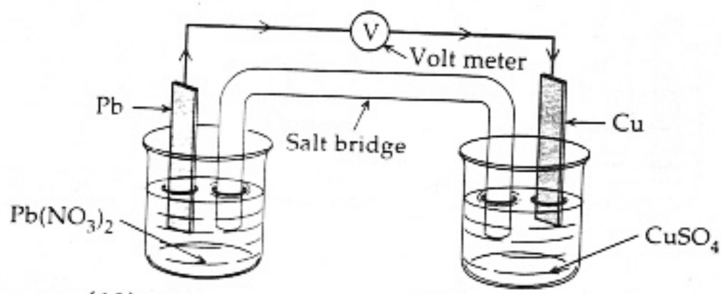
Check Your Understanding

Fill in the blanks with the following terms: *half-cell(s), external conductor, salt bridge; spontaneous, voltage*. The underlined terms will be used more than once.

Electrochemical cells are made of two **(6)**____________________, a(n) **(7)**____________________, and a(n) **(8)**____________________. A(n) **(9)**____________________ reaction takes place without outside energy. A(n) **(10)**____________________ is a tube of salt connecting two half-cells. A measure of electric force is **(11)**____________________. A(n) **(12)**____________________ contains a metal placed in a solution of ions of that metal.

Use Fig. 42-6 to complete items 13 – 17. Lable the half cells in items 13 and 14.

Fig. 42-6



(13) _______________ **(14)** _______________

15. In which half-cell is there a loss of electrons? ____________________
16. In which half-cell is there a gain of electrons? ____________________
17. On the lines below, calculate E° for the cell.

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In items 18-21, underline the correct answer.

18. Which metal will replace nickel from solution? Use the table on page 207 to find out. (copper, lead, silver, iron)

19. In an electrochemical cell, ions move through the (salt bridge, external conductor, metal strip, voltmeter).

20. What is the voltage of a cell made of a zinc half-cell and a copper half-cell? (0.55 v, 1.10 v, 1.35 v, 1.85 v)

21. Of the following, which is the most active metal listed in the table on page 207? (gold, hydrogen, zinc, lithium)

Answer the following questions. Use the table on page 207 for help.

22. Which metal will replace chromium but not aluminum from solution?

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23. Explain why silver will not react with hydrochloric acid but magnesium will react with this acid. ______________________________

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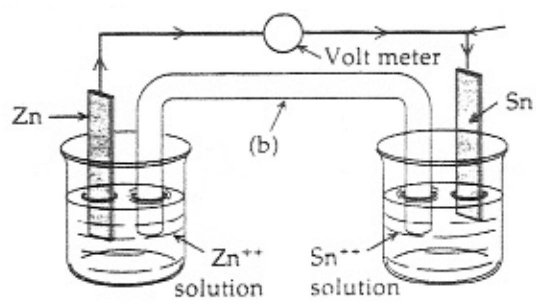
An electrochemical cell is set up as shown in Fig. 42-7. Use the diagram to complete items 24 – 29.

Fig. 42-7



Which metal loses electrons? **(24)**________________ Which metal gains electrons? **(25)**________________ What are the voltages of each half-reaction? **(26)**________________ What is the voltage of the whole cell? **(27)**________________ In which half-cell does oxidation take place? **(28)**________________ In which half-cell does reduction take place? **(29)**________________