6.4 Voltaic Cells

We're people on the go…with laptop computers, portable drills, and electronic games that kids can play in the car. To keep all of these tools and toys working, we need batteries, and because the newer electronic devices require more power in smaller packages, scientists are constantly searching for stronger and more efficient batteries. The goal of this section is to help you understand how batteries work and to describe some that may be familiar to you and some that may be new.

A **battery** is a device that converts chemical energy into electrical energy using redox reactions. To discover what this means and how batteries work, let's examine a simple system that generates an electric current using the reaction between zinc metal and copper(II) ions described in Figure 6.4. In this redox reaction, uncharged zinc atoms are oxidized to zinc ions, and copper(II) ions are reduced to uncharged copper atoms.

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

$$\text{oxidation:} \quad Zn(s) \rightarrow Zn^{2+}(aq) + 2e^-$$

$$\text{reduction:} \quad Cu^{2+}(aq) + 2e^- \rightarrow Cu(s)$$

The last section showed how this reaction takes place when zinc metal is added to a solution of copper(II) sulfate. When a Cu^{2+} ion collides with the zinc metal, two electrons are transferred from a zinc atom directly to the copper(II) ion.

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A clever arrangement of the reaction components allows us to harness this reaction to produce electrical energy. The setup, shown in Figure 6.5, keeps the two half-reactions separated, causing the electrons released in the oxidation half of the reaction to pass through a wire connecting the two halves of the apparatus. The proper name for a set-up of this type is a **voltaic cell**. Strictly speaking, a **battery** is a series of voltaic cells joined in such a way that they work together.

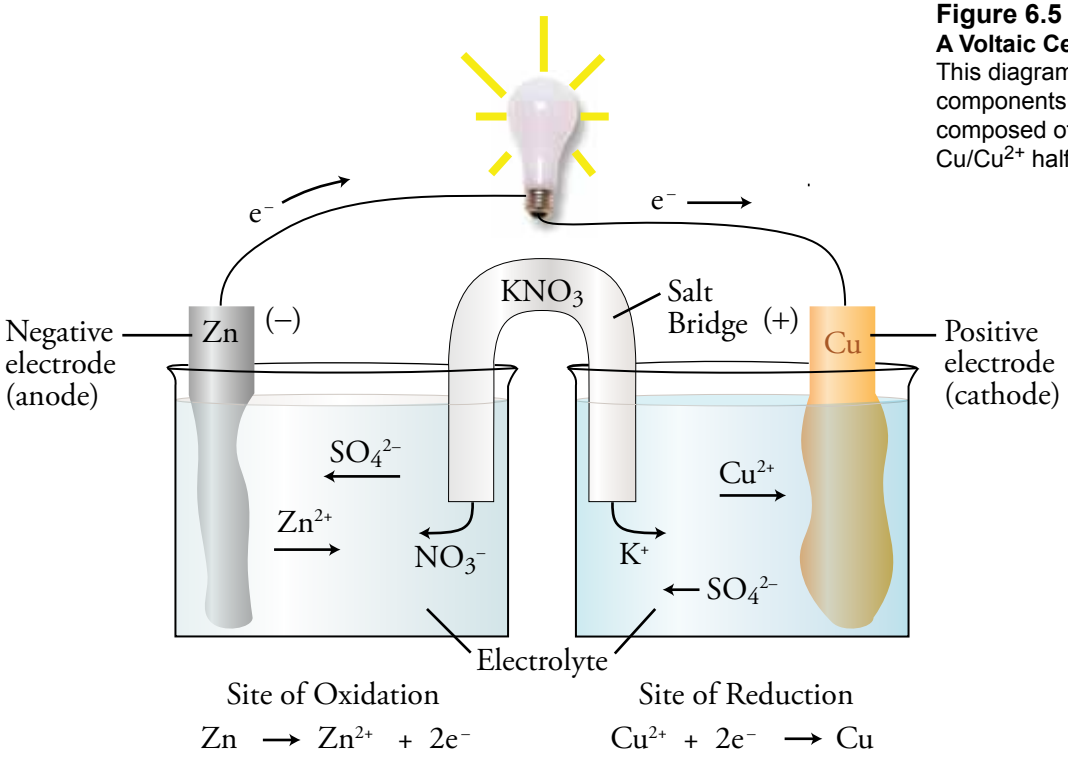

Figure 6.5
A Voltaic Cell
This diagram shows the key components of a voltaic cell composed of the Zn/Zn^{2+} and Cu/Cu^{2+} half-cells.

A voltaic cell, then, is composed of two separate half-cells. In the case of the zinc and copper(II) redox reaction, the first half-cell consists of a strip of zinc metal in a solution of zinc sulfate. The second half-cell consists of a strip of copper metal in a solution of copper(II) sulfate. In the Zn/Zn^{2+} half-cell, zinc atoms lose two electrons and are converted to zinc ions. The two electrons pass through the wire to the Cu/Cu^{2+} half-cell, where Cu^{2+} ions gain the two electrons to form uncharged copper atoms. The zinc metal and copper metal strips are called **electrodes**, the general name for electrical conductors placed in half-cells of voltaic cells.

Messages were originally sent through telegraph wires by voltaic cells composed of Zn/Zn^{2+} and Cu/Cu^{2+} half-cells.

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The electrode at which oxidation occurs in a voltaic cell is called the **anode**. Because electrons are lost in oxidation, the anode is the source of electrons. For this reason, the anode of a voltaic cell is designated the negative electrode. Because electrons are lost, forming more positive (or less negative) species at the anode, the anode surroundings tend to become more positive. Thus anions are attracted to the anode. In our voltaic cell, Zn is oxidized to Zn^{2+} at the zinc electrode, so this electrode is the anode. The solution around the zinc metal becomes positive due to excess Zn^{2+} ions, so anions are attracted to the zinc electrode.

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The **cathode** is the electrode in a voltaic cell at which reduction occurs. By convention, the cathode is designated the positive electrode. Because electrons flow along the wire

to the cathode, and because substances gain those electrons to become more negative (or less positive), the cathode surroundings tend to become more negative. Thus cations are attracted to the cathode. In our voltaic cell, Cu^{2+} ions are reduced to uncharged copper atoms at the copper strip, so metallic copper is the cathode. Because cations are removed from the solution there and anions are not, the solution around the copper cathode tends to become negative and attracts cations.

The component of the voltaic cell through which ions are able to flow is called the **electrolyte**. For our voltaic cell, the zinc sulfate solution is the electrolyte in the anode half-cell, and the copper(II) sulfate solution is the electrolyte in the cathode half-cell.

As described above, the Zn/Zn^{2+} half-cell tends to become positive due to the loss of electrons as uncharged zinc atoms are converted into Zn^{2+} ions, and the Cu/Cu^{2+} half-cell tends to become negative due to the gain of electrons and the conversion of Cu^{2+} ions into uncharged copper atoms. This charge imbalance would block the flow of electrons and stop the redox reaction if something were not done to balance the growing charges. One way to keep the charge balanced is to introduce a device called a **salt bridge**.

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One type of salt bridge is a tube connecting the two solutions and filled with an unreactive ionic compound such as potassium nitrate in a semisolid support such as gelatin or agar. For each negative charge lost at the anode due to the loss of an electron, an anion, such as NO_3^-, moves from the salt bridge into the solution to replace it. For example, when one zinc atom oxidizes at the anode and loses two electrons to form Zn^{2+}, two nitrates enter the solution to keep the solution electrically neutral overall. For each negative charge gained at the cathode due to the gain of an electron, a cation, such as K^+ ion, moves into the solution to keep the solution uncharged. For example, each time a copper ion gains two electrons and forms an uncharged copper atom, two potassium ions enter the solution to replace the Cu^{2+} lost.