> A motor and a generator are actually the same device, with input and output reversed. The electrical device in a hybrid car operates both ways.
>
> **Insights**

Any current in the loop has one direction in the upper side of the loop and the opposite direction in the lower side (because charges flowing into one end of the loop must flow out the other end). If the upper side of the loop is forced to the left by the magnetic field, the lower side is forced to the right, as if it were a galvanometer. But, unlike the situation in a galvanometer, the current in a motor is reversed during each half revolution by means of stationary contacts on the shaft. The parts of the wire that rotate and brush against these contacts are called *brushes*. In this way, the current in the loop alternates so that the forces on the upper and lower regions do not change directions as the loop rotates. The rotation is continuous as long as current is supplied.

We have described here only a very simple dc motor. Larger motors, dc or ac, are usually manufactured by replacing the permanent magnet by an electromagnet that is energized by the power source. Of course, more than a single loop is used. Many loops of wire are wound about an iron cylinder, called an *armature,* which then rotates when the wire carries current.

The advent of electric motors brought to an end much human and animal toil in many parts of the world. Electric motors have greatly changed the way people live.

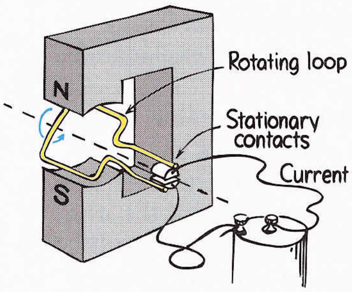

FIGURE 24.19
Interactive Figure
A simplified electric motor.

CHECK YOURSELF

What is the major similarity between a galvanometer and a simple electric motor? What is the major difference?

Earth's Magnetic Field

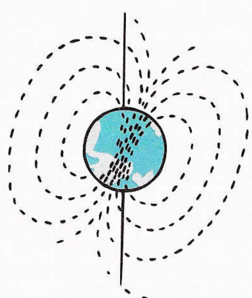

FIGURE 24.20
The Earth is a magnet.

A suspended magnet or compass points northward because Earth itself is a huge magnet. The compass aligns with the magnetic field of the Earth. The magnetic poles of the Earth, however, do not coincide with the geographic poles—in fact, the magnetic and geographical poles are widely separated. The magnetic pole in the northern hemisphere, for example, is now located nearly 1800 kilometers from the geographic pole, somewhere in the Hudson Bay region of northern Canada. The other pole is located south of Australia (Figure 24.20). This means that compasses do not generally point to the true north. The discrepancy between the orientation of a compass and true north is known as the *magnetic declination*.

CHECK YOUR ANSWERS

A galvanometer and a motor are similar in that they both employ coils positioned in a magnetic field. When a current passes through the coils, forces on the wires rotate the coils. The major difference is that the maximum rotation of the coil in a galvanometer is one-half turn, whereas, in a motor, the coil (wrapped on an armature) rotates through many complete turns. This is accomplished by alternating the current with each half turn of the armature.

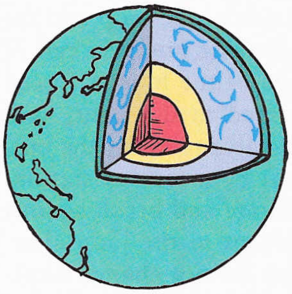

FIGURE 24.21
Convection currents in the molten parts of the Earth's interior may drive electric currents to produce the Earth's magnetic field.

We do not know exactly why Earth itself is a magnet. The configuration of Earth's magnetic field is like that of a strong bar magnet placed near the center of Earth. But Earth is not a magnetized chunk of iron like a bar magnet. It is simply too hot for individual atoms to hold to a proper orientation. So the explanation must lie with electric currents deep in the interior. About 2000 kilometers below the outer rocky mantle (which itself is almost 3000 kilometers thick) lies the molten part that surrounds the solid center. Most Earth scientists think that moving charges looping around within the molten part of Earth create the magnetic field. Some Earth scientists speculate that the electric currents are the result of convection currents—from heat rising from the central core (Figure 24.21)—and that such convection currents combined with the rotational effects of the Earth produce Earth's magnetic field. Because of the Earth's great size, the speed of moving charges need only be about a millimeter per second to account for the field. A firmer explanation awaits more study.

Like tape from a tape recorder, history of the ocean's bottom is preserved in a magnetic record.

Insights

Whatever the cause, the magnetic field of the Earth is not stable; it has wandered throughout geologic time. Evidence of this comes from the analysis of magnetic properties of rock strata. Iron atoms in a molten state are disoriented because of thermal motion, but a slight predominance of the iron atoms align with the magnetic field of the Earth. When cooling and solidification occurs, this predominance records the direction of the Earth's magnetic field in the resulting igneous rock. It's similar for sedimentary rocks, where magnetic domains in grains of iron that settle in sediments tend to align themselves with Earth's magnetic field and become locked into the rock that forms. The slight magnetism that results can be measured with sensitive instruments. As samples of rock are tested from different strata formed throughout geologic time, the magnetic field of the Earth for different periods can be charted. This evidence shows that there have been times when the magnetic field of the Earth has diminished to zero, followed by reversal of the poles. More than twenty reversals have taken place in the past 5 million years. The most recent occurred 700,000 years ago. Prior reversals happened 870,000 and 950,000 years ago. Studies of deep-sea sediments indicate that the field was virtually switched off for 10,000 to 20,000 years just over 1 million years ago. We cannot predict when the next reversal will occur because the reversal sequence is not regular. But there is a clue in recent measurements that show a decrease of more than 5% of the Earth's magnetic field strength in the last 100 years. If this change is maintained, we may well have another reversal within 2000 years.

The reversal of magnetic poles is not unique to the Earth. The Sun's magnetic field reverses regularly, with a period of 22 years. This 22-year magnetic cycle has been linked, through evidence in tree rings, to periods of drought on Earth. Interestingly enough, the long-known, 11-year sunspot cycle is just half the time during which the Sun gradually reverses its magnetic polarity.

Varying ion winds in Earth's atmosphere cause more rapid but much smaller fluctuations in Earth's magnetic field. Ions in this region are produced by the energetic interactions of solar ultraviolet rays and X-rays with atmospheric atoms. The motion of these ions produces a small but important part of Earth's magnetic field. Like the lower layers of air, the ionosphere is churned by winds. The variations in these winds are responsible for nearly all of the fast fluctuations in the Earth's magnetic field.