The Motor Principle

What would life be like without the electric motor? Many devices depend on the electric motor: computers, fans, elevators, car windows, and amusement park rides, to name a few. How did the electric motor come to be?

Moving Conductors with Electricity

Oersted's discovery inspired much interest in electricity and magnetism among other scientists. When English physicist Michael Faraday saw that an electric current in a wire caused a compass needle to move, he was curious to see if the reverse would be true. Could a magnetic field cause a current-carrying conductor to move? Not only did he succeed in showing that it could, but he was able to make the electrical conductor rotate. In 1821, Faraday supported a bar magnet in a pool of mercury, which is a good conductor of electricity. He then suspended a copper wire alongside the bar magnet, allowing the copper to make contact with the liquid mercury. The wire and the liquid mercury were connected to a power source to complete the circuit. When the circuit was connected, the wire rotated around the magnet. This was the first electric motor (**Figure 1**).

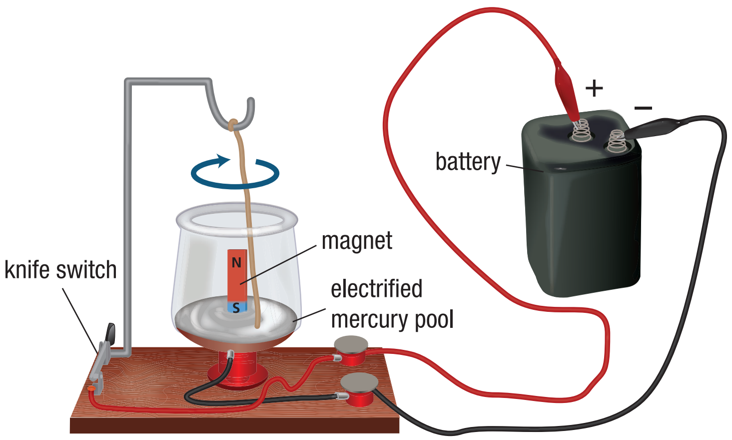

Figure 1 Faraday's motor

The copper wire in Faraday's motor design moved because the magnetic field in the copper wire interacted with the magnetic field of the permanent bar magnet. Let us examine the interaction between the two fields. In **Figure 2(a)** there are two separate magnetic fields. One magnetic field is from a current-carrying conductor with the conventional current directed into the page. The other magnetic field is from the external magnets. Where the two interacting magnetic field lines are pointed in the same direction there is a repulsion force. Where the two interacting field lines are pointed in opposite directions there is an attraction force. The final result is that the conductor is forced downward, as shown in **Figure 2(b)**.

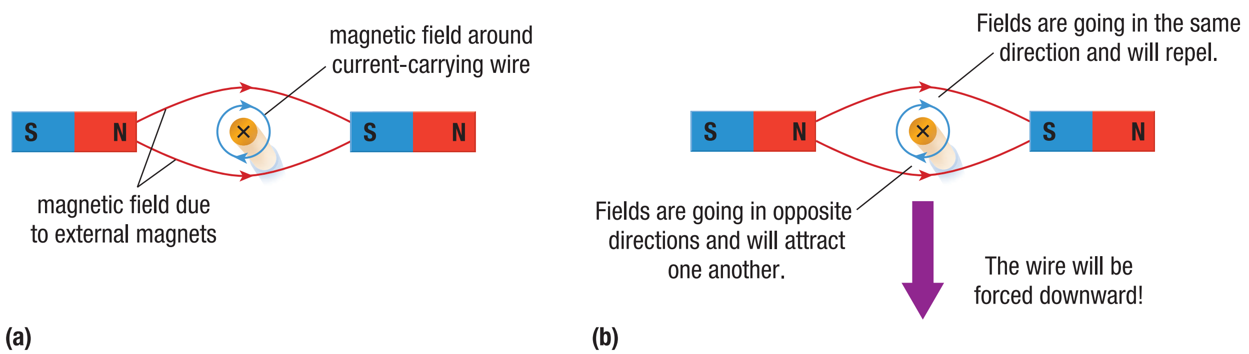

Figure 2 (a) The magnetic field lines around a current-carrying conductor and two permanent magnets (b) The magnetic fields interact to force the conductor in a downward direction.

motor principle a current-carrying conductor that cuts across external magnetic field lines experiences a force perpendicular to both the magnetic field and the direction of the electric current

The movement of a current-carrying conductor in an external magnetic field is described by the motor principle. The **motor principle** states that a current-carrying conductor that cuts across external magnetic field lines experiences a force perpendicular to both the magnetic field and the direction of the electric current. The magnitude of this force depends on the magnitude of both the external field and the current, and the angle between the conductor and the magnetic field it cuts across.

Mini **Investigation**

Moving Wires

Skills: Predicting, Performing, Observing, Analyzing

SKILLS HANDBOOK **A2.1, A2.4**

You will recreate Faraday's experiment using modern equipment.

Equipment and Materials: a DC power supply; a horseshoe magnet; 2 or 3 alligator clip leads

1. Connect the equipment as shown in **Figure 3**.
2. Based on what you have learned about the motor principle, predict which way the wire will move when you turn on the power supply.

Always have your teacher check your circuit. This circuit can produce high currents—turn on the power only briefly.

3. Turn on the power supply and observe any movement. The higher the current, the more noticeable any effect will be. Be sure to hold the insulated part of the lead. You are in effect shorting a power supply, so you should turn on the power only briefly. Turn off the power supply and observe any movement. Repeat if necessary.

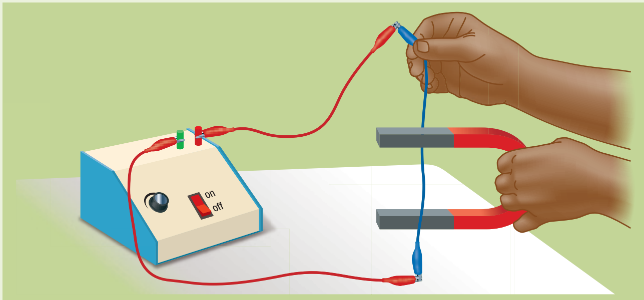

Figure 3 Recreating Faraday's experiment

A. How did your prediction compare to your observation when the power was turned on? T/I C

B. Explain, using the motor principle, why the wire moved in the direction that it did. K/U C

C. Predict which way the wire will move if the horseshoe magnet is flipped over. Test your prediction if your teacher permits you to. K/U T/I C

Right-Hand Rule for the Motor Principle

right-hand rule for the motor principle if the fingers of your open right hand point in the direction of the external magnetic field and your thumb points in the direction of the conventional current, then your palm faces in the direction of the force on the conductor

A third right-hand rule can be used as a tool to determine the direction of force acting on a current-carrying conductor. This time your hand is held flat with your thumb at a right angle to your fingers. The **right-hand rule for the motor principle** states that if the fingers of your open right hand point in the direction of the external magnetic field and your thumb points in the direction of the conventional current, then your palm faces in the direction of the force on the conductor (**Figure 4**).

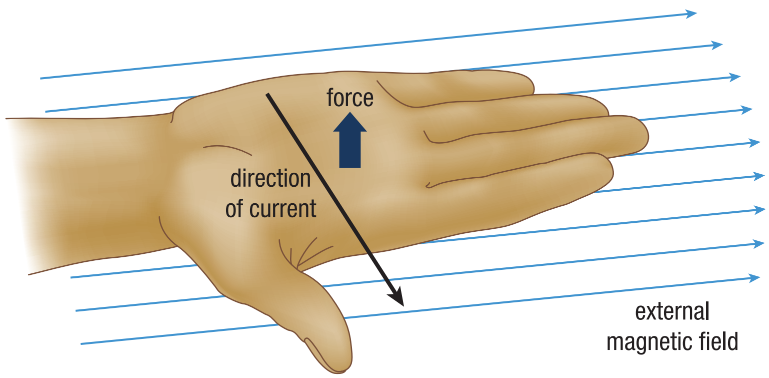

Figure 4 The right-hand rule for the motor principle

LEARNING **TIP**

Right-Hand Rule for the Motor Principle

A shorter way to state the right-hand rule for the motor principle is "thumb points in direction of current, fingers point south, palm faces force."

The Analog Meter

One of the first practical uses of the motor principle was the development of meters for measuring electrical quantities. The motor principle was used to develop the galvanometer—a sensitive meter for measuring current. The first meters were analog. Analog means that the reading is shown using a moving needle or pointer on a scale; there is no digital display. In the analog meter shown in **Figure 5(a)**, you can see the looped conductor where the current enters. Note that the current is directed to the positive terminal, through the loop and then out of the negative terminal. The needle is perpendicular to the coil and fixed to it. The needle and the coil are free to rotate on an axle. The spring provides just the right amount of tension and does not let the needle continue forward. The scale is there to provide a spot to take readings from. Looking at the cross-sectional view in **Figure 5(b)**, you can see the current directed into the page on the right side and out of the page on the left side. Using the right-hand rule for the motor principle, you can see that the loop is forced up on the left side and down on the right side. This causes the needle to rotate toward the right side of the scale. The main advantage of analog meters over digital meters is that it is much easier to see the rate at which changes in readings occur.

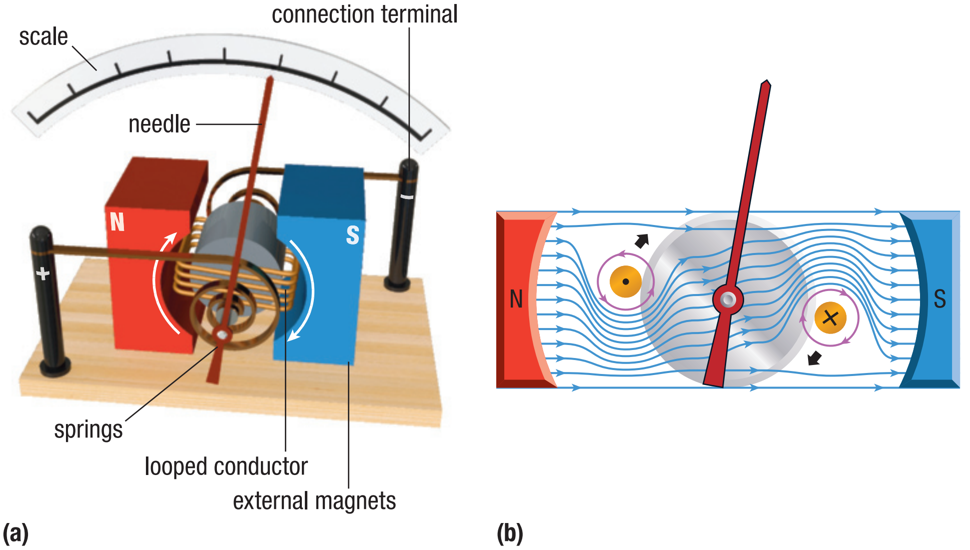

Figure 5 (a) An analog meter and (b) a cross-section of an analog meter

Ammeters

Ammeters measure current in an electric circuit. Ammeters are made from a galvanometer and a resistor. The galvanometer is placed in parallel with a resistor that has a much smaller resistance than the resistance of the galvanometer itself (**Figure 6**). Ammeters are connected in series with the device for which the current is to be measured. When the current is directed to the ammeter, electrons can go through either the galvanometer or the resistor. Since the resistance of the resistor is much smaller, a higher current is directed through the resistor and not the galvanometer. This protects the sensitive coils of wire in the galvanometer's looped coil. The value of the resistor is chosen depending on the range of current that is to be measured.

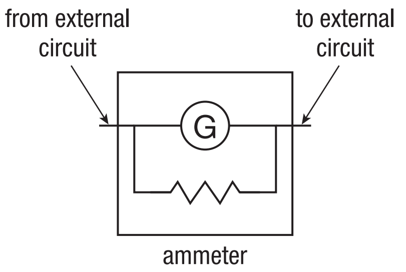

Figure 6 An ammeter with an internal galvanometer

Voltmeters

Voltmeters measure electric potential difference (voltage). Voltmeters are made by placing a galvanometer in series with a resistor with a very high resistance (**Figure 7**). Voltmeters are connected in parallel with the device for which the voltage is to be measured. When the voltmeter is connected to the circuit to measure the voltage,

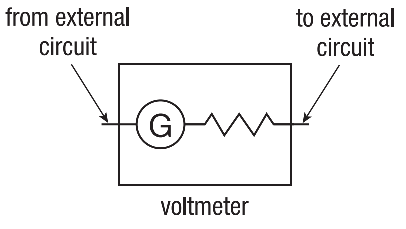

Figure 7 A voltmeter with an internal galvanometer

most of the current is directed into the circuit because of the large resistance in the voltmeter. This protects the galvanometer from large currents.

You may wonder how a galvanometer that measures current is used to measure voltages. Recall from Section 11.7 that Ohm's law describes the relationship between voltage and current. When the galvanometer acts as a voltmeter, the instrument's scale is determined by that relationship, $V = IR$.

12.5 Summary

- An external magnetic field can cause a current-carrying conductor to move.
- The motor principle states that a current-carrying conductor experiences a force perpendicular to both the magnetic field and the direction of the electric current.
- The magnitude of the force on a current-carrying conductor depends on both the magnitude of the external magnetic field and the magnitude of the current.
- The right-hand rule for the motor principle states that if the fingers of your open right hand point in the direction of the external magnetic field and your thumb points in the direction of the conventional current, then your palm faces in the direction of the force on the conductor.
- Analog meters such as the galvanometer, ammeter, and voltmeter operate according to the motor principle.

12.5 Questions

1. Copy each diagram in **Figure 8** into your notebook, and draw the magnetic field lines of both the magnet and the conductor. Then determine the direction of the force on the conductor. T/I C

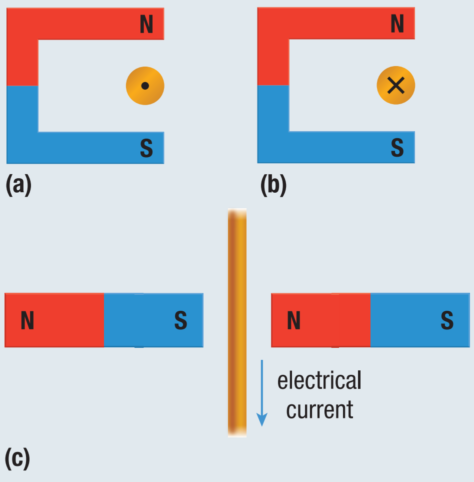

Figure 8

2. What two things can be done to increase the force on a current-carrying conductor according to the motor principle? K/U
3. How would increasing the number of loops in the looped conductor of a galvanometer affect the operation of the galvanometer? K/U
4. (a) Which way will the needle move on a galvanometer if the electron flow model is used?
   (b) Would the needle move in the same direction if the leads connected to the galvanometer were reversed? K/U
5. Suppose that an ammeter is connected in parallel instead of in series to a part of a circuit you wish to measure. What will happen to the amount of current going into the ammeter? T/I
6. A student is repairing a voltmeter by replacing the resistor. The student replaces the resistor with one of a much lower value than the original. What will happen to the amount of current going into the voltmeter when the voltmeter is connected? A