Solenoids

12.4

One of the great conveniences in today's motor vehicles is that you can unlock or lock the doors simply by pressing a button on the keys, even from a distance. With older vehicles you have to insert the car key in the door lock. The newer unlocking mechanism works by using the magnetic field of a coiled current-carrying conductor.

Ampère's Experiment

André-Marie Ampère was fascinated by Oersted's discovery, so he decided to investigate other aspects of electricity and magnetism. Ampère took two parallel wires and conducted an experiment to see if the wires would attract or repel one another when opposing currents were sent through them (**Figure 1**).

In Section 12.1, you learned about the properties of magnetic fields. Two magnetic fields can interact with each other to cause a force. The force can either be attractive or repulsive, depending on the directions of the two interacting fields. If two field lines point in the same direction, a repulsion force is applied. Conversely, if two field lines point in opposite directions, an attractive force is applied. Applying the same reasoning to the parallel wires in Ampère's experiment, you can see that the magnetic field lines go in the same direction in between the two wires. This means that the wires should repel each other. Imagine how excited Ampère was when the wires actually did repel.

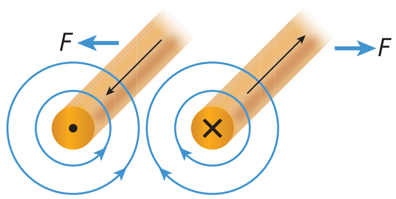

Figure 1 Ampère experimented with two parallel wires with opposing currents. The arrows on the wires show the direction of conventional current.

Coiled Conductors

Now, instead of two parallel wires, let us examine what the magnetic field around a single loop of current-carrying wire looks like. **Figure 2(a)** shows iron filings forming circles around each side of the loop of wire. Note that in the centre of the loop, the magnetic field points straight through. The positive and negative signs on Figure 2(a) denote the direction of the conventional current from positive to negative. A diagram of the magnetic field lines is shown in **Figure 2(b)**.

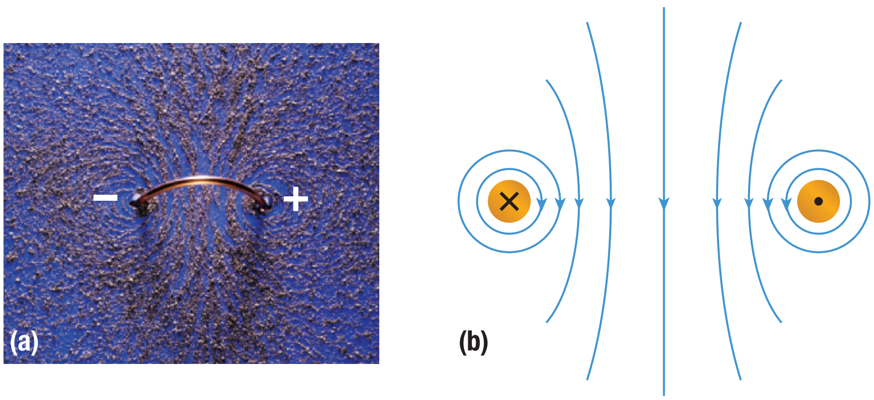

Figure 2 The magnetic field around a loop of wire (a) using iron filings and (b) showing the magnetic field lines

solenoid a coiled conductor

Now imagine winding the conductor into a coil containing several loops. Another name for a coiled conductor is a **solenoid**. The magnetic field around a solenoid has a shape similar to that of a bar magnet. To understand why this is so, look closely at **Figure 3(a)**. The convention of dots and X's is used to show the direction of conventional current. The circular magnetic fields around each dot and X combine to form an overall magnetic field that is a close approximation to the magnetic field of a bar magnet (**Figure 3(b)**). The magnetic field is strongest at the poles or ends of the coils and is weakest at the sides.

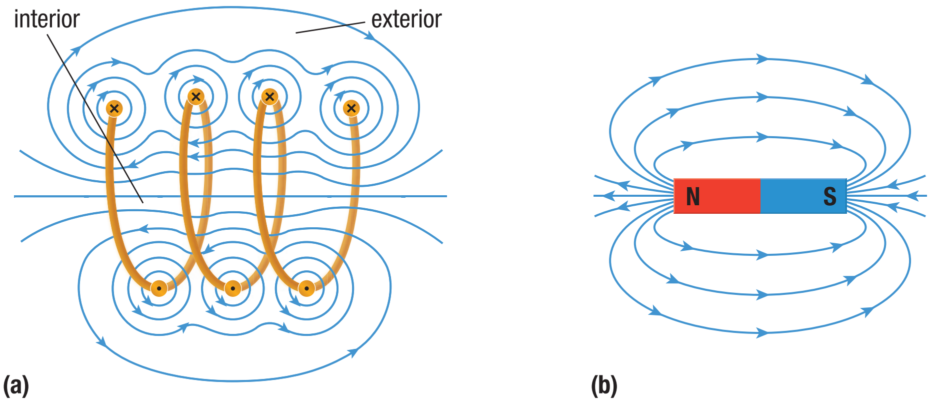

Figure 3 The magnetic field lines around (a) a solenoid and around (b) a bar magnet

electromagnet any device that produces a magnetic field as a result of an electric current

So now we have a way to make an electrically powered bar magnet—an electromagnet. An **electromagnet** is a device that has a magnetic field produced by an electric current. The benefit of the electromagnet is that it can be switched on and off. The strength of the electromagnet can be increased by increasing the number of loops in the coil, increasing the current, or introducing a core made from a material that is quickly magnetized. Soft iron is such a material, and it can be just as quickly de-magnetized when the current is switched off. A core material like soft iron concentrates the magnetic field. To make a very powerful magnet, we include all three factors. The most powerful electromagnets have several thousand loops of wire, work with large currents, and have a soft-iron core.

Right-Hand Rule for a Solenoid

right-hand rule for a solenoid the fingers of your right hand wrap around the coil in the direction of the conventional current, while your right thumb points in the direction of the north magnetic pole of the coil

There is another right-hand rule to help you determine the direction of the magnetic field or the direction of the conventional current. The **right-hand rule for a solenoid** states that if the fingers of your right hand wrap around a coil in the direction of the conventional current, your thumb will point in the direction of the north magnetic pole of the coil (**Figure 4**).

LEARNING TIP

Right-Hand Rule for a Solenoid

A shorter way to state the right-hand rule for a solenoid is "fingers follow current, thumb points north."

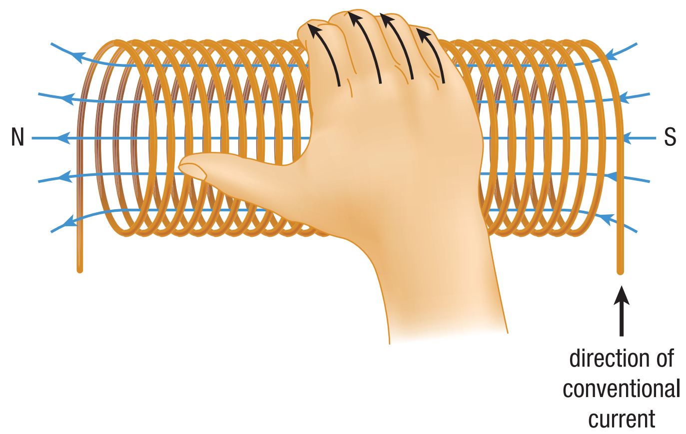

Figure 4 The right-hand rule for a solenoid

Applications of Solenoids

A solenoid has many uses because it operates like a bar magnet, but it can be switched on and off. So a solenoid can be used to turn things on and off, to pick up things and to then let go, or to cause motion and then reverse the motion. Solenoids are used in many devices, such as audio speakers, electric bells, and cars.

Solenoids in Subwoofers

A subwoofer is a speaker that produces only low-frequency or deep bass sounds. Subwoofer speakers have become popular because they can produce the low-frequency sound effects in surround-sound systems. To produce sound you have to create longitudinal vibrations in the air, with compressions and rarefactions. The subwoofer has a cone made from paper or plastic that quickly moves outward to cause a compression and then quickly moves inward to cause a rarefaction. To move the cone, a permanent circular magnet surrounds a solenoid called the voice coil. The voice coil is connected to the cone. Current is directed through the voice coil by an amplifier, which produces a magnetic field that repels the voice coil and the cone away from the magnet. The amplifier then reverses the direction of the current and produces a magnetic field that attracts the voice coil and the cone toward the magnet. This process repeats continually, producing compressions and rarefactions to create sound (**Figure 5**).

Solenoids in Electric Bells

The school bell signals the beginning or the end of a period. Many schools still have bells based on a solenoid. The design of the electric bell allows it to be rung continuously for as long as needed. **Figure 6** shows the operational parts of an electric bell. When the switch is closed, current is directed to the solenoids. The solenoids produce a magnetic field that is amplified by the soft-iron cores. The soft-iron armature is attracted to the core and the bell rings once. Now the armature pulls away from the contact, so the circuit is interrupted. Since the armature is on a spring, it springs back and makes contact, completing the circuit once more. The process then repeats as long as the switch is closed.

Solenoids in Cars

There are many places in cars where a magnetic field can be used to perform a task. In the starter, a solenoid is used as a switch that completes a circuit to initiate the starter motor, which starts the car. Once the car has started, the solenoid is used to switch off the starter motor because the engine is running. In the door-unlocking mechanism, a solenoid is again used as a switch that completes a circuit to cause an actuator (a device that exerts a force) to unlock the car. Even in a car's automatic transmission, a solenoid is used to initiate gear shifts.

Investigation 12.4.1

Magnetic Fields around Electromagnets (p. 575)

In this investigation, you will apply what you have learned about solenoids to observe and identify the properties of the magnetic fields around electromagnets.

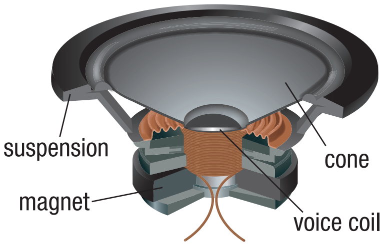

Figure 5 A cross-section of a subwoofer

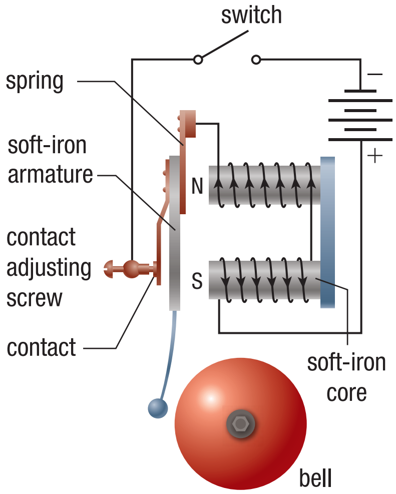

Figure 6 An electric bell

12.4 Summary

- Two parallel wires placed close to one another with opposing currents will repel one another.
- A current in a loop of wire will produce circular magnetic fields around the wire and a straight-line field inside the centre of the loop.
- A current in a coil of wire, or solenoid, will produce a magnetic field that is similar to that of a bar magnet.
- The strength of a solenoid's magnetic field can be increased by increasing the number of loops, increasing the amount of electric current, including a soft-iron core, or any combination of these.
- The right-hand rule for a solenoid is as follows: the fingers of your right hand wrap around the coil in the direction of the conventional current, while your thumb points in the direction of the north magnetic pole of the coil.
- Solenoids are used in many technologies, including subwoofers, electric bells, car starter motors, and car-door locking and unlocking mechanisms.

12.4 Questions

1. Copy the diagrams in **Figure 7** into your notebook, and draw the direction of the conventional current or the magnetic field lines. Also indicate the location of the north and south poles where appropriate. K/U C

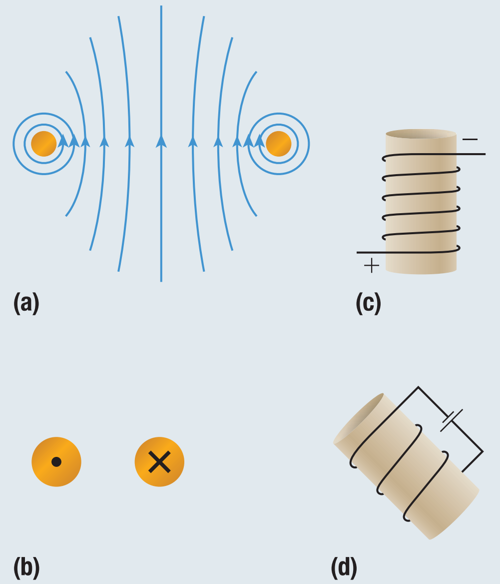

Figure 7

2. Copy the diagrams in **Figure 8** into your notebook, and label the compasses with an arrow pointing in the appropriate direction. K/U C

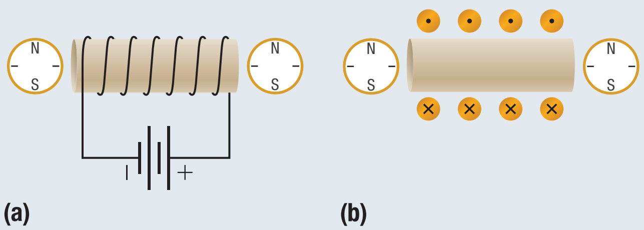

Figure 8

3. If two parallel wires are placed beside each other and current is sent down each wire in the same direction, will the wires repel or attract one another? Explain using a diagram that shows the magnetic field lines. T/I C
4. Electromagnet A has 20 loops and a current of 1 A. Electromagnet B has 21 loops and a current of 1.1 A. All other characteristics of electromagnets A and B are the same. T/I
   (a) Which electromagnet is stronger? Explain your choice.
   (b) Would the addition of a soft-iron core to electromagnet A change your answer? Explain.
5. An electromagnetic relay is a device used to trigger another circuit. An illustration of it is shown in **Figure 9**. K/U C
   (a) Describe how it works.
   (b) Describe a situation where an electromagnetic relay may be used.

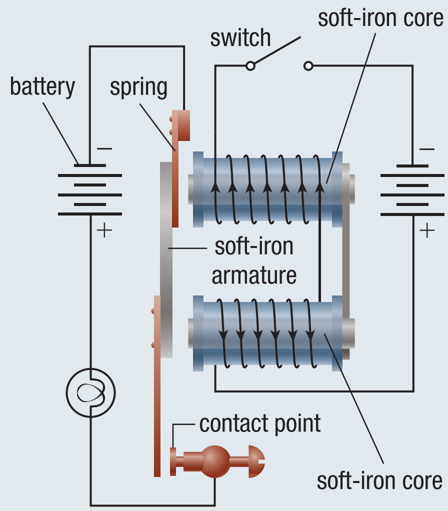

Figure 9

6. Describe how you could adapt an electric bell to become a flashing light. Explain or draw a diagram of your adaptation. C A
7. What factors can be changed to increase or decrease the strength of an electromagnet? Copy **Table 1** into your notebook and complete it. K/U

Table 1 Factors That Can Affect the Strength of an Electromagnet

Factor	An electromagnet can be made stronger by	An electromagnet can be made weaker by