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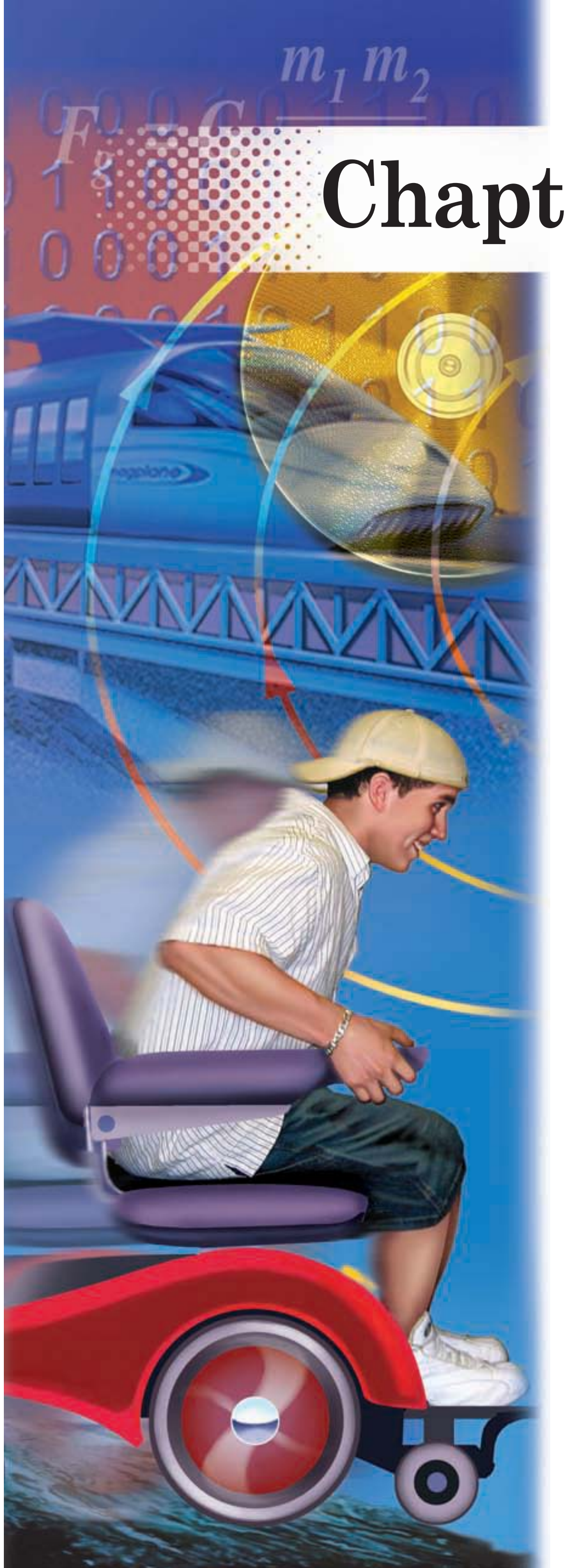


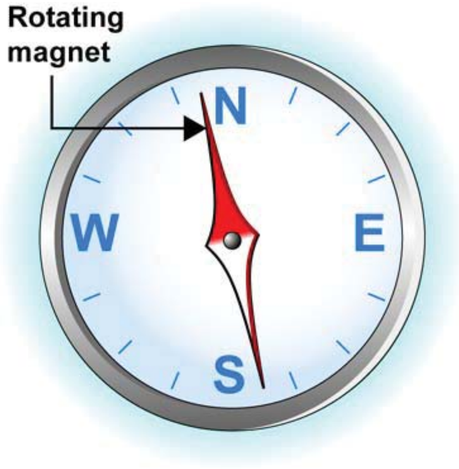
Chapter 17

Electromagnets and Induction

Electricity and magnetism may not seem very similar. You don't get a shock from picking up a magnet! However, you can create magnetism with electric current in an electromagnet. Why does electric current create magnetism?

In 1909, a teacher named Hans Christian Øersted tried an experiment in front of his students for the first time. He passed electric current through a wire near a compass. To his surprise, the compass needle moved! A few years later Michael Faraday built the first electric motor. Today we know electricity and magnetism are two faces of the same basic force: the force between charges. In this chapter you will see how our knowledge of electricity and magnetism allows us to build both an electric motor and also an electric generator. It would be hard to imagine today's world without either of these important inventions.

As you read this chapter, you will see that our study of the atom, electricity, and magnetism has come full circle! This chapter will help you understand exactly how the electricity that we use in our homes, schools, and offices is generated. It is actually all about magnets! Isn't that amazing?



Key Questions

- ✓ Why are there magnets in an electric motor?
- ✓ How is the electricity that powers all of the appliances in your home generated?
- ✓ What is the purpose of a transformer on a power line?

17.1 Electric Current and Magnetism

For a long time, people believed electricity and magnetism were unrelated. As scientists began to understand electricity better, they searched for relationships between electricity and magnetism. In 1819, Hans Christian Øersted, a Danish physicist and chemist, placed a compass needle near a wire in a circuit. When a switch in the circuit was closed, the compass needle moved just as if the wire were a magnet. We now know that magnetism is created by the motion of electric charge and that electricity and magnetism are two forms of the same basic force.

The effect of current on a compass

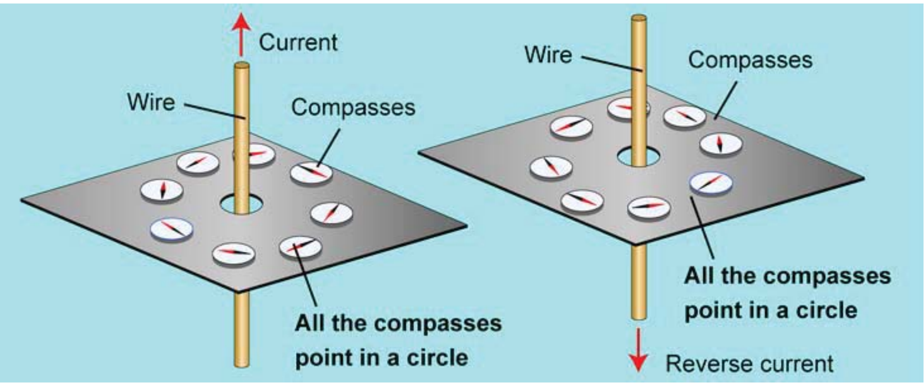
An experiment with a wire and compasses

Magnetism is created by moving charges. Electric current is made of moving charges (electrons), so there is a magnetic field around a wire that carries current. Consider the following experiment. A long straight wire is connected to a battery and a switch. The wire passes through a board with a hole in it. Around the hole are many compasses that can detect any magnetic field.

Magnetism is created by moving charges.

Compasses react to electric current

When the switch is off, the compasses all point north (Figure 17.1). As soon as the switch is closed, current flows, and the compasses point a circle (see graphic below). The compasses point in a circle as long as there is current in the wire. If the current stops, the compasses return to pointing north again. If the current is reversed in the wire, the compasses again point in a circle, but in the opposite direction.



Vocabulary

coil, solenoid

Objectives

- ✓ Describe the effect an electric current in a wire has on a compass.
- ✓ Explain how to change the strength and direction of a wire's magnetic field.
- ✓ Determine whether two wires or coils will attract or repel.

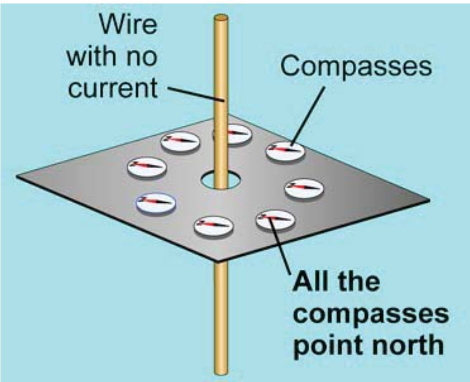
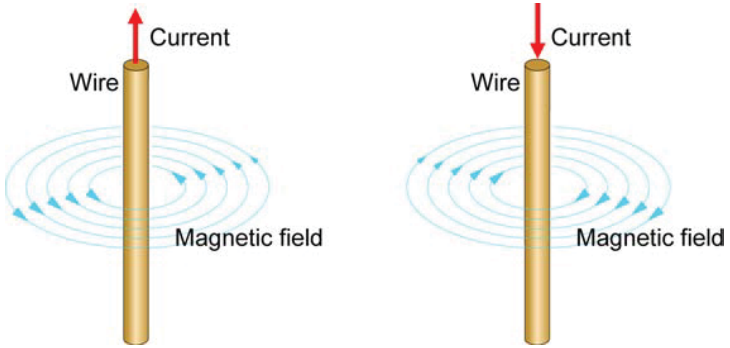


Figure 17.1: *When there is no current in a wire, all of the compasses point north.*

The magnetic field of a straight wire

The magnetic field of a wire

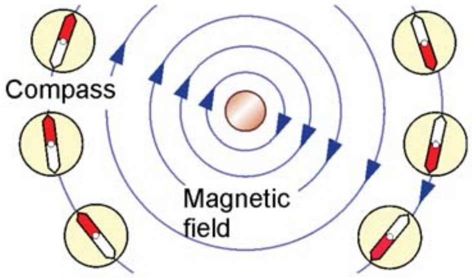
The experiment with the compasses shows that a wire carrying electric current makes a magnetic field around it. The magnetic field lines are concentric circles with the wire at the center. As you may have guessed, the direction of the field depends on the direction of the current in the wire. The *right-hand rule* can be used to tell how the magnetic field lines point. When your thumb is in the direction of the current, the fingers of your right hand wrap in the direction of the magnetic field.



The strength of the field

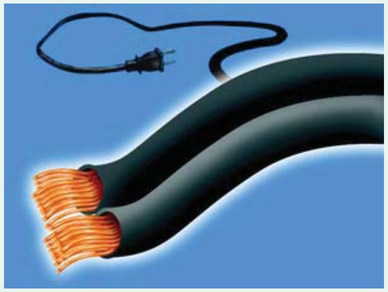
The strength of the magnetic field near the wire depends on two factors:

1. The strength is directly proportional to the current, so doubling the current doubles the strength of the field.
2. The field strength is inversely proportional to the distance from the wire. The field gets stronger as you move closer to the wire. Decreasing the distance to the wire by half doubles the strength of the field.



Near a straight wire, the north pole of a compass needle feels a force in the direction of the field lines. The south pole feels a force in the opposite direction. As a result, the needle twists to align its north-south axis along the circular field lines.

Electrical wiring



There is a magnetic field around all wires that carry current. So why don't you notice magnetic fields created by electrical wiring in your house?

The reason is that the wires in your home are actually made of two parallel wires. If you look at an appliance wire, you will notice the two wires inside the plastic covering. At any instant, the current in one wire is opposite the current in the other wire. Each creates a magnetic field, but the fields are in opposite directions so they cancel each other out.

Because the wires are not at exactly the same location, and field strength depends on distance, the fields do not completely cancel each other very close to the wire, but quickly fall off to nothing only a short distance away.

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The magnetic field of loops and coils

Making a strong magnetic field from current

The magnetic field around a single ordinary wire carrying a safe amount of current is too small to be of much use. However, there are two clever ways to make strong magnetic fields from reasonable currents in small wires.

1. Parallel wires placed side-by-side can be bundled together. Ten wires, each carrying 1 amp of current, create ten times as strong a magnetic field as one wire carrying 1 amp.
2. A single wire can be looped into a **coil**, concentrating the magnetic field at the coil's center. The magnetic field of a coil has the same shape as the field of a circular permanent magnet (Figure 17.2).

Coiling wires

When a wire is made into a coil, the total magnetic field is the sum of the fields created by the current in each individual loop. By wrapping a wire around into a coil, current can be "reused" as many times as there are turns in the coil. A coil with 50 turns of wire carrying 1 amp creates the same magnetic field as a single-wire loop with 50 amps of current. Virtually all electrical machines use coils because it is much easier and safer to work with 1 amp of current than to work with 50 amps of current.

Coils and solenoids

A coil concentrates the magnetic field at its center. When a wire is bent into a circular loop, field lines on the inside of the loop squeeze together. Field lines that are closer together indicate a higher magnetic field. Field lines on the outside of the coil spread apart, making the average field lower outside the coil than inside. The most common form of electromagnetic device is a coil with many turns (Figure 17.3) called a **solenoid**.

Where coils are used

The simple electromagnet made of a nail with wire wrapped around it (see Section 16.2) is one example of a solenoid. Solenoids and other coils are also used in speakers, electric motors, electric guitars, and almost every kind of electric appliance that has moving parts. Coils are the most efficient way to make a strong magnetic field with the least amount of current, which is why coils are found in so many electric appliances.

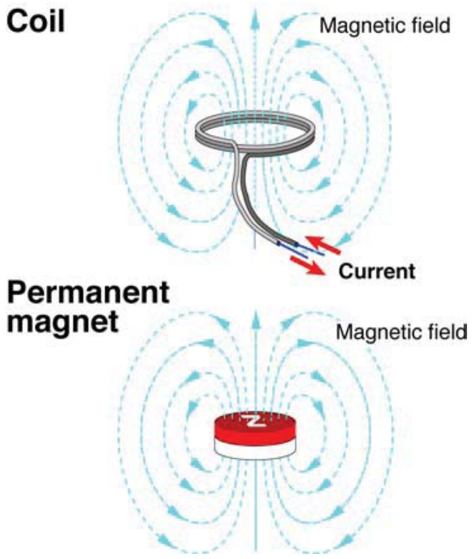


Figure 17.2: *The magnetic field of a coil of wire carrying a current resembles the magnetic field of a permanent magnet.*

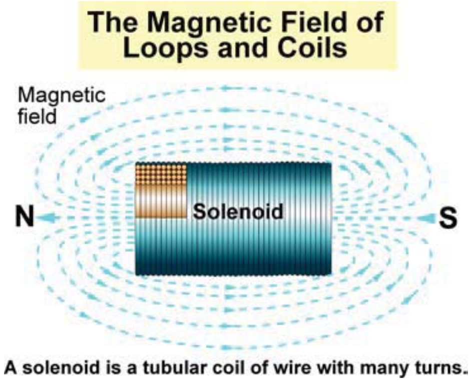


Figure 17.3: *A solenoid is a tubular coil of wire with many turns. The upper left corner of the solenoid in the diagram has been cut away to show the arrangement of wires.*

Magnetic forces and electric currents

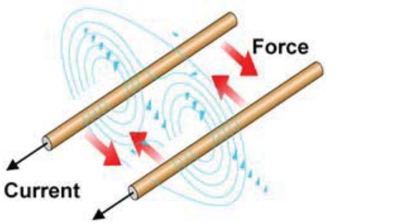
The force between two coils

Two coils carrying electric current exert forces on each other, just as magnets do. The forces can be attractive or repulsive depending on the direction of current in the coils (Figure 17.4). If the current is in the same direction in both coils, they attract. If the currents are in opposite directions, they repel.

Observing the force between wires

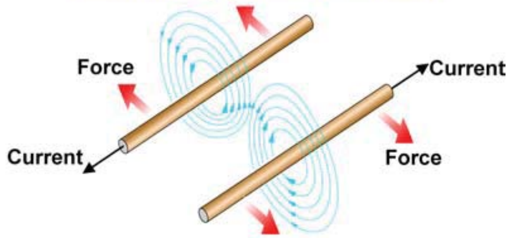
Two straight wires have a similar effect on each other. When the current is in the same direction in both wires, they attract each other. If the currents go in opposite directions, the wires repel each other. For the amount of current in most electric circuits, the forces are small but can be detected. For example, if the wires are one meter long and each carries 100 amps of current (a lot), the force between them is 0.1 newton when they are one centimeter apart.

Current in the ***same*** direction



Wires are ***attracted*** to each other

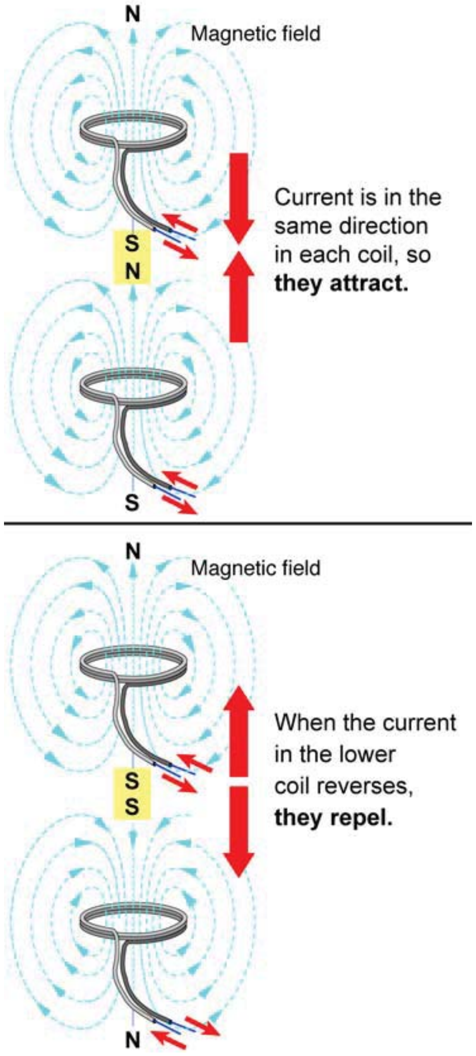
Current in ***opposite*** directions



Wires ***repel*** each other

Permanent magnets

The force between wires comes from the interaction of the magnetic field with moving current in the wire. A similar effect can be seen with a wire in the magnetic field created by a permanent magnet. A wire can attract or repel a permanent magnet just as it can attract or repel another wire.



Current is in the same direction in each coil, so **they attract.**

When the current in the lower coil reverses, **they repel.**

Figure 17.4: *Two coils attract if their currents are in the same direction. They repel if their currents are in opposite directions.*

17.1 Section Review

1. Why does a compass change direction when it is near a current-carrying wire?
2. What is the shape of the magnetic field created by a current-carrying wire?
3. How can you increase the magnetic field created by a wire? How can you change the direction of the field?
4. Do the two wires inside an appliance cord attract or repel each other?

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17.2 Electric Motors

Permanent magnets and electromagnets work together to make electric motors and generators. In this section you will learn about how an electric motor works. The secret is in the ability of an electromagnet to reverse its north and south poles. By changing the direction of electric current, the electromagnet attracts and repels other magnets in the motor, causing the motor to spin. **Electric motors** convert electrical energy into mechanical energy.

Using magnets to spin a disk

Imagine a spinning disk with magnets

Imagine you have a disk that can spin on an axis at its center. Around the edge of the disk are several magnets. You have cleverly arranged the magnets so they have alternating north and south poles facing out. Figure 17.5 shows a picture of your rotating disk.

Making the disk spin

You also have another magnet which is not attached to the disk. To make the disk spin, you bring your other magnet close to its edge. The magnet attracts one of the magnets in the disk and repels the next one. These attract and repel forces make the disk spin a little way around.

Reversing the magnet is the key

To keep the disk spinning, you need to reverse the magnet in your fingers as soon as the magnet that was attracted passes by. This way you first attract the magnet, and then reverse your magnet to repel that magnet and attract the next one around the rotor. You make the disk spin by using your magnet to alternately attract and repel the magnets on the disk.

Knowing when to reverse the magnet

The disk is called the **rotor** because it can rotate. The key to making the rotor spin smoothly is to reverse your magnet when the disk is at the right place. You want the reversal to happen just as each magnet in the rotor passes by. If you reverse too early, you will repel the magnet in the rotor backward before it reaches your magnet. If you reverse too late, you attract the magnet backward after it has passed. For it to work best, you need to change your magnet from north to south just as each magnet on the rotor passes by.

Vocabulary

electric motor, rotor, commutator, armature, brushes

Objectives

- ✓ Describe the role of magnets in electric motors.
- ✓ Explain how electric motors operate.
- ✓ Learn the main three parts of an electric motor.
- ✓ Explain how a battery-powered motor works.

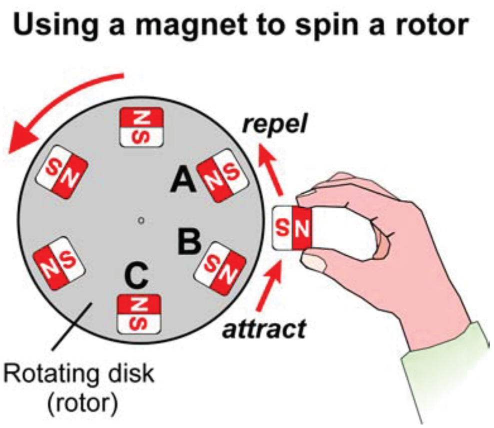


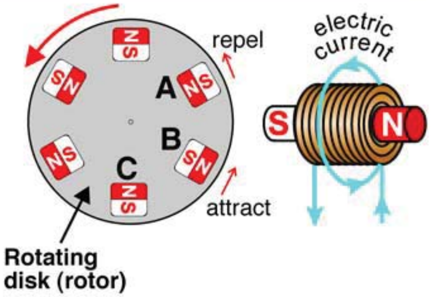
Figure 17.5: *Using a single magnet to spin a disk of magnets. Reversing the magnet in your fingers attracts and repels the magnets in the rotor, making it spin.*

How the electromagnets in a motor operate

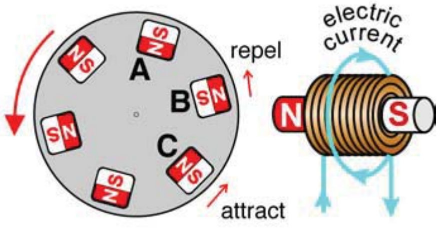
How electromagnets are used in electric motors

In a working electric motor, an electromagnet replaces the magnet you reversed with your fingers. The switch from north to south is done by reversing the electric current in the electromagnet. The sketch below shows how an electromagnet switches its poles to make the rotor keep turning.

First the electromagnet repels magnet A and attracts magnet B



Then the electromagnet switches so it repels magnet B and attracts magnet C.



The commutator is a kind of switch

Just as with the magnet you flipped, the electromagnet must switch from north to south as each rotor magnet passes by to keep the rotor turning. The device that makes this happen is called a **commutator**. As the rotor spins, the commutator reverses the direction of the current in the electromagnet. This makes the electromagnet's side facing the disk change from north to south, and then back again. The electromagnet attracts and repels the magnets in the rotor, and the motor turns.

Three things you need to make a motor

All types of electric motors must have three parts (Figure 17.6). They are:

1. A rotating part (rotor) with magnets that alternate.
2. One or more fixed magnets around the rotor.
3. A commutator that switches the direction of current in the electromagnets back and forth in the right sequence to keep the rotor spinning.

AC motors

Motors that run on AC electricity are easier to make because the current switches direction all by itself. Almost all household, industrial, and power tool motors are AC motors. These motors use electromagnets for both the rotating and fixed magnets (Figure 17.7)

The three main parts of an electric motor

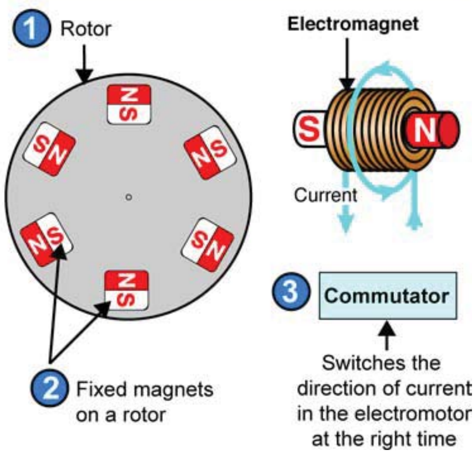


Figure 17.6: *An electric motor has three main parts.*

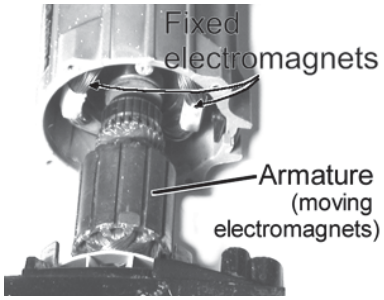


Figure 17.7: *The working parts of an AC motor. Electromagnets are used for both the rotating and non-rotating parts of the motor. There are no permanent magnets.*

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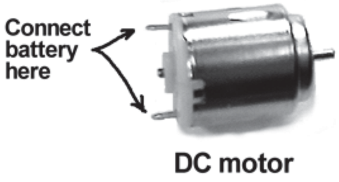
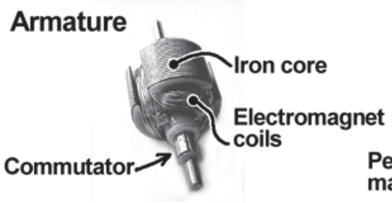
How a battery-powered electric motor works

Inside a small electric motor

If you take apart an electric motor that runs on batteries, it doesn't look like the motor on the previous page. But those same three essential mechanisms are there. The difference is in the arrangement of the electromagnets and permanent magnets. The picture below shows a small battery-powered electric motor and what it looks like inside with one end of the case removed. The permanent magnets are on the outside, and they stay fixed in place.





Electromagnets and the armature

The electromagnets are in the rotor, and they turn. The rotating part of the motor, including the electromagnets, is called the **armature**. The armature (see picture above) has three electromagnets corresponding to the three coils you see in Figure 17.8.

How the switching happens

The wires from each of the three coils are attached to three metal plates (commutator) at the end of the armature. As the rotor spins, the three plates come into contact with the positive and negative **brushes**. Electric current passes through the brushes into the coils. As the motor turns, the plates rotate past the brushes, switching the electromagnets from north to south by reversing the positive and negative connections to the coils. The turning electromagnets are attracted and repelled by the permanent magnets and the motor turns.

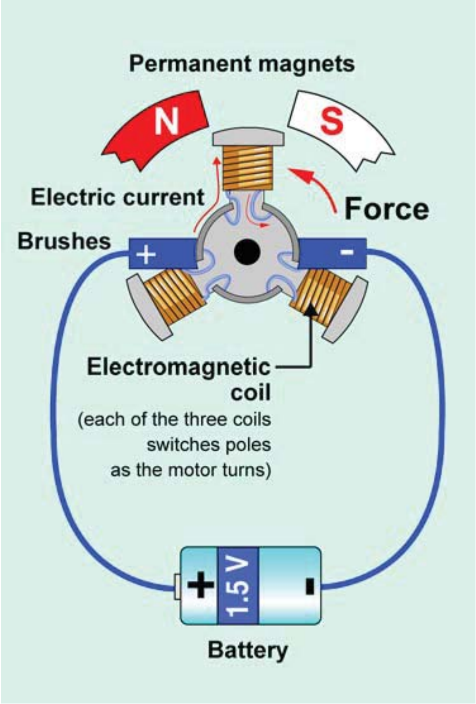


Figure 17.8: *A simple battery-powered motor has three electromagnets.*

17.2 Section Review

1. Explain how you can use a permanent magnet to make a rotor spin.
2. How do the magnetic poles in an electromagnet reverse?
3. List the three main parts every electric motor must have.

17.3 Electric Generators and Transformers

Motors transform electrical energy into mechanical energy. Electric *generators* do the opposite. They transform mechanical energy into electrical energy. Generators are used to create the electricity that powers all of the appliances in your home. In this section you will learn how generators produce electricity.

Electromagnetic induction

Magnetism and electricity

An electric current in a wire creates a magnetic field. The reverse is also true. If you move a magnet near a coil of wire, an electric current (or voltage) is *induced* in the coil. The word "induce" means "to cause to happen." The process of using a moving magnet to create electric current or voltage is called **electromagnetic induction**. A moving magnet *induces* electric current to flow in a circuit.

Symmetry in physics

Many laws in physics display *symmetry*. In physics, symmetry means a process works in both directions. Earlier in this chapter you learned that moving electric charges create magnetism. The symmetry is that changing magnetic fields also cause electric charges to move. Nearly all physical laws display symmetry of one form or another.

Making current flow

Figure 17.9 shows an experiment demonstrating electromagnetic induction. In the experiment, a magnet can move in and out of a coil of wire. The coil is attached to a meter that measures the electric current. When the magnet moves into the coil of wire, *as the magnet is moving,* electric current is induced in the coil and the meter swings to the left. The current stops if the magnet stops moving.

Reversing the current

When the magnet is pulled back out again, *as the magnet is moving,* current is induced in the opposite direction. The meter swings to the right as the magnet moves out. Again, if the magnet stops moving, the current also stops.

Current flows only when the magnet is moving

Current is produced only if the magnet is moving, because a *changing* magnetic field is what creates current. Moving magnets induce current because they create changing magnetic fields. If the magnetic field is not changing, such as when the magnet is stationary, the current is zero.

Vocabulary

electromagnetic induction, Faraday's law of induction, generator

Objectives

- ✓ Explain how a magnet can be used to produce current in a coil.
- ✓ Describe the design of a simple generator.
- ✓ Calculate the number of turns or voltage of a coil in a transformer.

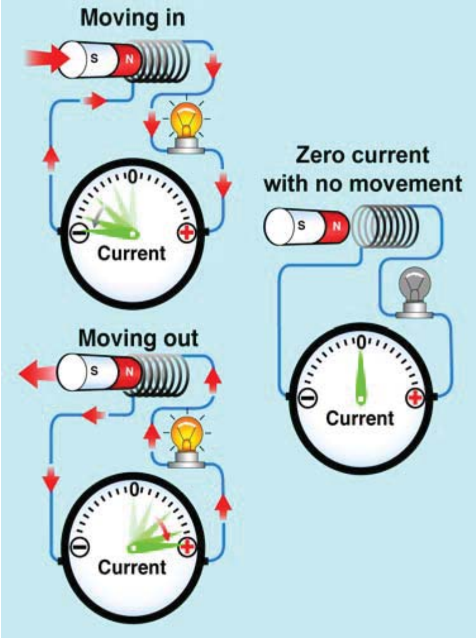


Figure 17.9: *A moving magnet produces a current in a coil of wire.*

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Faraday's law of induction

When current is induced Do you think a big current will flow in a coil if you wave a magnet around far away from the coil? If you guessed no, you are right. The coil has to be close to the magnet for any current to be induced. How close? Close enough that the magnetic field from the magnet passes *through* the coil (Figure 17.10). The induced current depends on the amount of magnetic field actually passing through the coil. Adding an iron core helps because iron amplifies the magnetic field and directs it through the coil.

Induced voltage Current flows because a voltage difference is created between the ends of the coil. A moving magnet like the one in Figure 17.10 induces a voltage difference between the ends of the wires that make the coil. If the wires were connected, current *would* flow. When the wires are disconnected you see the voltage difference instead. Because the currents can be quite small, in experiments it is easier to measure the induced voltage instead of the current.

Faraday's law The induced voltage or current depends on how *fast* the magnetic field through the coil changes. Michael Faraday (1791-1867), an English physicist and chemist, was first to explain it. He experimented with moving magnets and coils and discovered **Faraday's law of induction**. Faraday's law says the induced voltage is proportional to the *rate of change* of the magnetic field through the coil. If the magnetic field does not change, no voltage is produced even if the field is very strong.

> The voltage induced in a coil is proportional to the rate of change of the magnetic field through the coil.

Induced current, work, and energy As a magnet is pushed through a coil of wire, current is induced to flow and voltage develops. The induced current in the coil makes its own magnetic field that tries to push your magnet back out again. If you push a north pole into a coil, the coil itself will develop a repelling north pole from the induced current. If you pull the magnet back out again, the coil will reverse its current, making a south pole that attracts your magnet. Either way, you have to *push* the magnet in or out, doing work, to supply the energy that makes current flow (Figure 17.11). This is another example of conservation of energy.

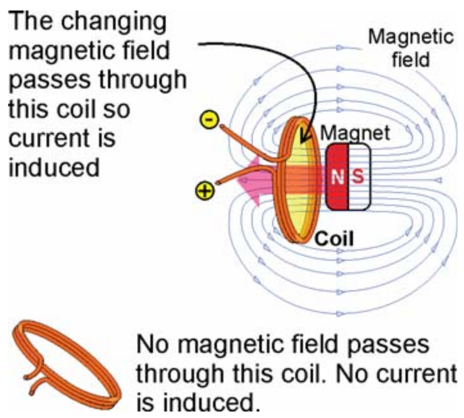


Figure 17.10: *The induced current depends on the magnetic field actually passing through the coil.*

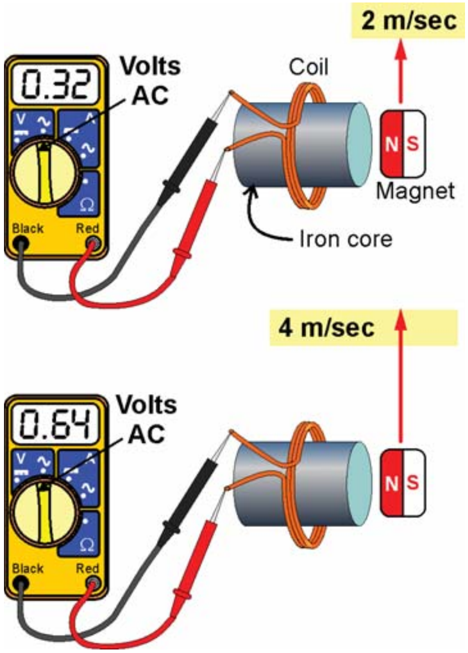


Figure 17.11: *The faster you move the magnet, the greater the induced current.*

Generating electricity

A simple generator

A **generator** converts mechanical energy into electrical energy using the law of induction. Most large generators use some form of rotating coil in a magnetic field (Figure 17.12). You can also make a generator by rotating magnets past a stationary coil (diagram below). As the disk rotates, first a north pole and then a south pole pass the coil. When a north pole is approaching, the current is in one direction. After the north pole passes and a south pole approaches, the current is in the other direction. As long as the disk is spinning, there is a changing magnetic field through the coil and electric current is created.

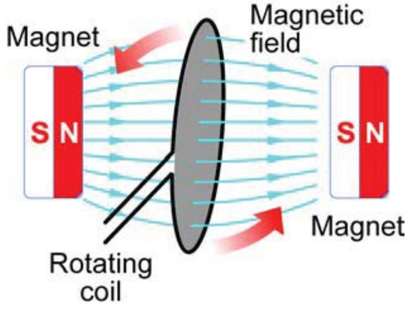
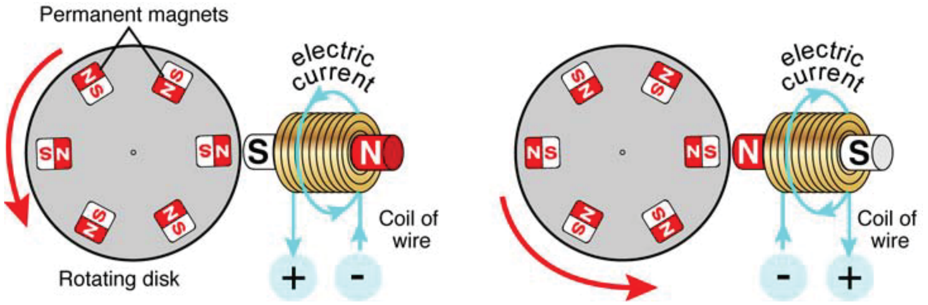


Figure 17.12: *Current is created when a coil rotates in a magnetic field.*



Alternating current

The generator shown above makes AC electricity. The direction of current is one way when the magnetic field is becoming "more north" and the opposite way when the field is becoming "less north". It is impossible to make a situation where the magnetic field keeps increasing (becoming more north) forever. Eventually the field must stop increasing and start decreasing. Therefore the current or voltage always alternates. The electricity in your home is produced by AC generators.

Energy for generators

The electrical energy created by a generator is not created from nothing. Energy must continually be supplied to keep the rotating coil (or magnetic disk) turning. In hydroelectric generator, falling water turns a *turbine* which spins the generator and generates electricity. Windmills can generate electricity in a similar way. Other power plants use gas, oil, or coal to heat steam to high pressures. The steam then spins turbines that convert the chemical energy stored in the fuels into electrical energy (Figure 17.13).

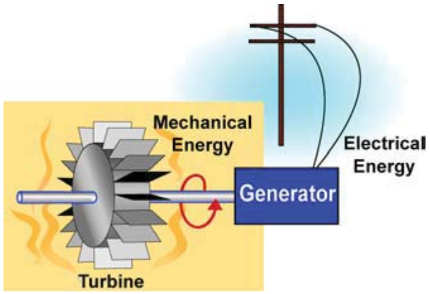


Figure 17.13: *A power plant generator contains a turbine that turns magnets inside loops of wire, generating electricity. Some other form of energy must be continually supplied to turn the turbine.*

Transformers

Electricity is transmitted at high voltage

From the perspective of physics, it makes sense to distribute electricity from a generator to homes using high voltage. For example, the main power lines on a city street carry AC current at 13,800 volts. Since power is current times voltage, each amp of current provides 13,800 watts of power. The problem is that you would *not* want your wall outlets to be at 13,800 volts! With a voltage this high, it would be dangerous to even plug in your appliances.

Electric power transformers

The voltage in your wall outlet is 120 volts. A transformer steps down the high voltage from the main power lines to the low voltage your appliances use. Transformers are useful because they efficiently change voltage and current with very little loss of power. A transformer can take one amp at 13,800 volts from the power lines outside and convert it to 115 amps at 120 volts (Figure 17.14). The total electrical power remains the same because 13,800 V × 1 A = 120 V × 115 A.

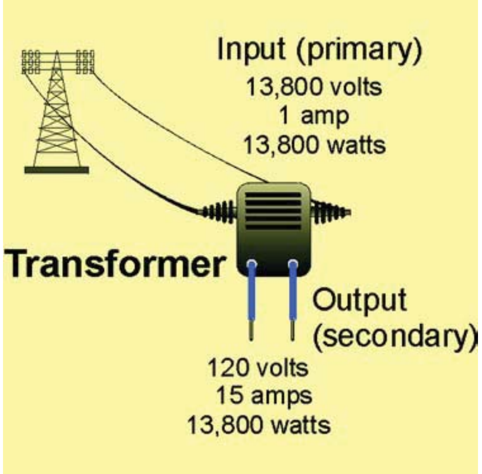


Figure 17.14: *A high power transformer can reduce the voltage keeping the power constant.*

Transformers operate on electromagnetic induction

A transformer uses electromagnetic induction, similar to a generator. Figure 17.15 shows what a transformer looks like inside its protective box. You may have seen one inside a doorbell or an AC adapter. The two coils are called the *primary* and *secondary* coils. The input to the transformer is connected to the primary coil. The output of the transformer is connected to the secondary coil. The two coils are wound around an iron core. The core concentrates the magnetic field lines through the centers of the coils.

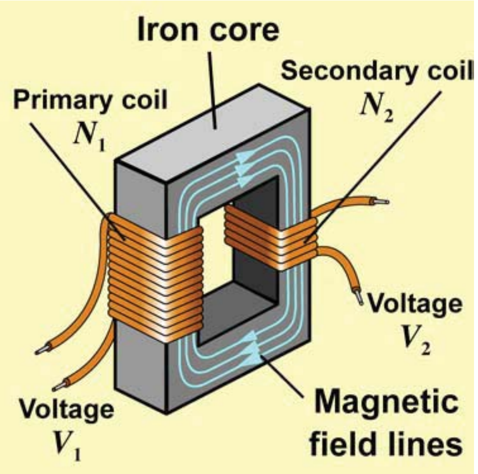


Figure 17.15: *A transformer contains coils wound around an iron core.*

How a transformer works

Consider the transformer between the outside power lines and your house:

1. The primary coil is connected to outside power lines. Current in the primary coil creates a magnetic field through the secondary coil. The primary coil's field is shown by the magnetic field lines in Figure 17.15.
2. The current in the primary coil changes constantly because it is *alternating current*.
3. As the current changes, so does the strength and direction of the magnetic field through the secondary coil.
4. The changing magnetic field through the secondary coil induces current in the secondary coil. The secondary coil connects to your home's wiring.

Voltage relationships for a transformer

The number of turns is important

Transformers work because there are different number of turns in the primary and secondary coils. The strength of an electromagnet's magnetic field, induced voltage, and induced current all depend on the number of turns (Figure 17.16). In the same changing magnetic field, a coil with 100 turns produces ten times the induced voltage or current as a coil with 10 turns.

Voltage and current

With fewer turns than the primary coil, the secondary coil also has lower induced voltage than the voltage applied to the primary coil. In this case, voltage is *stepped down*. With more turns than the primary coil, the secondary coil has greater induced voltage than the voltage applied to the primary coil and the voltage is *stepped up*. Because of energy conservation, the power (voltage × current) is the same for both coils (neglecting resistance).

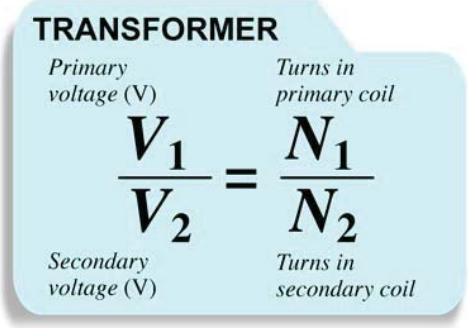


Figure 17.16: *The relationship between voltage and number of turns in a transformer.*

Changing voltage with a transformer

When you plug in a cell phone, a transformer on the plug changes the outlet's 120 volts to the 6 volts needed by the battery. If the primary coil has 240 turns, how many turns must the secondary coil have?

1. Looking for: You are asked for the number of turns of the secondary coil.

2. Given: You are given the voltage of each coil and the number of turns of the primary coil.

3. Relationships: $\frac{V_1}{V_2} = \frac{N_1}{N_2}$

4. Solution: $\frac{120\ \text{V}}{6\ \text{V}} = \frac{240\ \text{turns}}{N_2}$ $\quad N_2 = 12$ turns

Your turn...

a. A transformer has 20 turns on the secondary coil and 200 turns on the primary. What is the secondary voltage if the primary voltage is 120 volts? **Answer:** 12 volts

b. How many turns must the primary coil have if it steps down 13,800 volts to 120 volts with 112 turns? **Answer:** 12,880 turns

17.3 Section Review

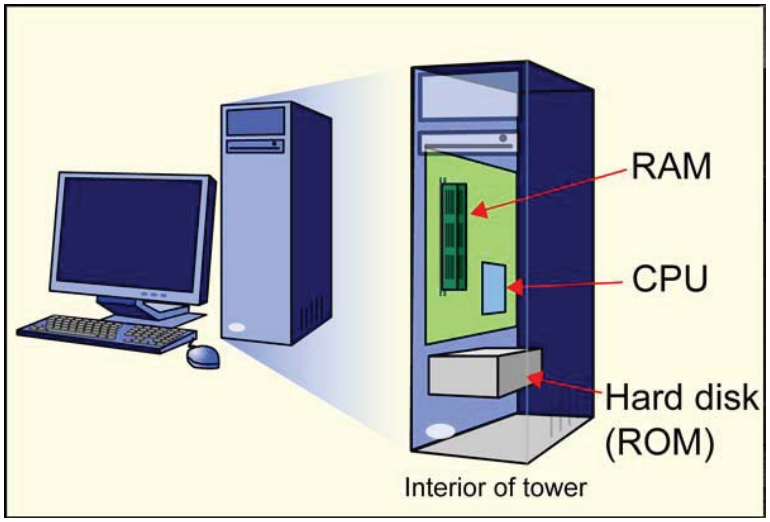
1. You hold a strong permanent magnet in place at the center of a coil. Is there a current induced in the coil? Why or why not?
2. Explain Faraday's law of induction.
3. What is the purpose of a transformer?

Does a Computer Ever Forget?

Many aspects of your life are bound to computers. Almost every piece of electronic equipment, from VCRs to cell phones, to microwave ovens, has at a tiny computer called a microcontroller. Like you, computers have a memory that allows them to store information. Computer memory and quick access to the information in memory are part of why computers are so useful.

It's all about information

The working of a computer can be broken down into three basic steps—putting information in, processing information, and sending information back out. Early computers required people to flip switches to enter information. Today there are many ways to input information: the mouse and keyboard, digital cameras, scanners, microphones, touch screens, and bar code readers. The list of these input devices grows each year. Familiar output devices include your monitor, printer, speakers. Other important outputs are connections to other computers through cables or wireless radio.



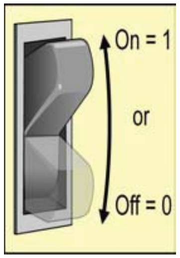
The long and the short of it

The two basic types of computer memory are short-term and long-term. Short-term memory is erased when the power is turned off. Long-term memory retains its information even with no power. Long-term memory is used for things that the computer uses many times such as *programs* that tell the computer what to do with the information in its memory. Programs use various languages such as C++ or Java to create complex lists of instructions that tell the computer how to accomplish tasks with information in memory.

Short-term or RAM (Random Access Memory) is on silicon chips that are used by the computer while it is actively working. Short term memory is thousands of times faster than long term memory, but also much smaller. When you activate a program, the computer loads the program from long term memory into short term memory where information can be used quickly. When the program is done, the computer erases it (and its data) from short term memory, freeing up this faster memory for other programs.

1-0-1-0-1-0

Almost all computers use magnetic disk drives (hard drives) for long term memory. A hard drive is actually one or more circular plates made of glass or metal covered with a fine layer of magnetic film. The Read/Write Head uses a miniature coil to "write" information on the disk as a sequence of magnetic north and south poles. When electricity is passed through the coil, a magnetic field is produced. This magnetic field causes the magnetic film on the surface of the disk to "record" the polarity of the field. Since each spot on the disk can only be north or south, all information must be represented as on or off, like a switch. Schematically, a north pole means "on" while a south pole means "off".



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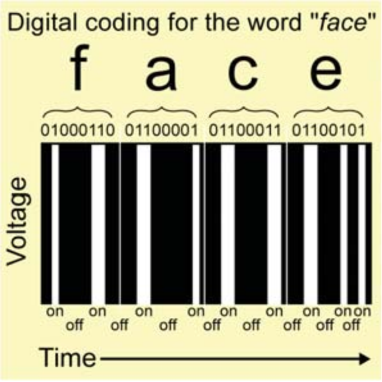
The on-or-off language is called *binary*. Like a switch that can be turned "on" and "off," there are only two digits in the language: 0 and 1. In computer terms the word *bit* stands for "**bi**nary digi**t**." The binary language is used by all computers to store information.

Eight bits form a *byte*. A code represents each letter or number as a different one byte sequence of 0s and 1s. The diagram shows how the word 'face' is represented by 4 bytes or 32 bits. The binary code language used here is called the ASCII Code.



Reading memory

To read information, the changing magnetic poles on the disk induce tiny voltages on the coil in the read/write head as the disk spins. The voltages are amplified and turned into digital ones and zeros that are stored in short term memory (RAM).

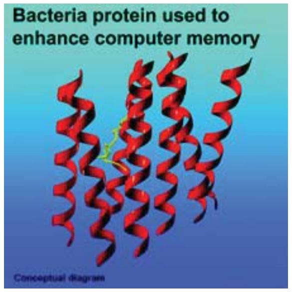
Growing capacity

The smaller the individual north and south poles on a disk can be made, the more information you can fit on a single disk. The memory capacity of hard disks has increased more than 100 times in the past ten years as newer technologies use smaller areas to store each bit. As the space needed to store a bit decreases, the strength of each bit's field must also decrease so as not to influence the surrounding bits. This has been done by improving the magnetic recording film, by more precise manufacture of the disks themselves, and by developing smaller and more sensitive read/write heads.

The future of computer memory

Words and numbers are relatively compact in terms of storage. All the words in this entire textbook would take up less than 100 kilobits of disk memory. However, pictures and movies are another story. A *single* digitized picture can take up 5 megabits, or 50 times as much memory. Because of the increased graphical capabilities of today's computers, increasing the capacity of computer memory is critically important. Therefore, scientists continue to explore new ways to store digital information.

For example, some scientists are investigating the possibility of storing information on a protein found in a bacterium. Different twisting forms of the protein are used to record digital ones and zeros. Since proteins are so small it may be possible to get 100 or 1,000 times as much information into the same space used by a conventional hard drive today.



Questions:

1. The functions of a computer can be broken down into three basic steps. In which step does the CPU play a role?
2. What is the difference between short-term and long-term computer memory?
3. How many bits are used to write the word "congratulations" using the ASCII Code?
4. The trend in computer technology seems to be that computers are getting smaller while memory and speed increase. How would you illustrate this trend on a graph?

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Chapter 17 Review

Understanding Vocabulary

Select the correct term to complete the sentences.

electric generator
electric motor
armature
brushes
electromagnetic induction
transformer
Faraday's law of induction
rotor
solenoid
commutator
coil

Section 17.1

1. A wire looped into a circular _____ can be used to create a magnetic field that is stronger than that of a single wire.
2. A coil with many turns called a _____ is a device commonly used in speakers, motors, and many other devices.

Section 17.2

3. A(n) _____ is used to convert electrical energy into mechanical energy.
4. A _____ is used in a motor to switch the direction of the magnetic field created by the current.
5. The rotating part of a motor that holds the electromagnets is called the _____.
6. Electric current passes through the _____ and into the electromagnets in an electric motor.

Section 17.3

7. A(n) _____ is used to convert mechanical energy into electrical energy.
8. Using a magnet to create electric current in a wire is called _____.
9. _____ explains the relationship between the current created in a coil and the rate of change of the magnetic field through the coil.
10. A _____ uses two coils to change the voltage of the electricity coming into your home.

Reviewing Concepts

Section 17.1

1. How is magnetism created?
2. What exists in the region around a wire that is carrying current and that exerts a force on another current-carrying wire?
3. Explain how the right-hand rule can help you determine the direction of the magnetic field lines around a current-carrying wire.
4. What effect does increasing the current in a wire have on the magnetic field?
5. What effect does reversing the direction of the current in a wire have on the magnetic field?
6. What happens to the magnetic field as you move farther away from a current-carrying wire?
7. Why do we not use a single wire with a large current if we wish to create a strong magnetic field?
8. What is the advantage of using a coil to create a magnetic field?
9. Why don't we usually notice the force between the current-carrying wire in an extension cord?

Section 17.2

10. A motor turns _____ energy into _____ energy.
11. Why is it necessary to use at least one electromagnet in a motor instead of only permanent magnets?
12. What is the purpose of the commutator in a motor?
13. Why must the direction of the current in a motor's electromagnets be switched repeatedly?
14. List the three main parts of an electric motor.

Section 17.3

15. What happens as you move a magnet toward a coil of wire in terms of electricity?
16. If you hold a magnet still near a coil of wire, will current or voltage be induced? Explain your answer.

17. State Faraday’s law of induction in your own words.

18. Why does a spinning coil near a magnet produce alternating current rather than direct current?

19. What is the voltage provided by electrical outlets in buildings?

20. The voltage of the electricity in outside power lines is much higher than the voltage of the electricity in buildings. How is the voltage reduced?

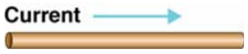
21. The primary and secondary coils in a transformer have different voltages and currents but the same _____.

22. A certain transformer has more turns in the secondary coil than in the primary coil. Does the transformer increase or decrease voltage?

Solving Problems

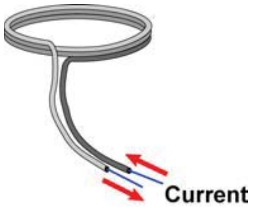
Section 17.1

1. Copy the diagram of the wire shown to the right and draw the magnetic field lines in the region around the wire. Don’t forget to include arrows to show the field’s direction.

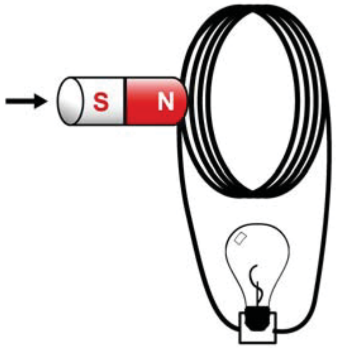


2. What happens to the strength of the magnetic field near a wire if you double the current? Triple the current? Quadruple the current?

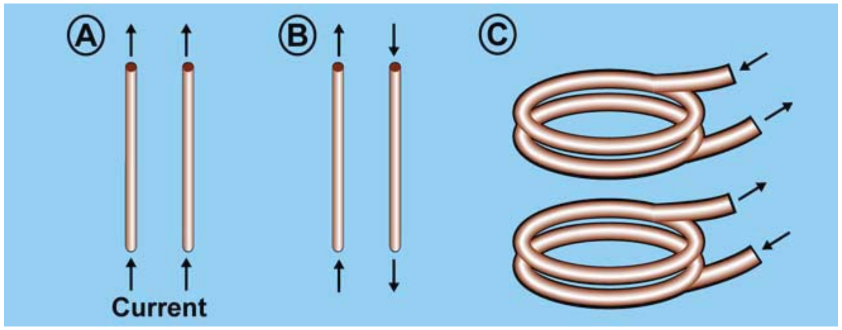
3. Copy the diagram of the coil shown to the right and draw the magnetic field in the region around it. Don’t forget to include arrows to show the field’s direction.



4. Explain how each of the following would affect the current produced by a magnet moving toward a coil of wire:
   a. using a stronger magnet
   b. moving the magnet toward the coil at a faster speed
   c. reversing the magnet’s motion so it moves away from the coil
   d. adding more turns of wire to the coil
   e. moving the magnet’s south pole toward the coil
   f. adding a second light bulb to the circuit

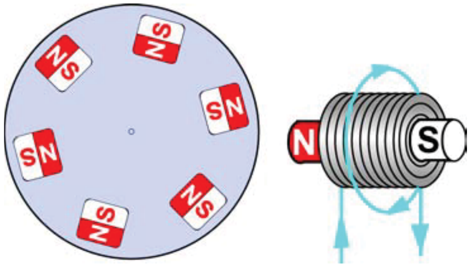


5. Decide whether each pair of wires or coils will attract or repel.

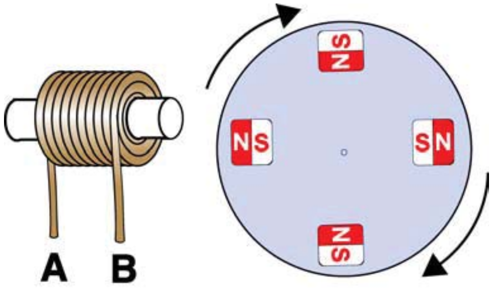


Section 17.2

6. At a certain instant, the electromagnet in the motor shown below has its north pole facing the rotor that holds the permanent magnets. In which direction is the rotor spinning?



7. The rotor in the motor below is spinning clockwise. Is the direction of the current in the electromagnet from A to B or from B to A?



Section 17.3

8. A transformer contains 1000 turns in the primary coil and 50 turns in the secondary coil.
   a. If the voltage of the secondary coil is 120 volts, what is the voltage of the primary coil?
   b. If the voltage of the primary coil is 120 volts, what is the voltage of the secondary coil?
9. A laptop computer uses a rechargeable 24 volt battery. A transformer is used to convert an electrical outlet's 120 volts to 24 volts.
   a. If the primary coil has 500 turns, how many turns must the secondary coil have?
   b. If the current in the primary coil is 1 ampere, what is the current in the secondary coil? (Hint: Calculate the power.)

Applying Your Knowledge

Section 17.1

1. Speakers use electromagnets and permanent magnets to create sound from electric currents. Research how electromagnets are used to produce the vibrations that create the music you listen to.

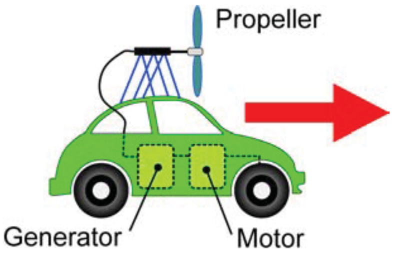
Section 17.2

2. The first motors were built to run on direct current. However, direct current could not be easily transmitted over long distances. In the late 1800's, Nikola Tesla invented a motor that ran on alternating current. Research Tesla's life and his invention of the AC motor.

Section 17.3

3. Suppose you have a transformer that provides a secondary voltage four times as great as the primary voltage. You have a cell phone that uses a 6 volt battery. Could you use a 1.5 volt battery and the transformer to power the phone?

4. A bicycle light generator is a device you place on the wheel of your bike. When you turn the wheel, the generator powers a light. When you stop, the light goes out. Explain how you think the generator makes electricity.



5. A clever inventor claims to be able to make an electric car that makes its own electricity and never needs gas. The inventor claims that as the car moves, the wind generated by the motion spins a propeller. The propeller turns a generator that makes electricity to power the car. Do you believe this car would work? Why or why not? (Hint: Think about conservation of energy.)

6. Some electric toothbrushes contain rechargeable batteries that are charged by placing the toothbrush on a plastic charging base. Both the bottom of the toothbrush and the base are encased in plastic, so there is no connection between the circuits in the toothbrush and the base. How do you think the battery in the toothbrush gets charged?