Physical Science V2

Science course from Educational Options

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Lesson 9: Electricity & Magnetism

Objectives

By the end of this lesson, students will be able to:

- explain electric charge, electric force, and static electricity
- distinguish between conductors and insulators
- discuss the ways in which electricity is generated
- calculate resistance, current, and voltage using Ohm's Law
- explain how electricity is transported from a power plant to a residential home
- distinguish between series circuits and parallel circuits

Click here for the course glossary

Introduction

Computer technology is one of the fastest growing industries in the United States. Computer technicians install and work on computers in businesses across the country. They know a lot about computer parts and the networks on which they are used. They also have to know a lot about the things that can affect a computer. Dust, interference from other electronics, and electric charges are all things that can cause damage to computers.

A computer technician takes apart a laptop.

The technician in this picture is taking apart a laptop. Notice the blue band he wears around his wrist. It is an anti-static bracelet. The bracelet has a clip on the wrist side, and a cord (dark blue like a telephone cord in this picture) with a clip on the end of it. The computer technician clips one side to the metal case of the computer he is working on. When he is connected to the computer, he will not transfer an electric charge in the form of *static electricity* to the computer equipment. An electric charge, even a tiny one, can seriously damage a computer. You will learn more about static electricity later in this lesson.

This lesson focuses on electric charge and electric current. You will read about how these charges are generated and how they are used. You will also learn how electricity ends up in your home. Last, you will learn about circuits.

What Is Electricity?

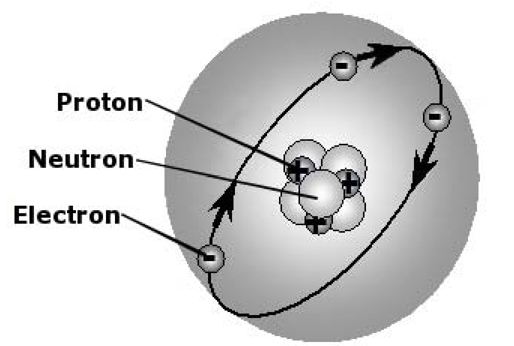
The world is made up of electrical charges in many different forms. Electric charges hold **molecules** together. Electrical energy can be created and transferred quickly and easily. It can also be stored for later use. In fact, most of modern technology is thanks to electric charge in the form of electricity. Electricity gives us power, heat, and light.

Electric Charge

But what is electricity? Electricity is made up of moving electric charges. To understand **electric charge**, we need to begin with the building block of matter: the **atom**.

This picture shows the charges inside a neutral atom. Remember that the **protons** and **neutrons** are gathered together in the center and make up the **nucleus**. **Electrons** travel around the nucleus.

Every atom has either a positive charge, a negative charge, or a neutral charge:



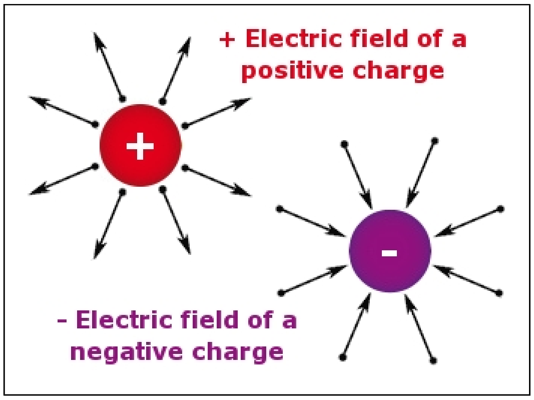
A neutral atom, with equal numbers of protons and electrons

+ When there are fewer electrons than protons, the atom has a positive charge.

— When there are more electrons than protons, the atom has a negative charge.

Ø When the number of electrons and protons are equal, the atom has a neutral charge.

When an atom is neutral, it is the loss or gain of electrons that produces an electric charge. Everything is affected by an electric charge. The effect of the electric charge depends on how the charges of different atoms interact.



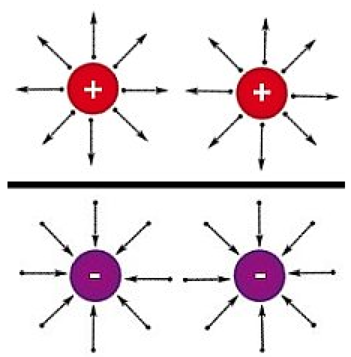
An **electric charge** is a property that causes the protons and neutrons to attract or repel each other. You have probably heard the phrase "opposites attract." In nature, opposite forces attract each other and like forces repel each other.

If you have ever held two magnets, you know that in one position the two magnets will be drawn together. If you flip one of the magnets over, you can feel the force as they push each other away. This is **repulsion**, and the force you feel is the electric force. **Electric force** is the attraction or repulsion between electrically charged objects. Electric force depends on the type of charge and the distance between objects. Look at this diagram to see why opposites attract.

Each atom shown here has a charge. The red one has a positive charge, so it must contain fewer electrons than protons. The purple one has a negative charge, so it must have more electrons than protons.

Each of these atoms has an electrical field around it. The electrical field around the positively charged atom pushes out. The electric field around the negatively charged atom pulls in.

Now take a careful look at the arrows. When atoms have opposite charges, the arrows point in the same direction. These fields work together to create a stronger force. This is where the phrase "opposites attract" comes from. When two atoms have like charges, they repel each other. Look at this picture of atoms with the same charges. The arrows point in opposite directions and the forces work against each other.


Like charges repel; the forces work in opposite directions.

Remember that the strength of the electric force depends on the direction of the force and the distance from the charge. An object that has a greater charge produces a greater force. An object with a lesser charge produces a weaker force.

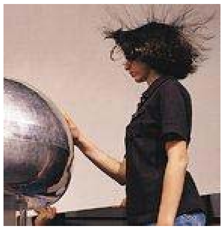
Static Electricity

Have you ever run across a carpet in your socks, and then touched a person or doorknob and received a shock? That happens when an electric charge builds up and gets transferred. Electricity is either stationary (which means it does not move) or it is moving. Stationary electricity is called *static* electricity. **Static electricity** is a stationary electric charge that builds up in an insulated material. The electric charge can be transferred to something (or someone) else by friction, by contact, or by induction.

Friction

If you rub a balloon on your head and slowly pull it away, your hair will stick to it. Your hair has been charged by **friction**. As you rub the balloon on your head, electrons move from your hair to the balloon. Since the balloon gains electrons, it also gains a negative overall, or *net*, charge. Your hair loses electrons, so its **net charge** becomes positive. Opposites attract, so your hair ends up stuck to the balloon.

Contact



Van de Graaff generator

Sometimes electric charge is transferred by contact. The girl in this picture is touching the metal sphere on a Van de Graaff generator. The metal sphere has an electric charge. When the girl touches the sphere, the electric charge is transferred to her body. The electric charge that is transferred causes the girl's hairs to repel each other, which makes it look like it is standing on end! The charge of the metal sphere is reduced when the electric charge is transferred to the girl.

Induction

Remember the example of the shock from a doorknob at the beginning of this section? You get this shock as a result of charging by **induction**. As you walk across the carpet, you pick up extra electrons from the carpet and you become negatively charged. As you reach for the doorknob (but before you touch it), the electrons in your hand repel the electrons in the doorknob. The part of the doorknob that is closest to your hand now has a positive charge. The charge of the doorknob has not changed, it just moved around.

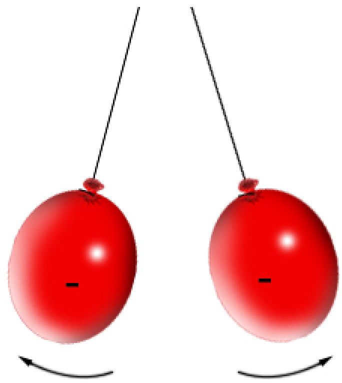
Multiple cloud to ground lightning strikes can be captured by time-lapse photography.

What causes the shock from the doorknob? The answer is *static discharge*. Static discharge happens when a new path opens up quickly through which a charge can travel. When you reach for the doorknob, the air in the small, empty space between your hand and the knob does get suddenly charged. The charged air provides a path for the electrons to flow from your hand to the doorknob. If it is dark, sometimes you can see the spark.

Lightning

Lightning is discharged static electricity. Storm clouds build up charges by friction from moving air masses. Scientists do not understand exactly how the clouds become charged. As the positive charges in the clouds increase, they are attracted to the charges on the ground. The charges build up until they are strong enough to charge the air, much like that space between your finger and the doorknob mentioned in the last section. When the air is charged, it makes a path for the electrons to be transferred to the ground. Some scientists believe that constant lightning strikes are what help to keep the Earth's surface at a constant negative charge.

Try This!



The Law of Electrostatic Attraction and Repulsion

The law of electrostatic attraction and repulsion states that two objects that are both negatively or both positively charged by static electricity will repel each other. Objects with unlike electrical charges, however, will be attracted to each other. You can test the law of electrostatic attraction and repulsion with this simple mini-experiment.

Blow up two balloons of the same size and attach a string on the end of each balloon. Hang the two balloons side by side 2 cm apart from each other. Take a piece of wool cloth or felt and rub the inner side of each balloon. What happens to the two balloons? The two balloons should move away from each other. When rubbing the balloons with a piece of wool, you transferred a negative static electric charge through friction. Because both balloons received a negative charge, the balloons repelled each other.

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Lesson 9B: Magnetism

Objectives

By the end of this lesson, students will be able to:

- define magnetic force and explain the phenomenon of attraction and repulsion
- describe the properties of magnetic fields
- distinguish between magnetized and non-magnetized properties
- explain how electric currents and magnets can affect one another
- apply the concept of magnetism to everyday life

Click here for the course glossary

Introduction

Have you ever seen a globe (like the one in this picture) that levitates, or floats in mid air? It is not an illusion; it is done by carefully placed magnets. The magnetic forces push away from each other with equal forces, holding the globe in the middle. It is easy to give such a brief explanation, but understanding why magnetic forces work this way might be more difficult.

A magnetic field suspends this globe in mid air.

Since ancient times, man has studied magnetism. Ancient Greeks, Romans, and Chinese civilizations studied the properties of lodestone, a mineral that can attract iron. These people observed that rubbing a piece of iron against the lodestone transferred a magnetic ability to the iron. The iron became able to attract other pieces of iron. By the 1200s, the compass (a magnetic instrument) was being used to navigate the open sea. But it was not until 1600 that an English physicist named William Gilbert published a book called *Of Magnets, Magnet Bodies, and the Great Magnet of the Earth* that detailed many of the properties of magnets.

Scientists around the world would continue to study the properties of magnets for the next 300 years.

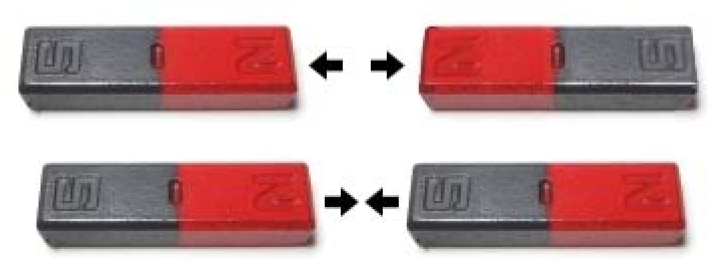
This lesson focuses on magnetic forces and fields. You will learn the connection between electric current and magnetism as well as how we use the properties of magnetism in our every day lives.

What Is Magnetism?

You probably know some of the properties of magnets. Sometimes they are drawn together and sometimes they push each other away. These are forces between magnetic materials. Magnetism affects all forms of matter. Scientists currently study magnetism to gain insight into the **atomic structure** of matter.

Magnetic Forces and Fields

If you hold a magnet in your hand, it does nothing obvious on its own. What you cannot see is the invisible force field around that magnet. This is what makes magnets special. If you hold *two* magnets in your hand, suddenly their behaviors change. In one position, a strong force draws them together. This is the force of **attraction**. In another position, the magnets work against each other, pushing each other away. This is the force of **repulsion**. We refer to this force of attraction and repulsion as magnetic force. **Magnetic force** is the force a magnet places on another magnet, magnetic material, or moving charges. The harder the force, the more the magnet will react. However, the strength of magnetic force also depends on distance.

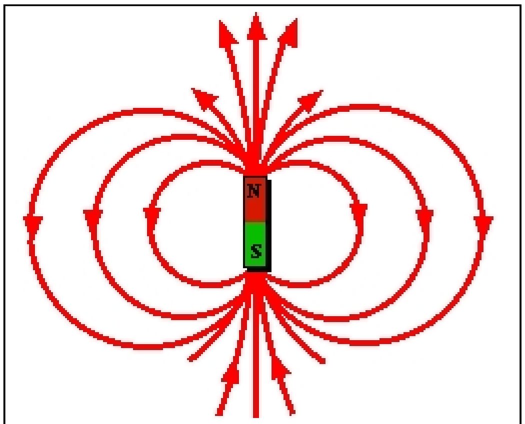


Like poles repel and opposite poles attract.

English physicist William Gilbert used a compass to experiment with magnets. He wanted to find out if there was a place on the magnet where the force was the strongest. He found that every magnet had on it two places where the force was stronger. Gilbert had found the **magnetic poles**: the regions where a magnet's force is the strongest. Every magnet has two poles: a north-seeking pole and a south-seeking pole. When Gilbert experimented some more, he found that the magnets behaved differently according to how the poles faced each other. If two north-seeking poles faced each other, the magnets pushed each other away. The same thing happened when two south-seeking poles faced each other. However, when a north pole faced a south pole, the magnets were drawn together. *Like* magnetic poles repel each other and *opposite* magnetic poles attract each other.

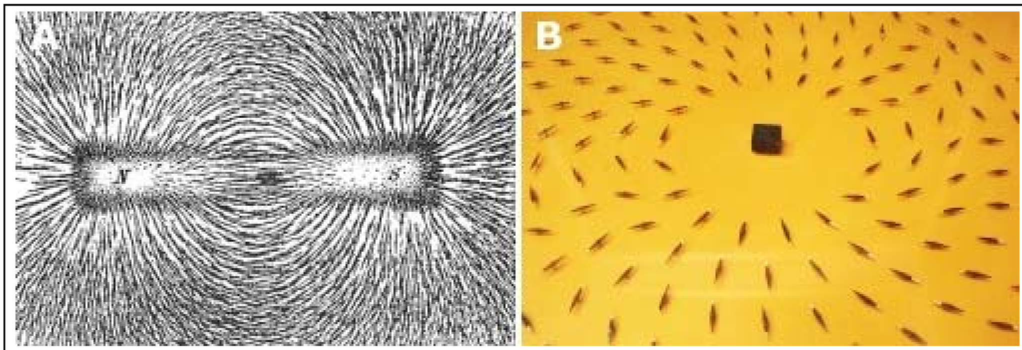
So, where on the magnet does the change from north-seeking to south-seeking occur? Compasses had been around for hundreds of years by the time Gilbert started studying magnetic properties. He found not only the point at which the magnet was strongest, but all of the points in between. He mapped the **magnetic field**, which is defined as the area around a magnet that exerts magnetic force.

Magnetic fields are easier to understand when you can see how they work. A magnetic field is usually represented by lines around a magnet called **flux lines**. Look at this diagram. It shows the magnetic field around a bar magnet. The red lines are the flux lines. You can imagine the flux lines as running through the middle of the bar magnet, so that each red line makes a closed circle. Flux lines also show where the magnetic field is strongest. Where the lines are close together, the field is strong. Where they are farther apart, the field is weak. The strength of the magnetic field is directly related to the amount of space between the flux lines.



Magnetic fields around a bar magnet

Magnetic fields, and therefore flux lines, are different for different-shaped magnets. A magnetic field can be mapped by shaking iron filings, tiny bits of shaved iron, over the magnet. Iron filings line up along the flux lines, showing where the magnet is strongest and weakest. Compare the pictures below:



Picture A shows the flux lines (and therefore the magnetic field) around a bar magnet. Picture B shows the magnetic field around a square magnet. Since these magnets are about the same size, you can see that the bar magnet in picture A is much stronger than the square magnet in picture B. The spaces between the flux lines are much closer together and the iron filings are crowded close together.

Think About It

The magnet in picture B does not appear to have any areas that are weaker or stronger. Where are its poles?

Magnetic Materials

Some materials are **natural magnets**. These are substances that are found in nature and have magnetic properties. Lodestone was one of the first natural magnets discovered and used by man. Magnetite is another natural magnet. It is a form of iron that can be found on many white sand beaches. Magnetite looks like tiny black grains of sand, and if you hold a magnet over them they will attract.

Remember that everything is made up of **atoms**. An atom contains a **nucleus**, the core where **protons** and **neutrons** are located. **Electrons** travel around the nucleus in pairs. Because of a property called *spin*, electrons act like tiny magnets. In many atoms, the paired electrons have opposite spins, and therefore cancel out each other's magnetic properties. This causes the material to have a very weak magnetic field.

In other materials, the electrons are not paired. They travel alone around the nucleus. This means that their magnetic fields are ready to attract or repel other electrons. In some materials the electrons do not match up, so those materials share a weak attraction. When the electrons in two materials match up and are drawn together, they form a magnetic domain. A **magnetic domain** is an area that has a high number of electrons with magnetic fields that match up.

Materials with magnetic domains can be magnetized or nonmagnetized:

Nonmagnetized materials

Just because a material has a magnetic domain does not mean that it is a magnet or that it has the power to attract and repel. A nail is a good example of this. A nail made of iron has electrons that could be matched with another material to create a magnetic domain. However, it is not normally near these materials, so it is considered nonmagnetized.

Iron nails are nonmagnetized materials. However, they have the potential to be magnetized.

Magnetized materials

A material is magnetized when its magnetic domain aligns with another material or magnetic field. In fact, you can magnetize a nonmagnetized material by placing it within a magnetic field. Have you ever magnetized a nail or the head of a pin? If you rub them on a magnet, they become magnetized. This effect wears off in most materials, usually when the alignment of electrons is suddenly jarred out of line again. This type of magnet is called a **temporary magnet**. Some metals, when mixed, can be made to hold their magnetism permanently. These are called **permanent magnets**.

How Are Magnetism and Electric Current Related?

One night in 1820, a Danish scientist named Hans Oersted wanted to share some things he had discovered while researching electricity. When he turned on the electric current necessary for one experiment, he noticed the needle on a nearby compass jump. He turned the current off, and it was still. He

Try This!

Magnets and Induction
As you learned in this lesson, you can create a temporary magnet by rubbing some nonmagnetic materials against a magnet. You can also create a temporary magnet through induction, or using a magnet to transfer a magnetic force to other materials. You can test magnetic induction by using a magnet and a handful of small metal paper clips. First, place the paper clips in a pile on a flat surface. Using one paper clip, test to see if the paper clips are magnetic. What happens when you place the single paper clip near the pile? Now place

turned it on again, and the needle moved again. Oersted had just accidentally discovered that electric current and magnetic fields are related. This discovery brought about a completely new understanding of what magnetism is and the effect it has on other natural forces.

the magnet next to one paper clip. What happens to the single paper clip? Using the paper clip that is attached to the magnet, try to pick up another paper clip from the pile. Does the originally nonmagnetic paper clip pick up another paper clip?

Electricity and Magnets

Most objects have a balanced force. You have read briefly about electrons' *spin*. In any given object, the electrons are spread out fairly evenly: half of the electrons *spin* one way and the other half *spin* the other way. All of these electrons move about the nucleus and are spread evenly throughout the object. But magnets are different. All of the electrons that *spin* one way collect at one pole, while the electrons that *spin* the other way collect at the other pole. The result is an unbalanced force is known as the magnetic field.

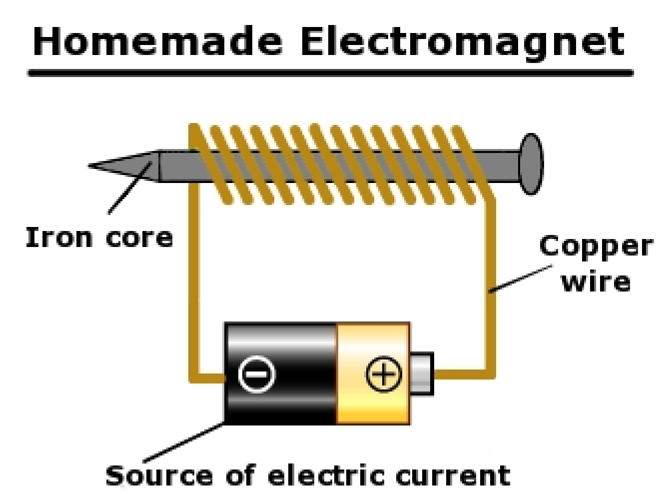
Magnetic force can generate electricity. When magnetic fields move, they push and pull electrons, which creates electric current. Moving magnets are used in electric generators to push electrons to create electric current.

Electromagnetism

The relationship between magnetism and electricity is called **electromagnetism**. Electromagnetism occurs when electric current flows through a wire and creates a magnetic field. Oersted was the first to find that a moving electric charge could produce a magnetic field. The moving electric charge can be **electric current** (as he found in his experiment) or charges that vibrate, as in the kind that make up an **electromagnetic wave**. The magnetic field builds up around the moving charge in circles. You can imagine it as a tube that closes around the charge.

Finding out how electricity and magnetism worked together was a great leap in technology in the 1800s. However, this knowledge was not enough. Before anyone could understand how to use an electromagnetic force, they would have to know what to do with the force. Soon scientists created the electromagnet. An **electromagnet** is a very strong magnet that can be turned on and off. Because it is a temporary magnet, it has many uses.

An electromagnet uses electric current and magnetized materials. To make an electromagnet, a **conductor**, such as copper wire, is wound around a piece of iron. When electric current is passed through the wire, it generates a strong magnetic field as the electrons align with the iron. The more loops of wire around the core, the stronger the magnetic field. When the current is switched on, the magnet is activated. When the current is switched off, the magnet switches off too. Electromagnets are often used to haul large or heavy metal objects (in scrap yards, for example) because they can be turned on and off to pick up and drop objects.



You can make an electromagnet at home with a battery, an iron nail, and some copper wire.

Electromagnetic Induction

Hans Oersted found that electric current can produce a magnetic field, but what about the other way around? Can a magnetic field produce electric current? In 1831, an English scientist named Michael Faraday asked that question and found the answer. He discovered that moving a wire through a magnetic field generated electricity. The motion of a conductor through a magnetic field is called **electromagnetic induction**. The motion inside the magnetic field makes electromagnetic induction work. It does not matter whether the conductor moves or whether the magnet moves; either motion generates electric current. The current comes from cutting through the lines of the magnetic forces.

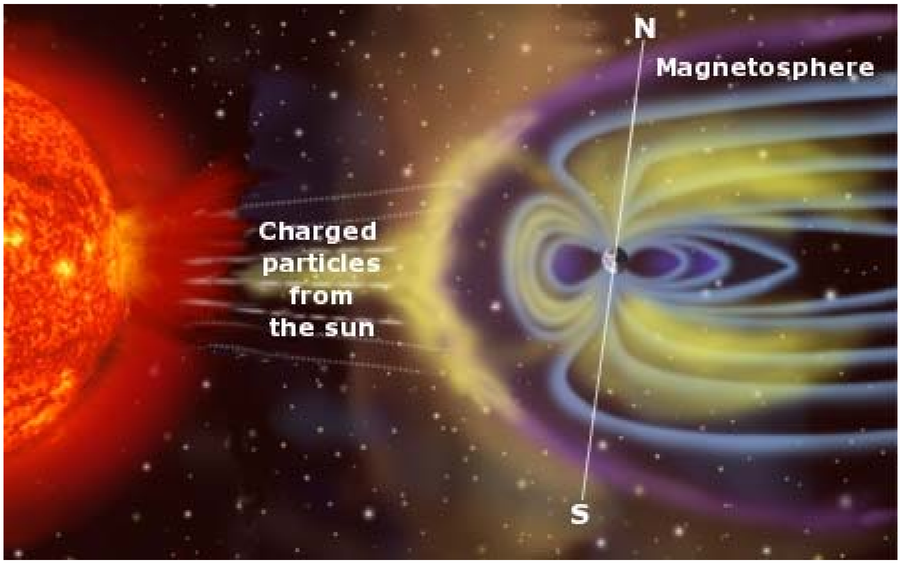
How Do We Use Magnetism?

Magnetism affects our everyday lives in many ways: sometimes directly and sometimes indirectly. Some examples are the use of electromagnets in generators and the effects of Earth's magnetic poles.

Earth's Magnetic Field

William Gilbert's book, *Of Magnets*, summarized many of the properties of magnets that were already known as well as revealed new theories about magnetism. One of the theories he stated in his book was that the Earth is one giant magnet. He also had a theory that the Earth would be found to have magnetic poles, although in 1600 he had no way of telling where they were.

Gilbert's theories proved correct. It was eventually discovered that the Earth behaves as if it had a bar magnet that runs down the middle, almost from top to bottom. There is a magnetic field around Earth that is strongest at the north and south magnetic poles. The area of space around Earth that is controlled by the Earth's magnetic field is called the **magnetosphere**. It is full of changing electric magnetic fields and protects the Earth from particles that are given off by the sun. Look at this drawing of the Earth's magnetosphere:



In this image, the strongest part of Earth's magnetic field can be seen at the magnetic north and magnetic south poles.

This is an artist's interpretation of what the magnetosphere looks like. The magnetosphere cannot be seen, but sometimes charged particles from the Sun collide and give off light that can be seen from space.

The Compass

Compasses have been used by navigators for hundreds of years. A compass is made from a magnetized needle that moves freely to always point north. The Earth's magnetic field affects the needle just as a bar magnet would. While the compass needle always points north, it does not point to what *we* refer to as north. Since discovering the world was round, we picture the world to have a north and south direction. The geographic north pole is at the "top" of our world. The geographic south pole is at the "bottom" of our world. We know these places as the North and South Poles. Scientists have discovered that they are not the true poles, so we refer to them as the **geographic poles**. The true north and south poles of the Earth are located not all that far from the geographic poles. We call them the **magnetic poles**. The magnetic north pole is actually in Canada, and the magnetic south pole is in the Antarctic Circle. Both are only about 1600 km away from the geographic poles.

An ancient Chinese compass made of lodestone; the Chinese called compasses "south pointers"

The fact that a compass does not point exactly to the North Pole is not a big problem in most locations. The Earth is so big and the difference in the location of the poles so small that an explorer or hiker would not be thrown off course. The difference becomes more important as one gets closer to the poles. An explorer or hiker very close to the poles would have to make careful calculations to make up the difference. The difference in the location of the magnetic and geographic poles is called **magnetic variation**, and it is different everywhere on Earth.

Think About It

Think about the Earth's orientation in space. Why don't the magnetic poles and geographic poles line up?

Recall that like poles repel and opposite poles attract. If the tip of the compass needle is its north pole and it points toward the magnetic north pole of the Earth, then something is not matching up. Shouldn't the two north poles repel? The answer is yes. Actually, the tip of the compass is correct. What we call the magnetic north pole is currently the magnetic south pole. This is because the Earth's poles change about every 200,000 years, although the time frame varies a lot. The last time Earth's poles reversed was about 780,000 years ago. Since it is not known exactly what causes the reversal, there is no way to predict when it will occur. The Earth's magnetic field is currently weakening, so it is possible that the Earth is beginning to undergo a pole reversal. However, the process takes thousands of years to complete. During a reversal, scientists expect that the magnetic field would be weak and there would be several magnetic poles in different places around the Earth. Radio communication would become almost impossible, and animals that migrate may have trouble knowing where to go.

As for the North and South Poles, scientists just accept that the names of the magnetic poles are named according to their locations near the geographic poles.

Medicine

Do you know anyone who has had an MRI? MRI stands for **M**agnetic **R**esonance **I**maging. It is a process that combines magnetic fields, radio waves, and computers to take pictures of the body. An MRI machine creates a strong magnetic field around the patient. This field works with the body's natural charges to create a transmission that the machine can interpret and turn into an image. An MRI image can be made from any angle, of any part of the body, and without risky or expensive surgery. MRIs play an important part in diagnosing many diseases and injuries.

There are a few other uses for magnets in conventional medicine. Electromagnets have been found to be useful in healing difficult bone fractures and in mapping areas of the brain to study psychiatric and pain disorders. Alternative medicine frequently uses magnets for pain management and therapy for certain disorders. These methods have not been scientifically proven to work, and research is still underway.

Transportation

Monorails, such as the one at Walt Disney World, usually use *induction motors*. The monorails do not turn around; they have a steering wheel at each end. After it pulls into a station one way, the conductor goes to the other end to drive it the other direction. To drive it, the conductor reverses the direction of the train by reversing the direction of the magnetic poles in the moving parts of the motor. This starts the monorail going in the opposite direction.

The monorail at Walt Disney World

Making Connections

In this lesson, you learned about magnetism and its properties. You also learned about the magnetic field around the Earth, and how the study of magnetism has influenced technology. This is the last lesson in the Physics section of this course. The next section focuses on Earth and Space sciences. As you continue through the last part of the course and you read about the Earth's plates, the planets, and other celestial bodies, keep in mind where this course started: all matter is made up of countless tiny atoms.