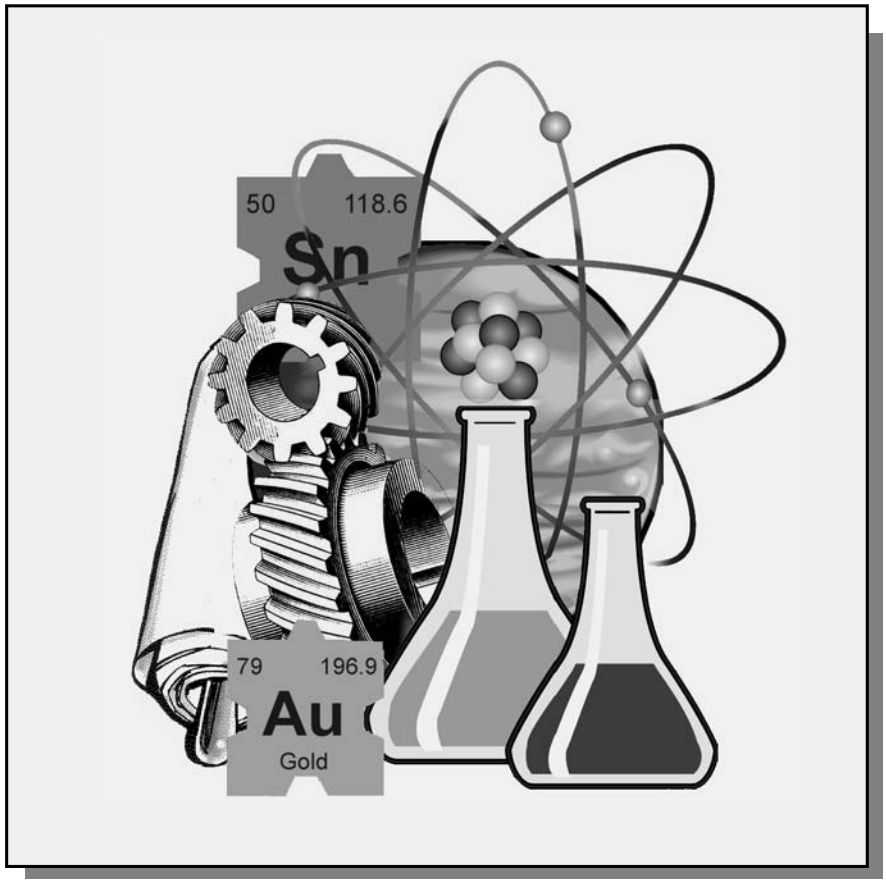
Integrated Physics & Chemistry

This chapter requires a companion activity book in which students respond to questions on text content. Answers are found in the *Teacher's Resource Kit*.



Chapter 6

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IPC, CHAPTER 6
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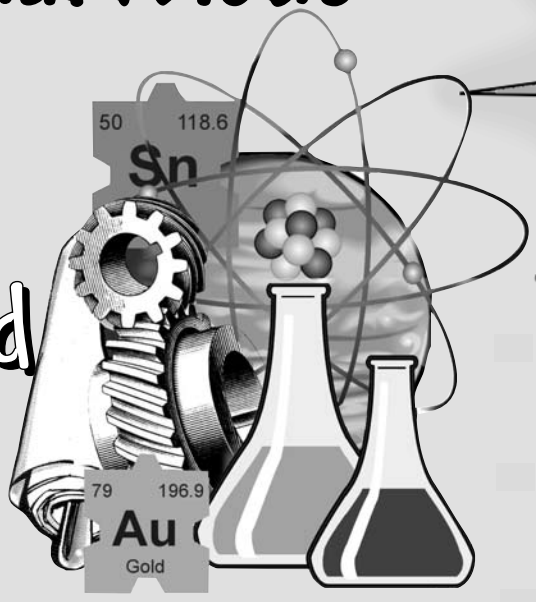
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"The study of science is the chronicle of man's quest to discover the essence of life and how the marvelous laws of creation are applied to human needs."



—Ronald Johnson, Ph.D.

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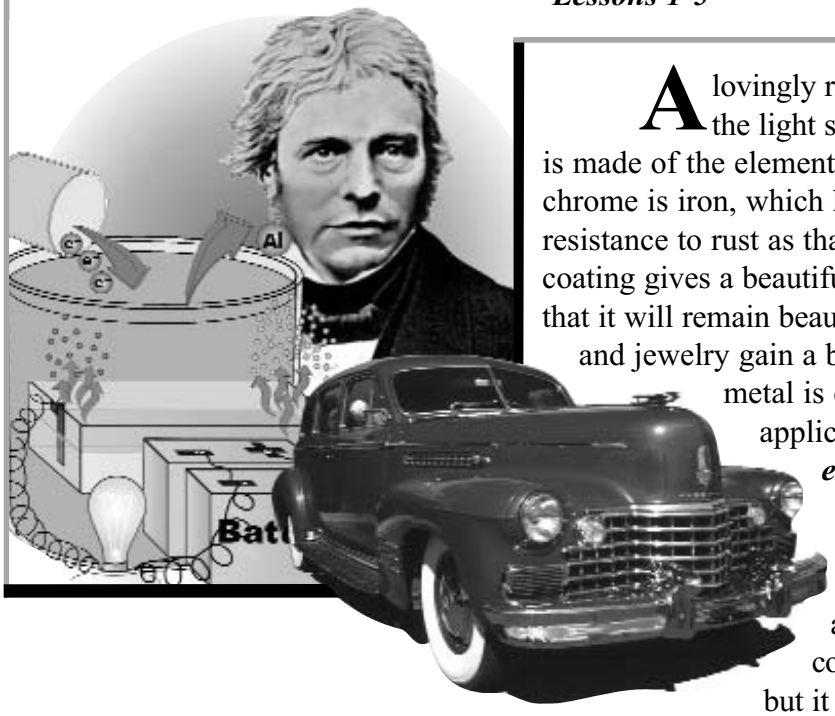
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Compounds

Chapter 6

MAKING IT SHINE

Section 1

Lessons 1-5



A lovingly restored classic car glitters from the light sparkling off the chrome. Chrome is made of the element ***chromium***. Underneath the chrome is iron, which has neither the luster nor the resistance to rust as that of chromium. The chrome coating gives a beautiful finish to the metal and ensures that it will remain beautiful for a long time. Dinnerware and jewelry gain a beautiful shine when the base metal is coated with silver. This is an application of ***electrolysis*** called ***electroplating***.

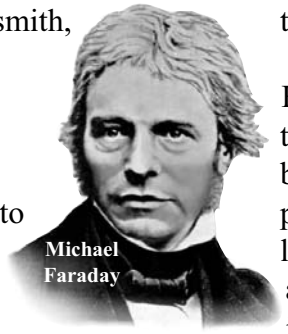
Electrolysis makes possible coating one metal with a layer of some other metal. Copper and gold are very good conductors. Copper is inexpensive, but it is easily corroded or eaten away. Gold, on the other hand, is not easily eaten away; it resists corrosion. The best contacts in electric equipment, such as computers and video equipment, make use of gold connections. However, because of the cost of the metal, only a very thin layer is used.

Michael Faraday was the first scientist to make a thorough study of how electrolysis works. His father was a blacksmith. Shortly after Michael Faraday was born, his parents and his older brother moved to London. The Faraday family was very poor, and they took lodging in rooms over a coach house. Michael had nine brothers and sisters. In London, Michael's parents paid tutors to train the children. Because of the expense, Michael's family could keep him in school only a short time. He learned the basics of reading, writing and simple arithmetic. Mr. and Mrs. Faraday taught Michael everything they could at home, including their strong Christian principles. Michael Faraday tried to remain faithful to his Christian beliefs throughout his life.

VOCABULARY

Chromium: metallic element that takes a high polish, used as body trim on cars to provide a hard, corrosion-resistant, lustrous finish, symbol is *Cr*
Electrolysis: the use of an electric current to cause chemical change
Electroplating: to coat or cover with a thin layer of metal by electrolysis

Michael was too small to follow in his father's trade as a blacksmith, so his parents found an apprenticeship for him as a bookbinder. The master bookbinder was Mr. George Riebau, who rented a room to Monsieur Masquerier, a French painter. These two men had important roles in Faraday's life. Master Riebau allowed Michael to read books that were left at the store for binding. The French painter loaned Michael books to read and taught him to sketch. Michael was fortunate that both Mr. Riebau and Monsieur Masquerier took an interest in his education. Many books of a scientific nature came through the store. Michael read them all and even did some of the experiments described in them. Michael enjoyed reading the books and decided that he wanted to become a scientist.


Michael Faraday

One of Michael Faraday's goals had been to attend the popular science lectures of Humphry Davy, but the tickets were far more than Michael could afford. Mr. Dance, a customer of the bookshop, had several extra passes to Davy's lectures, so Mr. Dance gave the passes to Mr. Riebau. Mr. Riebau, in turn, presented them to Michael, who attended the lectures, took careful notes and made detailed drawings. After the lectures, Humphry Davy received a letter from Michael with samples of the notes he had made.

About this time, Humphry Davy had another accident in his long series of laboratory accidents. He injured his eyes in an explosion of nitrogen chloride, and as a result, Davy could not read or write. Because of Michael Faraday's penmanship, Davy employed Michael to take dictation and copy manuscripts. The job ended when Humphry Davy recovered. Michael Faraday went back to the bookbindery. Mr. Dance and Mr. Riebau encouraged Michael not to give up his quest to become a scientist.

Michael wrote a full report of Humphry Davy's lectures. Faraday illustrated the report with colored drawings and beautifully bound the notes in leather. He then presented the book to Humphry Davy. Faraday's letter to the great man requested a position, any position. The great scientist was suitably impressed. He knew that life as a scientist for a person with no particular schooling might be as frustrating as working in a bookbindery. Davy advised Faraday to remain at the bookstore. He said, "Science is a harsh mistress and poorly rewarding."

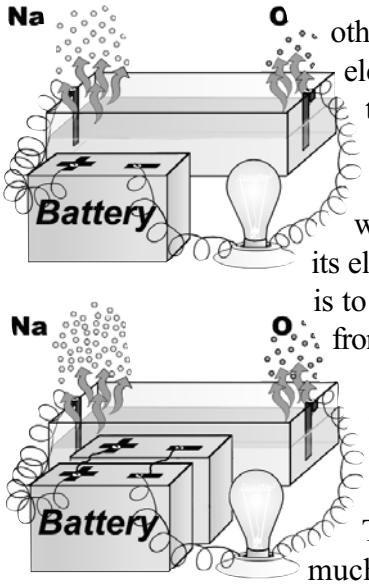
The very night that Faraday received the rejection from Davy, William Payne, one of Davy's assistants was involved in a brawl and consequently dismissed from his duties at the Royal Institute. Davy sent for Faraday and offered young Michael a job as a laboratory assistant. Davy asked, "Are you still eager to accept any position in science?" Michael Faraday assured him he was. The unschooled son of a blacksmith now worked with the best known scientist in the world. Faraday started at the bottom, washing bottles for a salary below what he had earned binding books. The next year, he accompanied Davy on a two-year tour of Europe where Faraday learned to speak French and some Italian. While in Paris, Michael Faraday met Andre Ampere. When the two Englishmen returned to London, Davy increasingly depended on Faraday. As the years passed, Michael Faraday took a greater role in the day-to-day work of the laboratory.

Michael Faraday not only worked at the Royal Institute; he lived there. Having his lodgings above the laboratory meant he could work at any small moment he might find. He could work through the night at no inconvenience to others. What he did was read, think and experiment. Faraday believed

in experimentation. Reading and thinking alone were not enough to satisfy Michael Faraday. He was never able to make a fact come alive unless he saw it in action. Faraday did every electric experiment he could imagine. He made a thorough study of electrolysis. He invented the terms electrolysis, electrode, cathode and anode. One of his important discoveries showed the relationship of chemistry and electricity.

Faraday's *First Law of Electrolysis* states that the amount of an element transformed at each electrode is proportional to the amount of electricity. In other words, the more electricity that flows through a compound, the more the compound will be separated into its elements. If the goal is to release sodium from sodium oxide, then twice as much current will release twice as much sodium. Three times as much electricity will release three times as much sodium and so on. At the other terminal, oxygen gas would be bubbling out of the electrolyte. If 10 liters of oxygen gas are released in an hour, and if the current remains constant, 20 liters will be released in two hours. Faraday's First Law of Electrolysis states a predictable relationship between the amount of electricity and chemical activity.

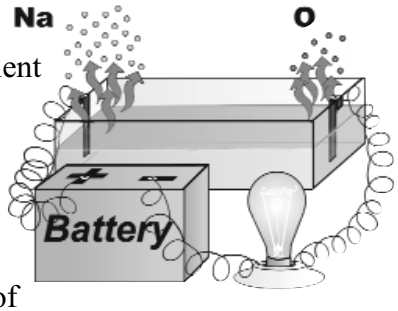
First Law of Electrolysis



To understand Faraday's Second Law of Electrolysis, a person must first understand equivalent weight. *Equivalent weight* is the weight of a particular element that is needed in a chemical reaction. Elements and compounds react in definite proportions by weight. If the process is begun with too much of one element, some of the element will be left untouched after the reaction is over. Too little of the element will result in an incomplete reaction. Equivalent weight is related to the valence number of the element. The *valence* number of an element is equal to the charge that an ion of that element will have. Remember that an ion is a charged particle. Different elements have different charges, depending upon the number of electrons the elements have.

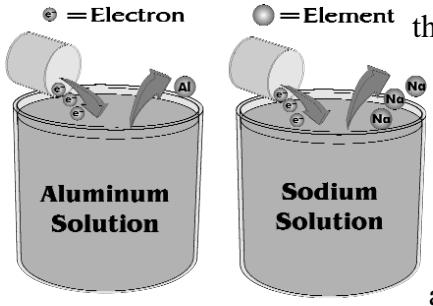
Faraday's *Second Law of Electrolysis* states that electrolysis releases elements proportional to their equivalent weight. Equivalent weight is the atomic weight divided by valence. Sodium has an atomic weight of 23, and its valence is +1; so its equivalent weight is 23. Suppose a certain amount of electricity releases 23 grams of sodium. Oxygen has an atomic weight of 16.00 and a valence of –2, so its equivalent weight is 8. The electricity that releases 23 grams of sodium will release 8 grams of oxygen. Aluminum has an atomic weight of about 27 and a valence of +3. It's equivalent weight is 27 / 3 = 9. Sodium has an equivalent weight of 23. The electricity that will free 23 grams of sodium will free only 9 grams of aluminum. By using the equivalent weight, the chemist is assured of having the right amounts of both elements.

Second Law of Electrolysis



More electricity is required to free aluminum than sodium. The difference is the valence. Sodium has a valence of +1, and its ion is Na^{+}. Aluminum has a valence of +3 and its ion is Al^{+++}. Electricity is the flow of

electrons. A sodium ion needs only one electron, e^-, to balance its single positive charge and make it a neutral atom. An aluminum ion needs three electrons to balance its triple positive charge and make it a neutral atom. Compared to sodium, three times as many electrons are needed to free the same number of aluminum ions from the electrolyte. The electron is shown by the symbol e^-. The small minus sign shows that it carries a unit negative charge.



$$Na^+ + e^- \rightarrow Na$$

$$Al^{+++} + 3e^- \rightarrow Al$$

The first equation shows that a sodium ion plus an electron gives a neutral sodium atom. The second equation shows that an aluminum ion plus three electrons gives a neutral aluminum atom.

Equivalent weight is used in the Law of Electrolysis because both electrolysis and valence depend on the number of electrons an element is willing to release or accept. Sodium releases but one electron, so its equivalent weight is equal to its atomic weight. Aluminum releases three electrons, so its equivalent weight is one-third of its atomic weight.

LIFE PRINCIPLE

"Success is the result of perfection, hard work, learning from failures, loyalty, and persistence."



—Colin Powell

Integrated Physics & Chemistry



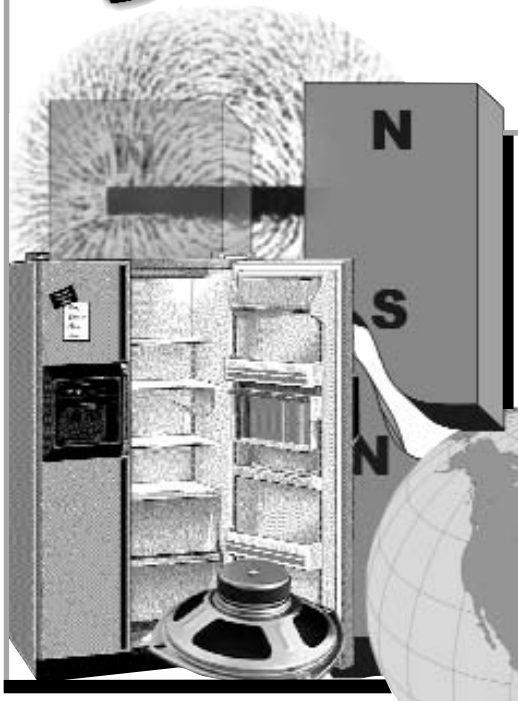
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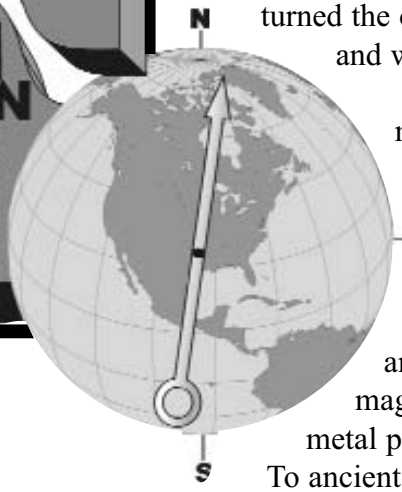
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AN ATTRACTIVE SUBJECT

Section 1

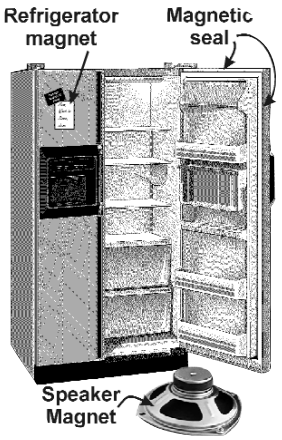
Lessons 1-5





Magnets fascinate everyone. A magnet can pick up a string of paperclips or hold a piece of paper on a refrigerator door. When two magnets are placed against one another a certain way, they snap together and hold tight. When they are turned the other way, they resist going together and will jump apart when released.

Permanent magnets are more than merely playthings. A permanent magnet is found in the core of amplifying loud speakers. A magnetic strip makes a simple but effective seal when a refrigerator door is closed. The doors to kitchen cabinets are held closed by magnets that attract a metal plate on the door.



To ancient people, magnetism was much more dramatic than static electricity. Charged amber would pick up pieces of fluff or bits of cloth. Natural magnets attracted the much heavier iron, and magnets did not have to be stroked.

The scientist who first wrote about magnetic effects was Thales of Miletus, the Greek philosopher. He had also investigated the static charge of amber. Thales learned of deposits of an iron ore in Magnesia, a province of Greece in Turkey. The iron ore would attract pieces of iron; this ore was magnetite (iron oxide, Fe_3O_4).

The province of Magnesia gave its name to magnetite, magnetic and magnet. Also, in the same province was magnesia, (magnesium oxide, MgO) the compound that gave magnesium its name.

VOCABULARY

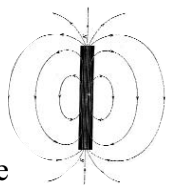
Permanent magnet: a ferromagnetic substance that retains its magnetism when removed from a magnetic field, steel makes a permanent magnet

Temporary magnet: a ferromagnetic substance that loses its magnetism when removed from a magnetic field; pure iron makes a temporary magnet

The age of exploration began in the 1400s when European navigators learned to suspend a long piece of magnetite by a string. The magnet rotated to point along a general north-south line. A natural magnet became known as a *lodestone*, a word meaning *leading stone.* Sailors made the first compasses by placing a magnetized needle on a pivot so it could freely turn. One end of the needle pointed north, and the other end of the needle pointed south.

One common form of a magnet is a bar. It has a north pole at one end and a south pole at the other end. Bending the bar around so the north and south poles are across from each other makes a horseshoe magnet. Both poles work together to attract iron objects. A horseshoe magnet can lift more than the single pole of a bar magnet.

If a magnet is rolled around in particles of iron and then removed, the magnet carries away more filings at the poles than it does in the middle. The attraction is demonstrated by placing a sheet of paper over the magnet and then sprinkling the paper with iron filings. If the paper is tapped slightly, the iron filings align themselves along great curving lines that begin at one pole and go to another pole. The lines become highly clustered at each pole. The amount of iron filings held by the poles and the number of lines leading to the poles show that the magnetic effect is most concentrated at the poles. Michael Faraday pictured the attraction of a magnet as a magnetic field with lines of force that reached out and touched objects. The strongest magnetic materials are the elements iron, nickel, cobalt and alloys containing them. Materials that are strongly attracted by a magnet are ferromagnetic. If a ferromagnetic material is placed near a magnet, then the lines of force will change direction so they pass through the ferromagnetic material. A material can be ferromagnetic without being magnetic. An iron bar may not have magnetic properties. It may not attract other pieces of metal. However, a magnet will attract the iron bar. Ferromagnetic materials can be made magnetic by putting them in a strong magnetic field. An iron needle will become magnetic if stroked by magnetite.

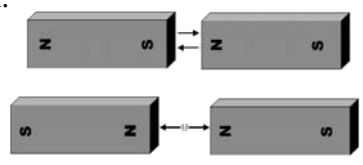




Magnetism made by placing iron or another ferromagnetic element in a magnetic field is *induced magnetism*. Soft iron readily becomes magnetic, but it also just as quickly loses the magnetism. Soft iron makes a ***temporary magnet***. Steel is more difficult to magnetize, but once it does become magnetic, it retains the magnetism. Steel makes a permanent magnet.

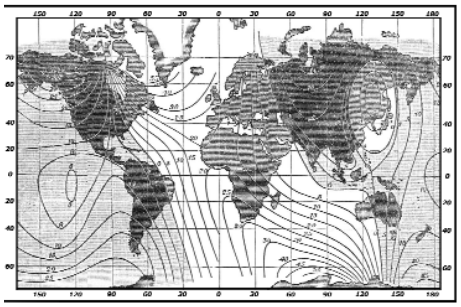
Some elements respond to magnets less strongly than iron. These elements include aluminum and magnesium. When aluminum is placed in a magnetic field, the lines of force change slightly so more of them pass through the aluminum than the air. A few elements such as gold and silver are slightly repelled by a magnetic field. Gold in the neighborhood of a magnetic field causes the lines of force to avoid it. The lines of force pass through air rather than going through the gold.

William Gilbert was the first scientist after Thales of Miletus to make a study of magnetism. In 1600, William Gilbert published a book describing his discoveries about magnetism. In the book, he stated the laws of magnetic attraction. Gilbert tested a non-magnetic piece of iron by bringing it first near the north pole and then near the south pole of a magnet. Either pole of the magnet attracted the iron. Next, he tested two bar magnets. Like magnetic poles repelled one

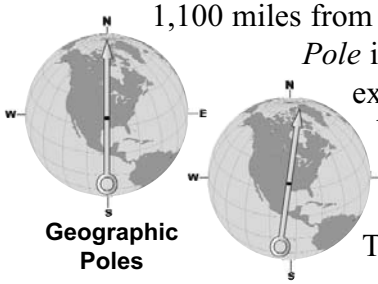


another, but unlike magnetic poles attracted one another.

People generally believed that a compass pointed north because of something in the heavens. To test the idea, William Gilbert mounted a compass needle vertically on a horizontal axis. Rather than being free to rotate left or right, the needle was free to point up or down. When he released the needle, it pointed down rather than up. The dip needle pointed to a point below the horizon thousands of miles away from London. Further experiments led William Gilbert to conclude that the earth has a giant magnetic field. One pole of the earth's magnet is located somewhere in the Arctic near the North Pole and the other in the Antarctic near the South Pole.

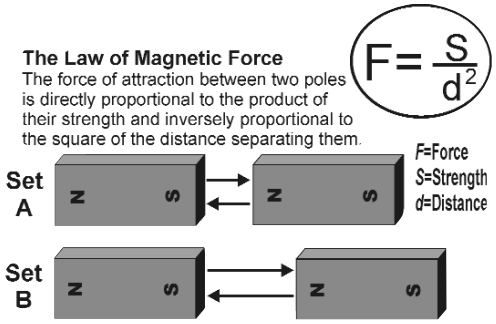


A compass needle does not point directly north. The magnetic pole in the Northern Hemisphere is located about 1,100 miles from the *geographic North Pole* in northern Canada. The exact location is revealed by the dip compass, which points straight down at that location. The magnetic pole in the Southern Hemisphere is located between Antarctica and Australia, about 1,200 miles from the *geographic South Pole*. Earth's magnetic poles do not coincide with the earth's geographic poles. The earth rotates on its axis, and this line makes true north. The compass needle does not point true north at most places on Earth. Along the West Coast of North America, a compass points about 15 degrees east of geographic north. Along the East Coast of North America, a compass points about 15 degrees west of geographic north. The difference between the direction of geographic north and magnetic north is *magnetic declination*. Hiking maps and maps used by airplane pilots show the magnetic declination. The magnetic declination slowly changes because Earth's magnetic field does not stay fixed in a set location. The magnetic poles drift. They slowly wander around by as much as several hundred miles. Maps that show magnetic declination must be updated once every 10 years or so.



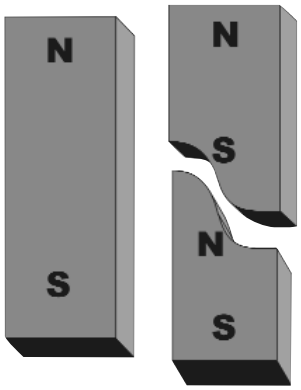
The difference between geographic and magnetic north is not the only reason that a magnetic compass needle may not always point true north. Although the earth's magnetic field is vast, it is also very weak. Should a compass be near ferromagnetic material or a magnet, the compass is easily pulled away from the true north-south line. The mineral composition of mountains can pull a compass needle far off course. In some portions of the Rocky Mountains, the north end of a compass points due south. Solar flares from the sun send charged particles streaming to the earth. These charged particles interact with the earth's magnetic field and cause compass needles to swing about without warning.

The *Law of Magnetic Force* states that the force of attraction between two poles is directly proportional to the product of their strength and inversely proportional to the square of the distance separating them.

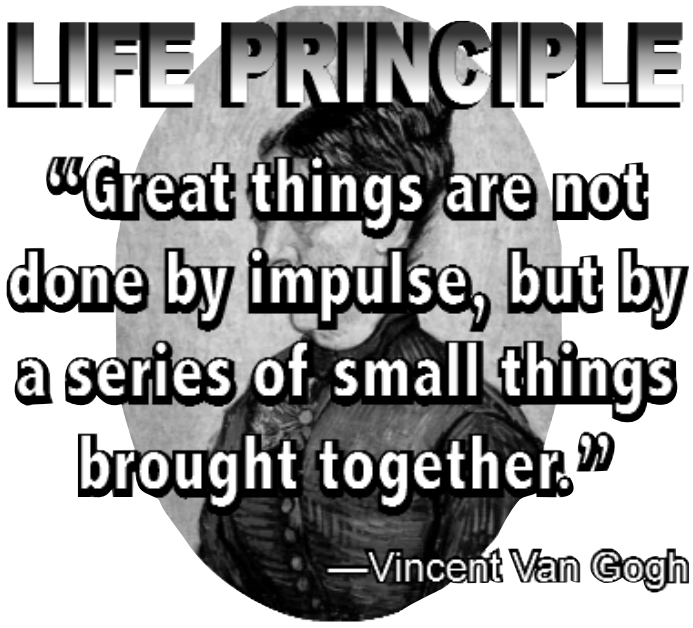


Magnetism, static electricity and gravity all follow the Inverse Square Law.

The force of gravity, static electricity and magnetic attraction do differ in some ways. Every experiment with gravity has shown that it is always a force of attraction. Static electricity can attract or repel. It has two types of charges, positive and negative. Magnetism can attract or repel. It comes in two types of attraction, a north pole and a south pole.



The electron carries the negative charge of static electricity, and the proton carries the positive charge. A negative charge (-) can be isolated without a positive charge (+) being nearby. That is not the case with magnetism. Magnetic poles always come in N-S pairs. A bar magnet has a north pole at one end and a south pole at the other end. If it is cut in half in the middle, this does not separate the poles. Instead, each half now has north and south poles. Some scientists believe a single magnetic pole may exist, but no experiment has ever detected such a magnetic monopole. It remains one of the great unsolved mysteries of science.



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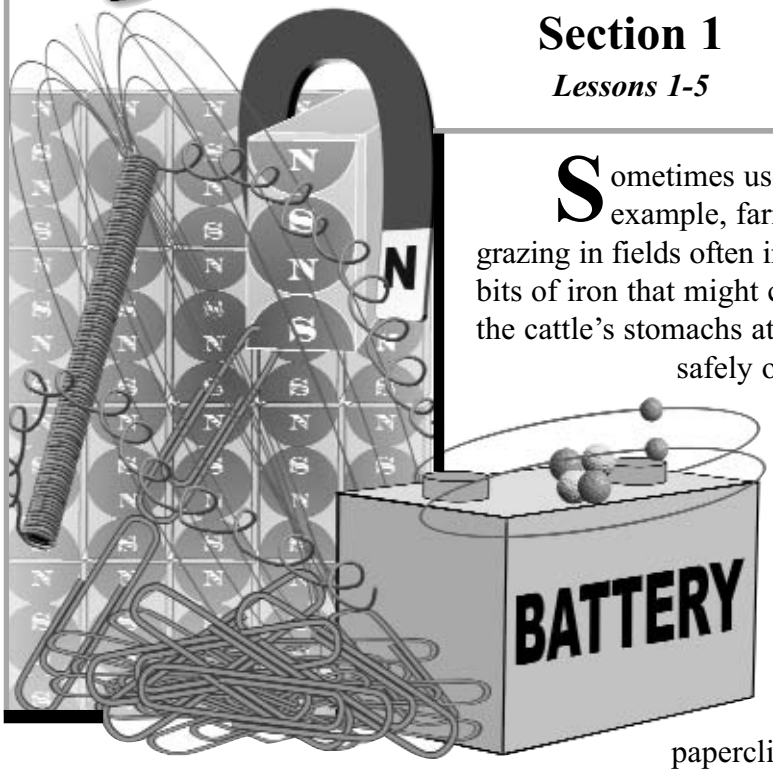
Lesson 3
Inventions & Discoveries

Chapter 6

Section 1

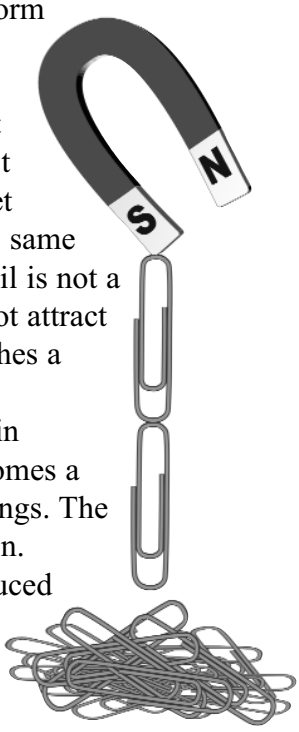
Lessons 1-5

PICKING UP PAPERCLIPS



Sometimes uses for magnets are surprising. For example, farmers feed magnets to cows. Cattle grazing in fields often ingest small pieces of wire or other bits of iron that might cause internal injury. The magnets in the cattle's stomachs attract the dangerous iron and keep it safely out of the rest of the digestive tract.

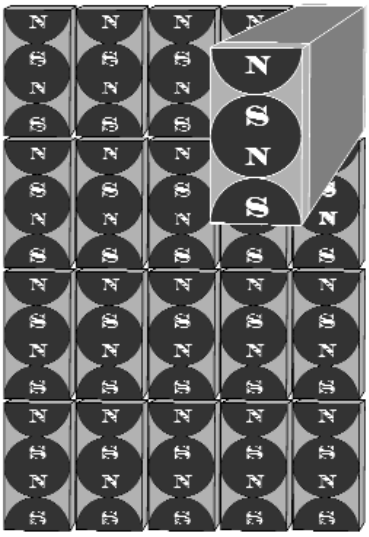
A person touches a permanent magnet to a pile of metal paperclips. As he pulls the magnet away, paperclips come along. Sometimes the paperclips form a long chain of one paperclip holding the next one. Yet, the first paperclip is not a magnet until the permanent magnet touches it. The same observation happens with nails. An iron nail is not a magnet. If touched to iron filings, it will not attract them. However, if one end of the nail touches a permanent magnet, the iron nail becomes magnetized. As long as the iron nail stays in contact with the permanent magnet, it becomes a weaker magnet, and it can pick up iron filings. The nail has been given magnetism by induction.



Magnetic ***domains*** can explain induced magnetism. When a bar magnet is cut in half, it becomes two magnets, each with a north pole and a south pole. If either of the two magnets is cut in half again, two more magnets result. Continued division of the smaller magnets eventually reaches a structure known as a domain. A domain is an elementary magnet made of a group of atoms aligned in the same way. Each domain acts as a miniature magnet embedded

VOCABULARY

Domain: a small, elementary magnet made of an association of atoms that give ferromagnetic metals their magnetic properties, domains are small but can be seen in a microscope
Induced: to bring about a different result than would have naturally happened



in the metal. A domain has a tiny north magnetic pole and a tiny south magnetic pole. Although small, domains are large enough to be seen with a microscope.

All ferromagnetic materials contain domains. In permanent magnets, the domains point in the same direction. The tiny north poles all point toward one end of the bar, and the south poles all point to the other end. The tiny magnetic field of one is strengthened and added to by those around it. They all act together.

Normally, an iron nail does not have its magnetic domains aligned in any particular order. Although each domain is a magnet, the iron as a whole is not magnetic because the domains point in different directions and do not act together.

A powerful magnet that is brought near a nail that is not magnetized will cause the nail's domains to shift around and point in the same direction. These domains will align with the magnetic field. Individually, the domains are weak, but by working together, they become much stronger. The combined effect of millions of domains accumulates, thus making the iron nail a temporary magnet. The effect is not perfect, however. Some domains never line up with the others. The nail is not as strong as the permanent magnet. If the iron nail is touched to a second iron nail, the process repeats. The second nail becomes a magnet, too, although it is weaker still. The second nail is being acted upon by the weaker magnetic field of the first nail. In the second nail, even fewer of its domains switch to be all the same direction. Finally, after a chain of five or six nails is made, the last one is too weak to pick up any more nails. The ***induced*** magnetism in the chain of nails weakens as one moves farther from the permanent magnet. When the permanent magnet holding the top nail is removed, the nails all lose their magnetism. The nails fall away, and the induced magnetism is lost.

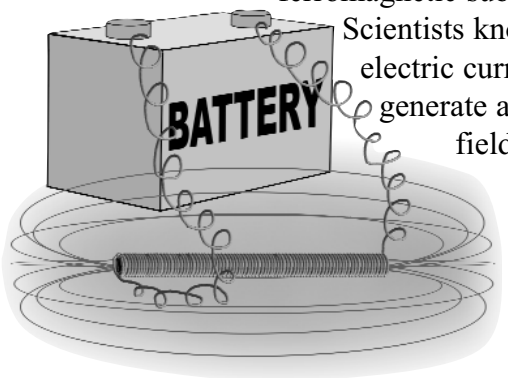
The more powerful magnetic field of the permanent magnet keeps the domains locked in place. When the permanent magnet is removed, the tiny elementary magnets in the nail are free to change orientation. A nail has heat energy at room temperature. Heat energy is movement of atoms and molecules. Because of its internal heat energy, the atoms and molecules of the iron are in constant motion. The random motion of the atoms and molecules causes the domains to again become disorganized. The domains fall into no preferred pattern, and the overall magnetism is lost.

Heating causes metals to lose their magnetism. Nickel stops being magnetic at about 345ºC (653ºF). This is well below its melting temperature of 1,455ºC (2,651ºF). Iron loses its magnetism at 790ºC (1,450ºF). It does not melt until heated to 1,535ºC (2,795ºF). All ferromagnetic substances lose their magnetism before becoming liquid. The random motion in liquids and gases is even greater than in solids. For that reason, liquids and gases do not carry magnetic fields. Heat can destroy the magnetic effect of any magnet, whether temporary or permanent.

Compared to steel and other alloys, pure iron is soft. It can be made magnetic easier than steel and the other alloys because the domains (the tiny elementary magnets inside) are easier to move. However, iron loses its magnetism just as easily. Steel and

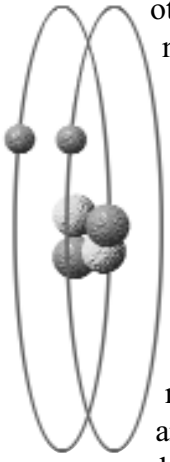
other alloys are harder to make into magnets, but once they become magnetic, the magnetism is less likely to be lost. A steel needle can be made permanently magnetic, but it has to be done in a certain way. The needle must be stroked in the same direction with a magnet. The magnet is moved from one end to the other in the same direction. The needle is pulled away and then brought back at the other end. This aligns the domains, the tiny elementary groups of atoms in the iron. Moving the magnet back and forth or moving it around randomly never aligns the domains. No overall magnetism is created. If a metal is already magnetic, and a magnetic field interacts with it in a direction that reverses the domains, the magnetism can be lost. If magnets are stacked together improperly with north to north and south to south, they will slowly weaken as their domains become disorganized. Magnetic fields can destroy the magnetic effect of any magnet, whether temporary or permanent. Magnets can also lose their magnetism if they are subjected to shock such as being struck or dropped on a concrete floor. If the domains are jarred violently enough, they shake around and fall out of alignment. Striking one magnet against another or hitting one with a hammer can destroy the overall magnetism. Mechanical action, such as hitting a magnet, can destroy the magnetic field of any magnet, whether temporary or permanent.

Domains cause the magnetism in a ferromagnetic substance. Scientists know that an electric current will generate a magnetic field.



Electromagnets can lift tons by having electricity flowing in coils of wire around an iron core. Electrons flowing through the wire produce a magnetic field.

A permanent magnet is not connected to a battery. All materials are made of atoms. The atom contains protons and neutrons in the dense central core, the nucleus. Electrons fly around outside of the nucleus. Most electrons in an element occur in pairs. In each electron pair, the electrons move in opposite directions. They each generate a magnetic field, but the two magnetic fields oppose one another. Overall, the motion of one electron makes a magnetic field that cancels the magnetic field created by the motion of the other electron. The atom is left with no overall magnetic field.



Atoms of iron and other ferromagnetic substances have atoms with unpaired electrons. These unpaired electrons give each atom a tiny magnetic field. The atom itself has a north magnetic pole and a south magnetic pole. The atoms in the same neighborhood influence one another and form domains. Magnetism, whether from an electric current or within an atom, is due to the motion of electric charge. Electrons usually carry the electric charge.

Magnetic poles always occur in pairs. A north magnetic pole is never found alone. A south magnetic pole will be nearby. Having a single north pole for experiments would be useful. Suppose a scientist has two bar magnets and brings them together so that the north pole of one is nearly touching the north pole of the other. The two north poles repel one another. Experiments about the force acting between magnets must take into account the effects of both poles being present.

LIFE PRINCIPLE

"Unlike magnetic poles and personalities, our character is like a magnet that attracts people like us and repels people not like us."



— N. S. Johnson

Integrated Physics & Chemistry



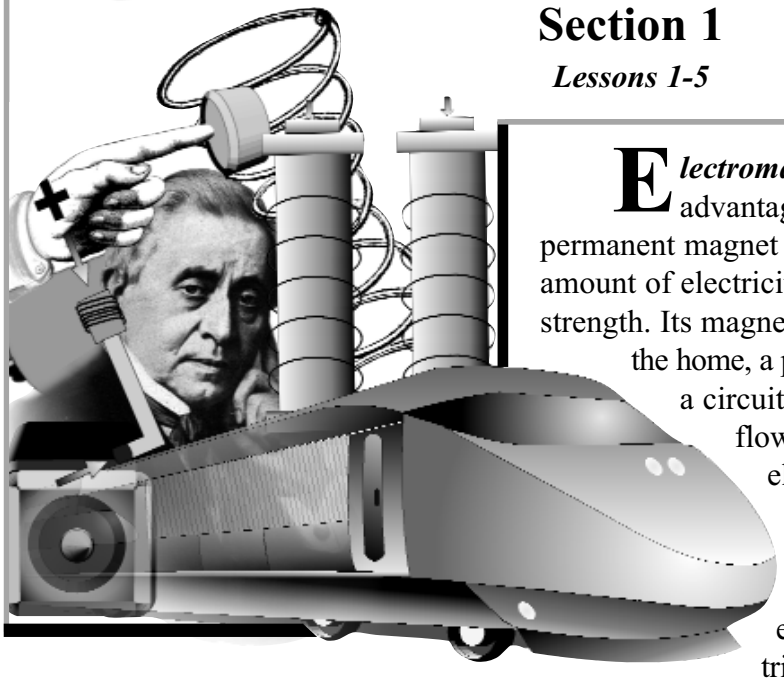
Lesson 4
Inventions & Discoveries

Chapter 6

FROM MAGNETS TO MARS

Section 1

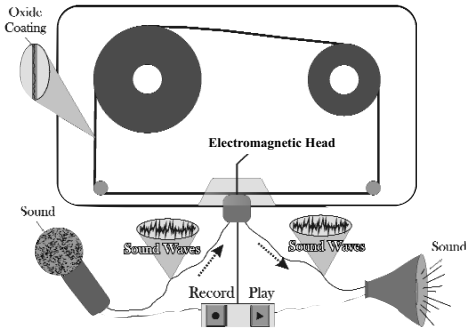
Lessons 1-5



Electromagnets are a part of daily life. The advantage of an electromagnet over a permanent magnet is that increasing or decreasing the amount of electricity that flows can vary the magnet's strength. Its magnetic field can be turned on and off. In the home, a press of a button completes a circuit causing electricity to flow. A button activates an electromagnet and causes the doorbell to ring. An electromagnet receives a surge of electricity from a short circuit and trips a circuit breaker.



The recording heads in audio and videocassette recorders are electromagnets. An electromagnet has a north pole and a south pole, but when the electricity changes direction, the poles reverse. The recording media is made of iron oxide particles coated on the tape. The oxide coating can be made magnetic. The recording heads are practically touching the tape that goes between them. The rapidly changing magnetic field of the recording heads makes the oxide particles magnetic. They stay permanently magnetized until erased or taped over. On playback, the magnetic imprint on the tape causes variations in the electrical flow of the playback head. The speakers or earphones also use electromagnets, which rapidly vibrate a diaphragm to generate sound waves.



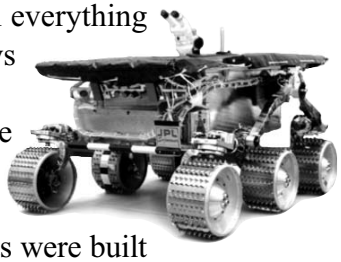
Streetcars and subways are stopped by electromagnets that cause clamps to grip the track. Electromagnets can accelerate

VOCABULARY

Electromagnet: a magnet produced by flowing electricity, it can be turned on and off by turning the electricity on and off, and its strength can change by varying the amount of electricity that flows
Concentric: one inside the other, circles are concentric if they share the same center
Solenoid: wire wound in a spiral around a cylinder
Relay: a switch that responds to a small current and activates another switch in an electric circuit

subatomic particles to speeds approaching the speed of light. Other electromagnets guide the high-speed particles to their targets.

The magnets in everything from doorbells to relays aboard the *Pathfinder* that landed on Mars are very similar to the first electromagnets. The first electromagnets were built within a few years after scientists discovered a connection between electricity and magnetism.



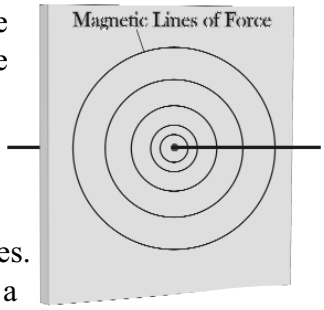
A wire that carries an electric current can cause a magnetic field. Hans Christian Oersted, a Danish scientist, first demonstrated this. Scientists had experimented with electricity and incorrectly concluded that electricity and magnetism were independent of one another. In other words, electricity was thought to be unrelated to magnetism. Hans Christian Oersted devised an experiment to show this supposed fact to his science class. A compass needle is a small magnet and very sensitive to magnetic attraction. Oersted placed a wire at right angles across a compass needle. He then hooked each end of the wire to an electric battery. When a student turned on the electricity, the needle did not budge. Oersted accidentally moved the wire so it was parallel to the needle. The compass needle suddenly swung to one side. Hans Christian Oersted knew he was onto an important discovery. Other scientists had found no way for electricity to make magnetism or vice versa. The failed experiment was an unexpected treat for the students. They had the privilege of seeing an important scientific breakthrough as it actually happened. Oersted had the student reverse the current by switching the wire's connection to the electrodes. The needle swung in the other direction. Switching the direction of the current caused the poles to reverse. The north pole became a south pole.



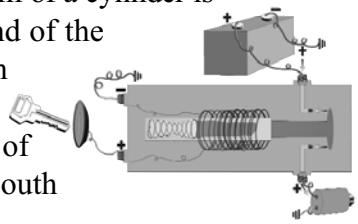
Standard Compass

After Oersted reported his discovery, scientists began an intense study of the subject. They found that static electricity did not produce a magnetic field. Electrons at rest do not produce magnetism. Current electricity does cause magnetism.

Suppose a wire is sent vertically through a piece of cardboard with the electrons flowing from top to bottom along the wire. A compass can reveal the magnetic field around a wire. Moving a compass around on the paper and marking the direction the needle points can make a map. The map shows that the lines of force form ***concentric*** circles. The magnetic field is a series of circles inside each other with the wire in the center.

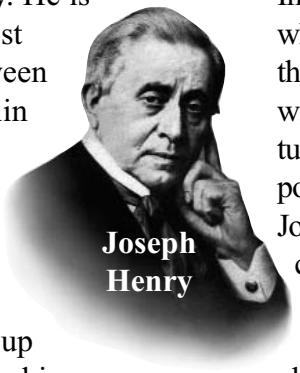


A magnet also has a field around it. Lines of force leave one pole and travel to the other pole. The lines can be thought of as going in either direction, but by convention, scientists have agreed to imagine the lines as originating at the north pole and traveling around the outside of the magnet in a great sweeping curve to the south pole. The lines of force show the direction a freely moving north pole would be pushed. The magnetic field around a wire is very weak, hardly strong enough to make the compass needle move. One way to increase the magnetic effect is to increase the amount of current flowing in the wire. A second way to increase the effect is by wrapping wire in a coil. A spiral of wire wrapped in the form of a cylinder is a ***solenoid***. One end of the solenoid is a north magnetic pole, and the other end of the solenoid is a south



magnetic pole. About five years after Oersted's experiment, William Sturgeon, an English scientist, discovered how to strengthen the magnetic field of a solenoid. He inserted an iron bar in the coil. William Sturgeon made the first electromagnet.

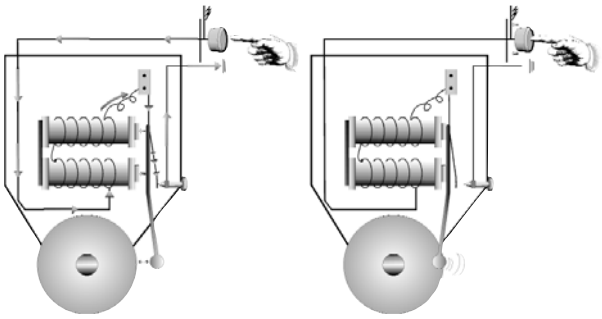
One of the people who experimented with the interaction of magnetism and electricity was Joseph Henry. He is considered America's greatest electrical experimenter between the time of Benjamin Franklin and Thomas Edison.


Joseph Henry

The early childhood of Joseph Henry followed a course like that of Michael Faraday. Joseph Henry and Michael Faraday both grew up in poverty and both succeeded in obtaining an education by a self-directed program of reading books. Both of these men became great scientists but remained humble Christians. Joseph Henry's mother earned extra income by boarding people. One of the men staying in the Henry home had a book about science experiments. Joseph Henry accidentally discovered the book and began reading it. When the boarder saw Joseph Henry's interest in the subject, the man gave Joseph the book. The book was so interesting that Joseph Henry wanted to become a scientist. Joseph Henry tried to enroll at Albany Academy, a local college. The president of the college pointed out that Joseph had not gone to high school. Joseph Henry began working through the high school textbooks with the help of the president of the college. Joseph Henry finished the entire high school course of study in only seven months.

Joseph Henry experimented with electricity and made a number of discoveries and inventions. Sturgeon's electromagnet was only a toy. Joseph Henry studied the electromagnet with the goal of improving it. Joseph Henry quickly found he could make it stronger by increasing the current or by wrapping more turns of wire around the iron bar. When he used too many coils of wire, the loops touched one another and short-circuited. Wire was used for many purposes then, but carrying electricity was not one of them. Insulated wire could not be purchased. Those who experimented with electricity had to make their own insulation. Joseph Henry insulated the wire by wrapping it with silk ribbon. With 800 turns of wire his electromagnet could lift 27 pounds. Soon, electromagnets designed by Joseph Henry could lift a ton. He built the first commercial electromagnet. It extracted iron from crushed iron ore.

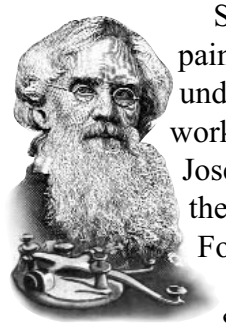
Joseph Henry made small electromagnets, too, and put them to use. He built one that would ring a bell. Students helped Henry string wires from the college



laboratory to his home, and each day, when he was finished at his laboratory, Joseph Henry would press a button to ring the bell at his home. Joseph Henry had invented the first doorbell. The distance from the laboratory to the Henry home was one mile. Joseph Henry came very close to making the first telegraph.

An electric signal weakens as it flows through a long length of wire. Joseph Henry put electromagnets in the circuit at regular intervals. Just before the current became too weak, the electromagnet would trip a switch to turn on the next circuit. Each circuit had

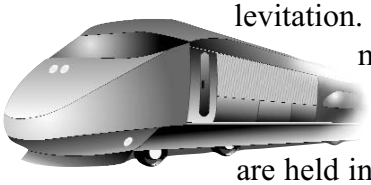
its own set of batteries. Henry's electric ***relay*** became an essential part of Samuel F. B. Morse's telegraph.



Samuel Morse was a portrait painter who needed help understanding how electricity worked. Samuel Morse came to Joseph Henry, and together they studied Morse's design. For a week, Joseph Henry worked privately with Samuel Morse to improve the design for the telegraph and to clear up some points that Samuel Morse did not understand about electricity. With Joseph Henry's help, Samuel Morse succeeded in building the first telegraph line from Washington to Baltimore. Despite his help, Joseph Henry never claimed credit for his role in making the telegraph possible. Henry had agreed to a private meeting with Morse and never revealed the particulars of what they discussed.

The core of an electromagnet is made of soft iron. The core's magnetic properties can be lost if it is heated. Recently, scientists have become very excited about the prospect of making very powerful magnets when they are cooled to extremely low temperatures.

Another area where research is progressing at great speed is in magnetic levitation. Because two like magnetic poles repel, it is possible to design vehicles that are held in the air by magnetic repulsion. To do away with drive wheels entirely some high speed trains use magnetic fields. The trains would zoom along only a few inches above the magnetic rails.



LIFE PRINCIPLE



"Action may not always bring happiness; but there is no happiness without action."

—Benjamin Disraeli

Integrated Physics & Chemistry

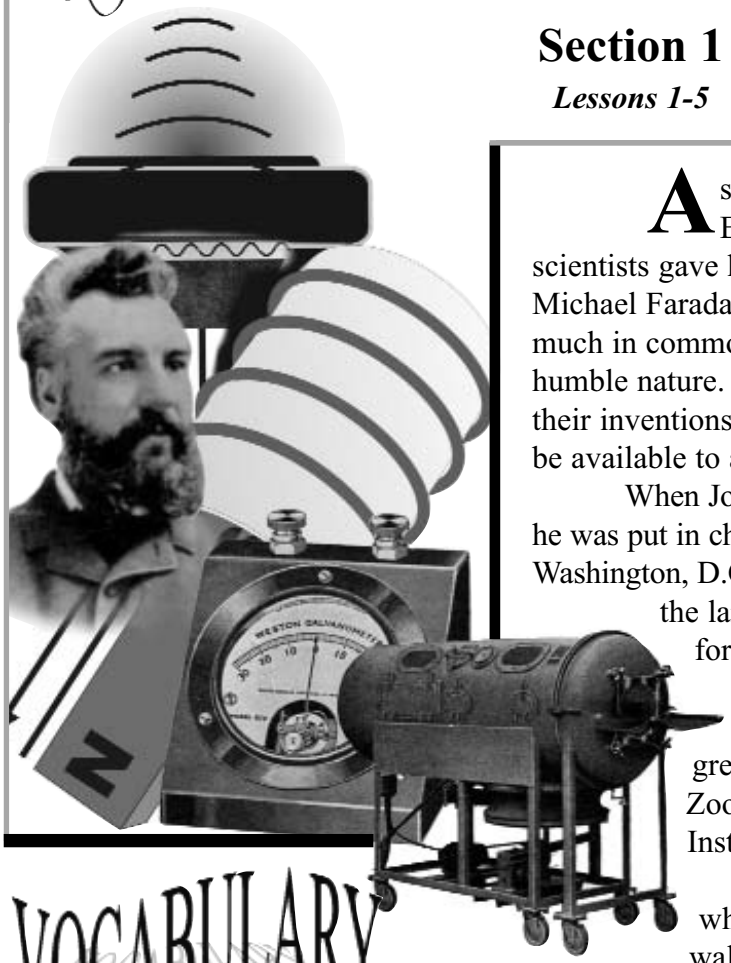
Lesson 5
Energy

Chapter 6

FORCE FIELDS

Section 1

Lessons 1-5



As his fame increased, Joseph Henry visited England. Faraday, Sturgeon and other scientists gave him a warm welcome. Joseph Henry and Michael Faraday became instant friends. They had much in common, including their Christian faith and humble nature. Neither Faraday nor Henry patented their inventions. They wanted the benefit of science to be available to as many people as possible.

When Joseph Henry returned to the United States, he was put in charge of the Smithsonian Institution in Washington, D.C. The Smithsonian Institution is today the largest museum in the world and a center for research. The Smithsonian Institution is home to the National Air and Space Museum and more than a dozen other great collections, including the National Zoo. Joseph Henry made the Smithsonian Institution famous.

During the dark days of the Civil War, when Abraham Lincoln could not sleep, he walked to the Smithsonian to visit Joseph Henry. Late one night, Abraham Lincoln watched as Joseph Henry experimented with signal lanterns. A passerby noticed the late night signals and, the next morning, told the authorities that Joseph Henry must be a Southern spy. The passerby had seen Joseph Henry and an unknown assistant sending signals after midnight. President Lincoln set the record straight.

One day, a young inventor came to visit Joseph Henry. The poorly dressed man was a teacher of speech. He had a crude electrical contraption for Joseph's inspection. The device used a small electromagnet in an attempt to turn human speech into an electrical signal. Joseph Henry worked with the young man for several hours. Henry assured the inventor that he had a good idea. "My advice to you is that you work with it until you succeed."

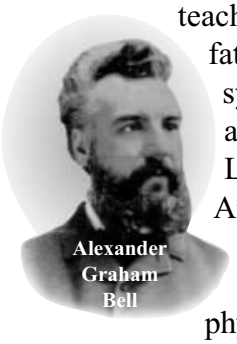
VOCABULARY

Iron lung: the first mechanical device to aid respiration, invented by Alexander Graham Bell

Force field: the region around a magnet in which its influence is felt

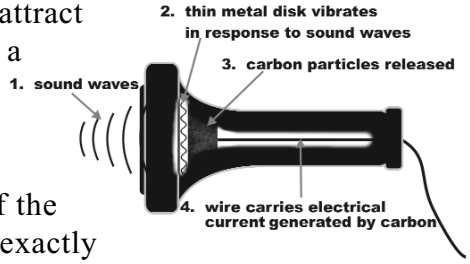
Lines of force: magnetic lines of force that indicate the path a north pole would follow if free to move in the magnetic field, the magnetic field is strongest where the lines are most dense

The young inventor was Alexander Graham Bell. Alexander Graham Bell was born in Edinburgh, Scotland, in 1847. Alexander Graham Bell assisted his father in teaching deaf children. His father had developed a system of "visible speech," a method of lip-reading. Later, the family moved to America. Alexander became a professor at Boston University. He studied the physical causes of deafness. As he studied and experimented, Alexander Graham Bell became convinced that he could convert sound to electrical impulses. A wire could carry these impulses over great distances. Alexander Graham Bell could then convert the electrical signals back into sound.

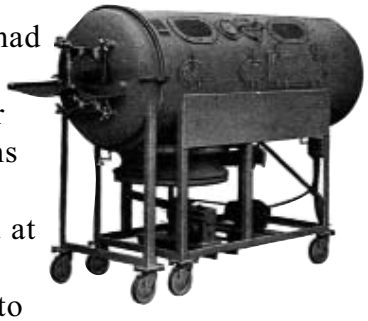

Alexander Graham Bell

In February 1876, Bell patented the telephone. He hurried to complete an improved model to demonstrate at the 1876 Centennial Exposition in Philadelphia. Because he was late for the show, the only space for Bell to show his invention was behind some stairs. Joseph Henry was one of the judges of the competition. Because he knew the value of Bell's invention, Joseph Henry made efforts to direct the committee behind the stairs to see Bell's work. Bell's telephone was a favorite of the Exposition. The judges created a special award just for the telephone.

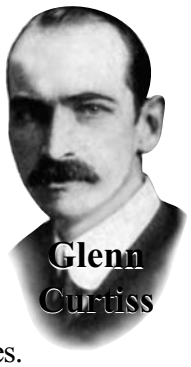
When scientists studied the design, its simplicity astonished them. Vocal cords in the larynx vibrate rapidly to produce human speech. Musical instruments make sounds by vibrating reeds, strings and tight membranes. All of these ways involve rapid back and forth motions. Air molecules are alternately compressed together and then released. In Bell's design, sound waves struck the mouthpiece and caused a thin metal disk to vibrate back and forth. The disk compressed and released carbon particles. Carbon conducts electrical current. Carbon conducts electricity better when the carbon is compressed. An electric current that flowed through the carbon grew stronger or weaker in perfect step to the sound waves. The receiver at the other end reversed the process. The varying electric field caused an electromagnet to alternately attract and release a thin iron disk. The rapid vibration of the diaphragm exactly reproduced the vibration of sound waves. The same scientific principle is used today in telephone receivers.



Alexander Graham Bell patented his telephone and became very wealthy. Bell used the money for other experiments. One of Bell's inventions was the *iron lung*. This device forces air in and out of the lungs of a person who cannot breathe because of illness or injury. A person can die within five minutes if the blood does not carry oxygen to the brain. Today, emergency rescue personnel carry respirators to help a person breathe who has stopped breathing because of a heart attack, electric shock or some other reason. Alexander Graham Bell's iron lung was the first mechanical method to keep a person alive who had stopped breathing. Another of Bell's inventions was the metal detector. It is used at airports and some Federal buildings to scan people for concealed weapons. Hobbyists also use metal detectors to look for coins and lost treasures in parks and on beaches.



Bell built a research hanger for Glenn H. Curtiss, an aviation pioneer. Together they designed planes that could take off and land on water. Bell and Curtiss made improvements to the Wright Brothers' airplane. Curtiss, not the Wrights, made the first public, mile-long flight of an airplane in the United States.



Alexander Graham Bell continued to teach deaf students and study speech. Helen Keller, who was both blind and deaf, was one of Bell's students. Helen Keller wrote a book about her life and dedicated the book to Alexander Graham Bell.

On March 7, 1876, Bell was issued a patent for his telephone. Five days later to commemorate the event, Alexander Graham Bell called Thomas Watson and spoke the first telephone message, "Watson, come here. I want you."

By 1916, telephone service reached from coast to coast. When Alexander Graham Bell died in 1922, all telephone service in the United States went silent for one minute in his memory.

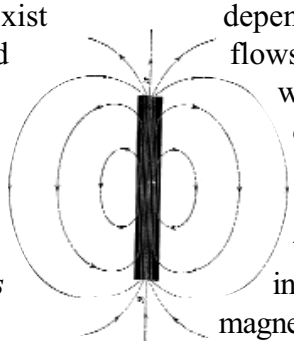
One of the ideas of science fiction books and movies is the ***force field***. When the lasers fire and strike a ship, a flare of light explodes; the ship is undamaged because a force field protects the ship. Fields do exist around magnets and electrically charged bodies. These fields have amazing properties, but not quite like the ones portrayed in science fiction books and movies.

A magnetic field is the region in which a magnet exerts its influence. ***Lines of force*** portray the region around a field. Lines of force show the strength and direction of the field. Where the lines of force are close together near the magnet, it is strong. Where the lines of force are more widely spaced, it is weaker.

The ideas of force fields and lines of force help explain the action of a magnet. A magnet can pick up a paperclip that contains iron before the magnet touches the paperclip. The magnet does not directly act across the distance on the iron. Instead, the magnet has around it a magnetic field. This field acts on the paperclip. When a paperclip jumps to a magnet before being touched, the paperclip is responding to the lines of force of the magnetic field.

Suppose a single north magnetic pole did exist in the form of a smooth ball. Drop it on a table in the neighborhood of a powerful magnet. The ball would be repelled by the north pole of the magnet and attracted to the south pole. The north pole would roll across the table toward the south pole of the powerful magnet. The line it traced out would be a magnetic line of force.

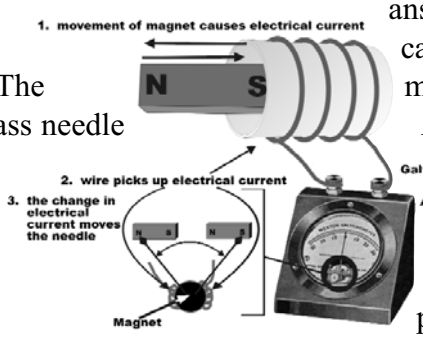
Michael Faraday repeated experiments in an effort to understand why electricity had a magnetic effect. The earlier scientists had worked with static electricity. Oersted and Faraday worked with current electricity. The key was that electricity had to be in motion. Static electricity cannot cause magnetism. Current electricity, which is electricity in motion, could cause a magnetic field. The wire would either attract or repel a magnet depending on the direction the current flows. The magnetic fields around wires that carry electricity are no different from those caused by ordinary magnets. The wire itself does not have to be ferromagnetic to create a magnetic field. Current in aluminum wire will give rise to a magnetic field, although aluminum itself is not magnetic.



Hans Christian Oersted showed that electricity would produce a magnetic field. Scientists immediately wondered if the

process would go the other way. Scientists could create current electricity only by chemical batteries. If a magnetic field could produce electricity, this would give scientists a new and perhaps better way to make electricity.

Michael Faraday sought to do the reverse of Oersted's experiment. Faraday sought to generate electricity with magnetism. He wound several coils of wire around a bar magnet and connected the wire to a galvanometer. A *galvanometer* is a sensitive device used to detect weak electrical currents. A galvanometer is especially sensitive and can measure extremely weak flows of electricity. The galvanometer is a compass needle with a coil of wire wrapped around it. When electricity flows, the coil creates a magnetic field that pulls the needle to one side or the other.



In Faraday's experiment, the galvanometer did not respond. No current flowed in the wire wrapped around the bar magnet. Michael Faraday kept coming back to the problem. Ten years passed before he discovered the key. It was motion.

One day, Michael Faraday attached a galvanometer to a coil of wire. Then he inserted the bar magnet in the coil. Faraday noticed that the galvanometer needle flickered and decided to remove the bar magnet. Again the needle moved but in the other direction. Now Faraday knew the answer. A magnetic field at rest will not cause electricity to flow. Instead, the magnetic field must be in motion.

Electromagnetic induction is the production of either electricity or magnetism by the other. A moving electric field produces magnetism. A moving magnetic field produces electricity. Motion is the key to electromagnetic induction.

LIFE PRINCIPLE

"The heights by great men reached and kept, Were not attained by sudden flight, But they, while their companions slept, Were toiling upward in the night."

—Henry Wadsworth Longfellow

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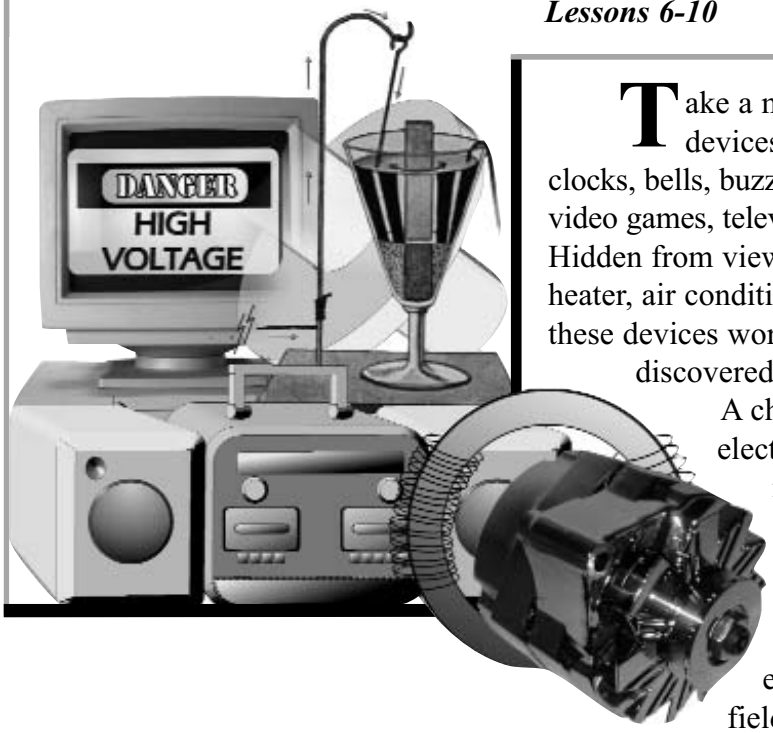
Lesson 6
Energy

Chapter 6

ELECTRIC TRANSFORMERS

Section 2

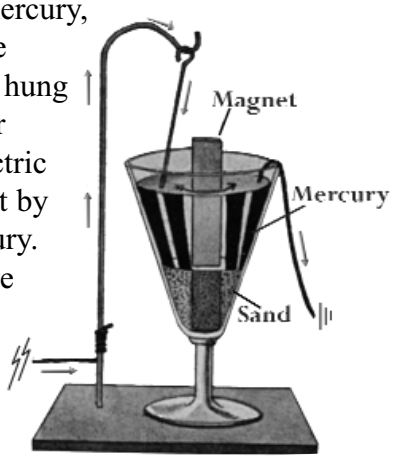
Lessons 6-10



Take a moment to think about the electric devices around you. You may see electric clocks, bells, buzzers, loud speakers, lights, computers, video games, televisions, sound systems and telephones. Hidden from view are thermostats that control the heater, air conditioner or hot water heater. Many of these devices work on simple principles that were first discovered by Michael Faraday.

A changing magnetic field can push electrons along a wire. This can be done in three ways. One, move the magnet around the electric wire. Two, move the wire around the magnet. Three, hold both the wire and magnet still but cause the magnetic field to expand and contract. The magnetic field of an electromagnet can be made to change by varying the amount of electricity that flows or by turning the electricity on and off.

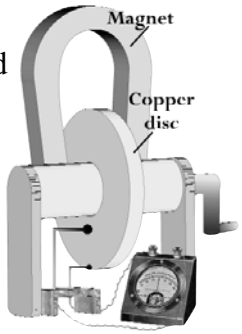
Michael Faraday invented the first ***electric motor***. An electric motor converts electricity into mechanical motion. Faraday stood a bar magnet upright in a wide mouth glass jar and poured a small amount of mercury, which conducts electricity, in the bottom of the jar. Next, Faraday hung a wire on a swivel beside the bar magnet. The wire carried an electric current and completed the circuit by brushing against a pool of mercury. When electricity flowed, the wire rotated around the bar magnet. This proved that electricity could be changed into mechanical motion.



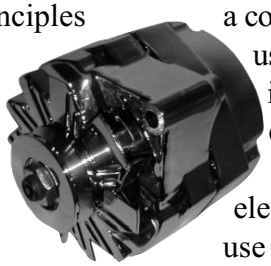
VOCABULARY

Electric motor: a device to change electricity into mechanical motion
Electric generator: a device to change mechanical motion into electricity
Transformer: a highly efficient device that transforms an electric current from one circuit to another without a direct connection between the two, usually a transformer also changes the voltage

Faraday also made the first ***electric generator***. An electric generator converts mechanical motion into electric energy. He turned a copper disk between the poles of a strong magnet. One wire of the circuit brushed against the outer rim of the disk; another wire brushed against the copper disk near the shaft and completed the circuit. As Faraday turned the copper disk, electricity flowed through the wires. The device converted the mechanical motion of the copper disk in the magnetic field into electric energy. The first generator was only a test device and not practical for making electricity. Later, Faraday designed and built the first successful electric generator.



The construction and principles of electric generators enable modern vehicles to operate, like miniature communities, with their own electric power plants. Once the engine starts, the alternator generates currents to charge the battery and power small electric motors in the vehicle that operates electric devices such as: turn signals, lights, door locks, windshield wipers and windows.



VOCABULARY

Step down transformer: a transformer that reduces the voltage, a step down transformer has fewer turns of wire in the secondary coil than in the primary coil

Step up transformer: a transformer that increases the voltage, a step up transformer has more turns of wire in the secondary coil than in the primary coil

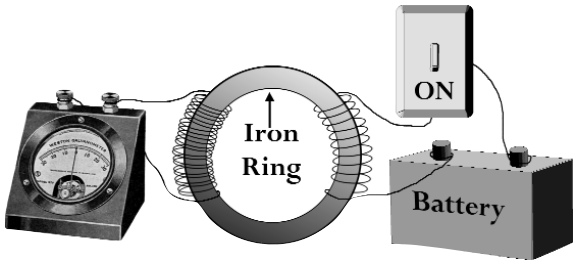
All around us today are examples of electric generators. The giant hydroelectric generating plants at dams produce megawatts of electricity for distribution to thousands of homes. Water above the dam has potential gravitational energy. As the water flows into the intake pipes, the water falls and gains speed. It then passes through the blades of a turbine, setting the blades in motion. The spin of the turbines is then converted into electricity. A hydroelectric plant converts the gravitational potential energy of water into electricity.

Most small electric generators rotate a coil of wire inside a magnetic field. The disadvantage of this method is that the electricity has to be removed from the rotating coil by metal brushes that can cause sparks. Another way to generate electricity is to use a series of magnets that are rapidly rotated inside a coil of wire. Powerful hydroelectric generators use this method. The electricity is generated in stationary coils and can be easily conducted away without sparks.

One small scale application of an electric generator is a flashlight that does not use batteries. Instead of batteries, the user of the flashlight squeezes a handle that is geared to run a small generator and light the bulb. One accessory for a bicycle is a generator. It is geared to a wheel that spins against one of the bicycle wheels.

Homes across the United States are connected to an extensive power grid. Hydroelectric plants, coal-fired generators or nuclear plants generate electricity. The electricity is transported cross-country by high voltage transmission lines for use in homes and factories. Michael Faraday invented three essential devices that make electricity so useful in everyday activities: the electric generator, the transformer and the electric motor.

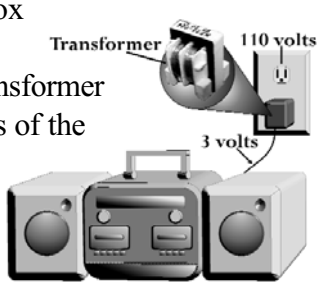
Michael Faraday developed the transformer while experimenting with electricity and magnetism. To produce a strong magnetic field, Michael Faraday wound a coil of wire around one side of an iron ring. Then, he wrapped several turns of wire around the other side of the iron ring while attaching the second coil to a galvanometer to detect electric current. Using a powerful battery, Faraday sent electricity through the first coil of wire. The iron ring then became a strong electromagnet. When the electricity was sent through the first coil, the galvanometer needle, attached to the second coil, swung to one side. This showed that a current flowed in the second coil, although that coil was not connected to any source of electricity. Then, the galvanometer needle fell back to zero, even though the first coil was still attached to the battery. Faraday turned off the battery to the first coil. Again, the galvanometer moved. This time the needle flicked in the other direction but only for a moment before it fell back to zero.



Faraday realized that the changing magnetic field caused the electricity. As electricity flowed in the first coil and built the magnetic field, the lines of force crossed the wires of the second coil and put the electrons in motion. Once established, the lines of force no longer moved and no longer put electrons in motion. When the electricity was turned off, the magnetic field collapsed in the first coil. As they fell back, the lines of force crossed the wires in the second coil and again put electrons in motion, this time in the opposite direction.

Current flowed in the second coil, although it was not connected to the first coil or to a battery. This was the first ***transformer***, a device to transfer electric current from one part of an electric circuit to another without a connection between the two. The transformer is capable of increasing voltage or decreasing voltage very efficiently.

A radio that runs on two batteries needs 3 volts to operate. Many of these battery-powered devices also have an accessory cord so the devices can be plugged into a household current. The end that plugs into the wall outlet has a small box that contains a transformer. The transformer changes the 110 volts of the household current down to the 3 volts that the radio needs. It uses a ***step down transformer*** because it changes a higher value to a lower value.



Higher voltage overcomes resistance and can produce a shock more easily than lower voltage. The higher the voltage, the greater the danger that a person may be electrocuted. Electric power lines on the street carry electricity at a dangerous level of 2,400 volts. As a safety measure, the electricity is stepped down to 110 volts by a transformer before the electricity enters the home.

Outside the city, the electrical energy is transmitted along the cross-country power lines at even higher voltages. Signs on the electrical towers that carry the wires warn of very high voltage, as much as 750,000 volts. To understand the reason electricity is transmitted at high voltages, a person must first understand electric power.

Power is the rate at which work is done: power = work/time. The metric unit for power is the watt. In electrical terms, power

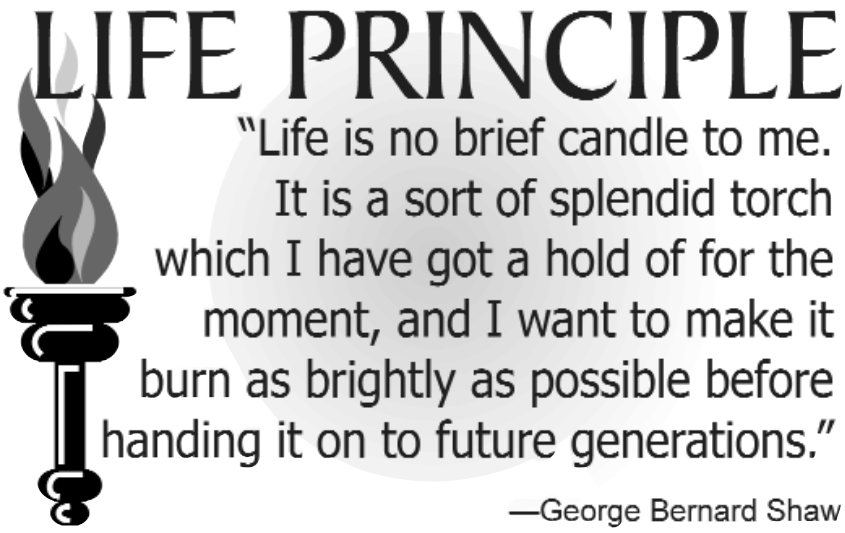
is the product of the voltage and current. Power = V * I, with power in watts, voltage in volts and current in amps. If the voltage is increased a hundred fold, then the current can be reduced to 1/100 of its original level and the same power is available.

High voltage and lower current is an efficient way to transmit electrical power. When current travels through a wire, the wire becomes warm. This heating effect is wasted energy. The amount of heat produced is proportional to the square of the current. If the current is doubled, then the heating increases by a factor of four. If the current is tripled, then the heating is increased by a factor of nine.



To reduce heat loss, the current should be low. Cutting the current in half reduces the heat loss to one-fourth. Cutting the current by a factor of 100 reduces the heat loss by a factor of 10,000. The formula, power = V * I, shows that power can be kept the same by increasing the voltage. Voltage has no effect on the heat loss. A high voltage or a low voltage makes no difference. The heating effect of a current carrying wire is independent of the voltage. If the current is low to prevent heat loss, then the voltage can be increased to maintain the same amount of power.

At an electric power plant, the turbines generate electricity at 2,400 volts. Before the electricity leaves the generating station, the electricity's voltage is changed with a ***step up transformer*** to hundreds of thousands of volts. A step up transformer has an output voltage that is greater than the input voltage. The higher voltage but lower current transmits power cross-country at a high efficiency. However, high voltage such as 750,000 volts is an extreme electrocution hazard. In the locality where it will be used, a step down transformer changes the voltage to 2,400 volts. The voltage is stepped down again to 110 volts for home use.



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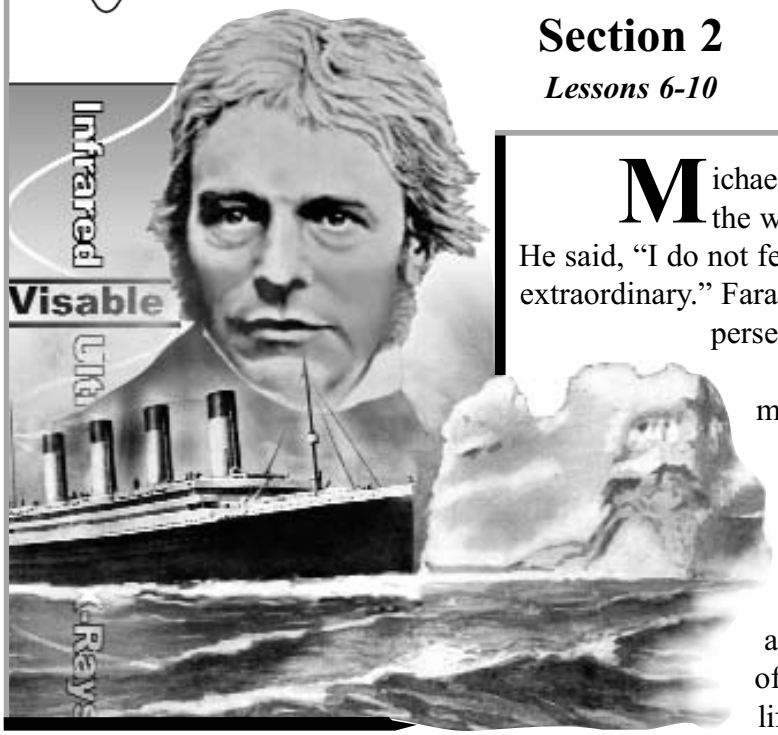
Lesson 7
Energy

Chapter 6

FROM ELECTROMAGNETISM TO LIGHT

Section 2

Lessons 6-10



Michael Faraday's accomplishments changed the world and made him famous. He said, "I do not feel that I possess anything extraordinary." Faraday believed his chief talent was his perseverance.

Although Faraday's inventions might have made him wealthy, he chose not to patent them. Michael Faraday and his wife worshipped at a small Protestant church that encouraged its members to live modestly. Service to his congregation and to Jesus remained a central part of the activities throughout Faraday's life. His Bible became well used as Michael read it and marked his favorite passages. Michael Faraday seldom missed church services, and as an elder of the congregation, Michael also prepared and preached some of the sermons.

Once, a man from the Royal Mint visited the Royal Institution. The visitor found an elderly employee cleaning a table filled with test tubes, chemicals and batteries. *This must be the janitor*, the visitor decided.

"Have you worked here long?" the visitor asked.

"Almost fifty years," the elderly man replied. Seeing the elderly man's worn clothes, the visitor said, "Maybe I can have a word with the management on your behalf. What is your name?"

"Michael Faraday," the snowy haired man replied.



Michael Faraday strove to live a humble life. He remembered his own childhood of poverty and gave free Christmas talks about science to youngsters. Faraday filled the lectures with dramatic experiments.

VOCABULARY

Infrared light: light just below the visible spectrum, infrared waves are longer than red visible light, have a lower frequency and longer wavelength

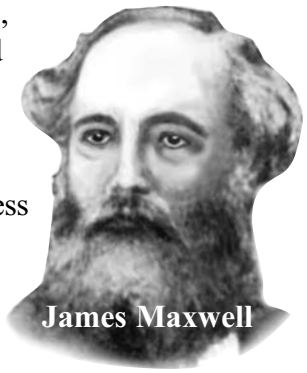
Ultraviolet light: light just above the visible spectrum, ultraviolet waves are shorter than violet visible light, have a higher frequency and shorter wavelength

He turned down knighthood. Michael Faraday declined an offer to become president of the Royal Society, and he gave away much of what he earned. Yet, Faraday's life was full and happy. He loved his wife, Sarah, and when Sarah's health made walking upstairs difficult, Michael looked for a more convenient place to live.

Queen Victoria offered him a house near the institute. The queen paid for repairs and improvements to eliminate steps. The Faradays moved into the house and lived there until Michael's death in 1867. Michael Faraday could have been buried in Westminster Abby near the grave of Isaac Newton. Before his death, Michael had given instructions to be buried at the cemetery next to the church where he had attended all of his life. Instead of an imposing monument at his burial site, a simple stone marker was used. That had been his wish.

Michael Faraday had received only a limited mathematical education. He used visual pictures rather than mathematical equations to express his ideas. He introduced the ideas of lines of force and electric and magnetic fields. The idea of lines of force is an essential concept in modern science. Both James Clerk Maxwell and Albert Einstein based much of their work on the idea of fields. They held Michael Faraday in high regard. On the wall behind his desk, Albert Einstein kept a portrait of Michael Faraday.

Michael Faraday proved a connection between electricity and magnetism. However, despite their best efforts, scientists could not find the scientific law relating one to the other. James Clerk Maxwell achieved success after a 10-year struggle with this difficult problem. He showed that electricity and magnetism are bound together as electromagnetism. Electric and magnetic fields give rise to *electromagnetic waves*. These waves can travel in a vacuum and transfer energy from one point to another. Maxwell calculated the speed of electromagnetic waves in a vacuum. He found their speed to be the same as light. Light itself is a form of electromagnetic waves.


James Maxwell

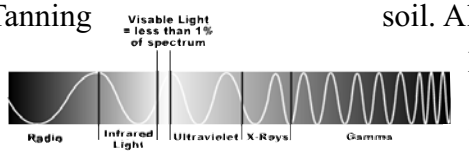
Maxwell predicted a whole range of electromagnetic waves of which visible light is but a small part. He knew of ***infrared light*** and ***ultraviolet light***. Maxwell's equations showed that the ***electromagnetic spectrum*** extended on either side of the infrared and ultraviolet. He was correct, of course. Visible light is but a small part of the electromagnetic spectrum. An AM radio receives electromagnetic waves of low frequency and long wavelength. The waves become shorter as one goes up the spectrum to the higher frequency FM radio band, television, microwaves and then infrared light. Infrared rays are the heating rays that one feels from a hot stove. Visible light of red, orange, yellow, green, blue and violet is next. Beyond visible light is ultraviolet. Ultraviolet rays are more

VOCABULARY

Electromagnetic spectrum: the complete range of electromagnetic waves, from radio, television, microwave, infrared, visible, ultraviolet, X-rays, gamma and cosmic rays, in this list from radio waves to cosmic rays, the frequency is increasing, the wavelength growing shorter, and the penetrating power increasing

Balanced for daylight: a light source that emits the same colors as sunlight and in the same proportion

penetrating and more energetic than light rays. When exposed to ultraviolet rays, a person's skin develops a tan to protect against those rays. Tanning beds have lamps that emit ultraviolet light. X-rays, gamma rays and cosmic rays are shorter still, have very high frequencies and carry more energy.



All of these electromagnetic waves are alike in that they travel at the speed of light in a vacuum. They differ in their frequency and wavelength. The human eye can see less than one percent of the entire electromagnetic spectrum. Photographic film and digital cameras can be made sensitive to the infrared regions. Special purpose radio gear can tune in even lower radiation.

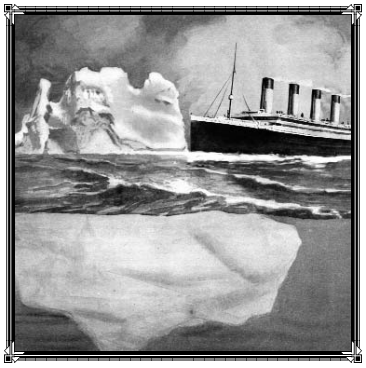
Understanding electromagnetic rays makes possible analyzing the composition of the earth from a distance. The progress of the gypsy moth as it attacks the forest of the eastern states can be tracked by the change in electromagnetic radiation the damaged trees reflect. Crops that are in stress from lack of moisture are visible in infrared photographs. Long before the Sahara desert crept into surrounding territory, the lack of moisture was detected by electromagnetic sensors.

Any object that is white hot, such as the filament of a light bulb, emits visible light. As the object grows cooler, it still emits electromagnetic waves but of a longer wavelength and lower frequency. Warm objects release infrared light. Helicopters equipped with infrared sensors can aid police in chasing down a suspect who is fleeing at night. Although invisible to the eyes, the fugitive's body heat is enough to make his presence known.

One of the most difficult types of forest fires to fight is a ground fire. The fire burns the leaves, dead limbs and rich humus soil. Although slow moving, such a fire is persistent and difficult to extinguish. Sometimes the fire is invisible because it burns below the surface. Fire fighters use airplanes equipped with infrared sensors to pin point hot spots where the fire burns.

Even cool objects give off microwave radiation. Water emits microwave radiation of one frequency, while ice emits microwave electromagnetic radiation of a still lower frequency and longer wavelength.

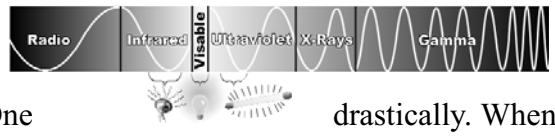
The great ocean liner *Titanic* sank because it struck an iceberg. Icebergs are still a threat to shipping in the North Atlantic. Scientists are better able to spot icebergs now because ice radiates microwaves at a frequency lower than that of open water. Ice-patrol aircraft use microwave detectors to spot the icebergs and warn ships.



Visible light from the sun is made of all of the colors of the spectrum from red to violet. No single color is white. The sensation of light that our eyes interpret as white is a combination of all of the colors. A white piece of paper appears white because it reflects all of the colors that fall upon it. Should the room be illuminated with a red light alone, then the white paper will appear red. The paper can only reflect what falls upon it. If red is the only color available for the paper to reflect, then the paper will appear red.

Sunlight contains all of the colors of the light spectrum. A source of light that provides those same colors in the same intensity as sunlight is ***balanced for daylight***. Not all sources of light are color balanced.

Some light sources may be missing some colors or be brighter in one color than in another. For instance, incandescent light bulbs emit all of the colors but produce more red than blue. The human brain compensates and makes objects illuminated at night by incandescent bulbs appear with the proper colors. The mind uses what it knows about the subjects so they appear normal. However, photographic film does not have this built-in compensation. A photograph taken at night will come back from the photo shop looking far redder than a person remembers the scene. One solution is to use a filter with a slightly blue tinge over the lens of the camera. The filter will filter out some of the red to bring more balance with the blue.



Fluorescent tubes that are used to illuminate some classrooms and offices differ significantly from sunlight. Fluorescent light has more blue and green, and some of the colors are missing entirely. The illumination is close enough to what a person expects so that the brain can compensate. A photograph under fluorescent tubes gives a person green looking skin tones. Compensating completely for missing colors with filters is impossible. One solution is to use a flash attachment with the camera, which is daylight balanced.

Sodium and mercury vapor lamps are even less complete in their output. A light green car under sodium vapor lamps looks yellow. Some people have trouble finding their vehicles on large parking lots at night because the color shifts so drastically. When you look at your hands under sodium or mercury vapor lamps, the color is so different from normal that your mind does not compensate. The skin is vivid shades of purple, red and yellow. For a subject to appear normal, the light source must be balanced for daylight. The light source must provide all of the colors of the rainbow and in the same proportion as sunlight.

LIFE PRINCIPLE



"Genuine humility is a mark of true greatness."

— Hebrew Proverb

Integrated Physics & Chemistry



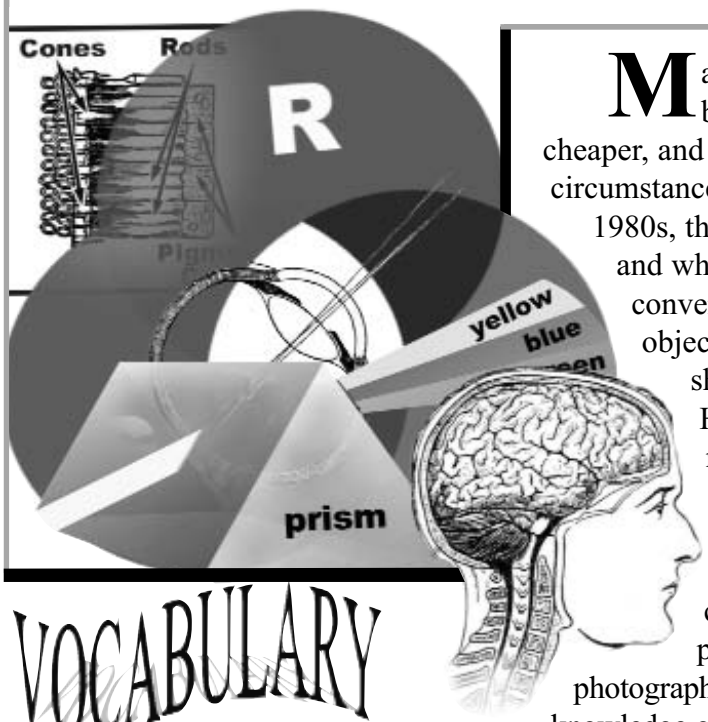
Lesson 8
Inventions & Discoveries

Chapter 6

COLOR VISION

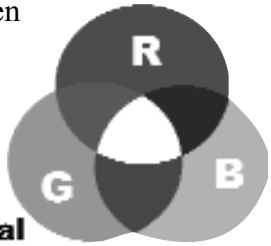
Section 2

Lessons 6-10



Many of the great movies were filmed in black and white. Black and white film was cheaper, and movies could be made under difficult circumstances in black and white. Starting in the 1980s, the film companies who owned the black and white movies began to use computers to convert the films into color. Some people objected. A film made in black and white should stay black and white, they said. However, when converted to color, the movies drew a fresh group of viewers.

Photography was invented in the 1840s and remained a black and white process for years. If a person wanted a color photograph, it had to be hand painted. The first person to make a full color photograph was James Clerk Maxwell. He used his knowledge of color to overcome the limitations of black and white film. Maxwell took three photographs of a colorful ribbon. For one of the exposures, he put a red filter over the camera. For the next photograph of the same ribbon, he used a green filter. Then for the third photograph, he used a blue filter. The photographs were in black and white on transparent sheets of glass that could be projected onto a screen. Mr. Maxwell used three projectors. Each one had a corresponding filter—red, green or blue. The three images on the screen added the three colors together and made a final image that was in full color. Maxwell made the color photographs to prove his idea that color vision relies upon only three ***primary colors*** – red, green and blue.



red, green and blue light in equal amounts make white light

VOCABULARY

Primary colors: colors that can create the other colors of the spectrum, usually red, green and blue

Additive color: color produced by combination of two or more colors, adding together red, green and blue gives white light

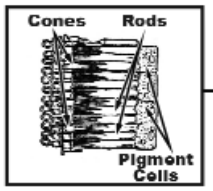
Rods: light receptors of the retina of the eye that detect light and dark

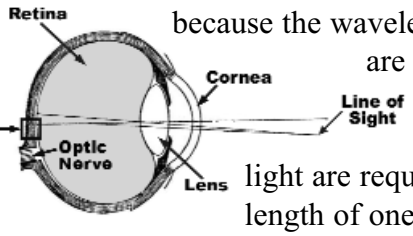
Cones: light receptors of the retina of the eye that detect color

Physical color: color based on the physical properties of the wavelengths of light

During the ***additive*** process, the three primary colors are put together, to produce white. If equal amounts of red, green and blue are combined, the eye sees white light. People who work with spotlights to create lighting effects during stage productions use additive color.

How color vision works is not completely understood. Although the human eye receives the light, the human brain processes the signal and interprets the image. Vision is a combination of the light that enters the eye, the ***rods*** and ***cones*** that receive the light and the brain that processes the signal. The human eye has both color and black-and-white receptors. Receptors in the human eye are located at the back of the eye where the image is formed on the retina. At night or when a person is in a dim room, the black and white receptors are at work. They are known as rods and are especially sensitive to low levels of light. The color receptors are cones and respond to colors. Only three types of cones exist, one type for each primary color: red, green and blue. When light falls upon the receptors, they send a signal to the brain that is interpreted as an image of a certain color.





Rods and cones are very sensitive because the wavelengths of light are very small. About 20,000 waves of green light are required to have a length of one centimeter. A green wavelength is about 0.000050 cm or 50 millionths of a centimeter. Red waves are about 0.000075 cm long. Violet has a wavelength of 0.000035 cm. Red waves are about twice as long as violet waves. All the other colors fall between those two wavelengths. The human eye is designed to detect these small differences.

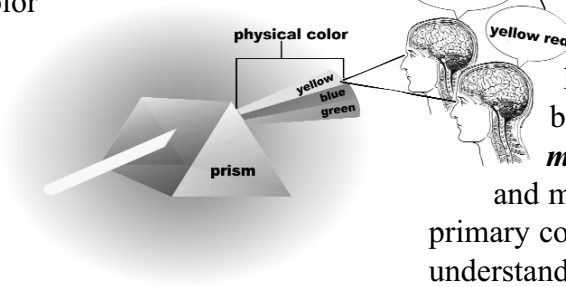
If only one type of cone is stimulated, only that color can be seen. For instance, if the eye forms an image of a red convertible on the retina, then only the red cones respond, and the car appears red. Suppose, however, the convertible is yellow. Yellow has a wavelength that is a little shorter than red light but a little longer than green light. The yellow will cause some of the red cones to respond and some of the green cones to respond. Receiving signals from both the red and green cones at once causes the brain to interpret the color as yellow.

One of the reasons color vision is difficult to understand is the difference between ***physical color*** and ***physiological color***. Physical color includes properties of light such as the wavelength, frequency and brightness. Light exists in an endless number

VOCABULARY

Physiological color: color based on the interpretation of light by the human eye and brain
Cyan: the complement of red, composed of green and blue
Magenta: the complement of green, composed of blue and red
Color wheel: the colors red, yellow, green, cyan, blue, magenta arranged in a circle so each color is opposite its complement
Complementary colors: two colors that together will give white light, the complement of red is cyan, the complement of green is magenta and the complement of blue is yellow
Subtractive color: color that remains when some of the colors of the spectrum are removed, subtracting out red, green and blue gives black

of wavelengths, each one slightly longer or shorter than those on either side. Physiological color involves perception of color. The full range of physiological color can occur with but three colors. The difference between physical color and physiological color can be vast.



Yellow is a physical color. When sunlight is separated into the colors by a prism, one of the colors is yellow. It is a light of a certain wavelength, a little longer than the wavelength of red light and a little shorter than the wavelength of green light. When the yellow beam is separated from the other colors and projected on a white screen, the human eye interprets the color as yellow.

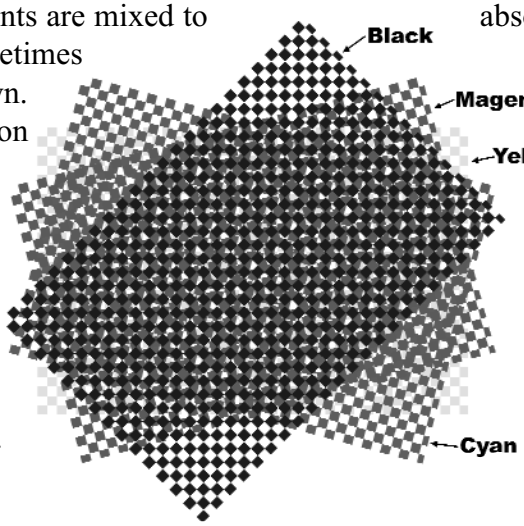
A person can see physiological yellow where no yellow exists. Suppose a spotlight of red light is aimed on a screen. Then, a spotlight of green light is aimed so it strikes the same screen and overlaps the red. In the place where they overlap, yellow is formed. To the eye, the yellow made by combining red and green is identical to the pure yellow separated from white light by a prism. One is pure yellow. The other is a mixture of two colors. Pure yellow is physical color. The mixture of two colors to produce yellow is physiological color. Both appear to be the same color to the human eye.

Color television and video camcorders are an application of the fact that three colors can produce the full range of colors. Instead of broadcasting all of the colors in the rainbow, the television studio sends out only three signals of red, green and blue. On the television screen, the complete range of colors is visible to the eye. Examine a television screen up close and you will see tiny dots, each one a shade of red, green or blue.When the red and green cones are stimulated, yellow is seen. When green and blue are stimulated, a color known as ***cyan*** is produced. When blue and red are stimulated, ***magenta*** is produced. Yellow, cyan and magenta are complements of the primary colors. A ***color wheel*** helps a person understand the three primary additive colors and their complements. Going around the wheel are red, yellow, green, cyan, blue, magenta and back to red. Cyan is opposite red and between green and blue. Magenta is opposite green and between blue and red. Yellow is opposite blue and between red and green.

Two colors that can produce white are ***complementary colors***. Two colors opposite one another in the color wheel will produce white when projected together. Red and the color opposite it, cyan, are complements. When they are projected on a screen, the result is white. The green and blue of cyan combine with red to give white. The idea of complementary colors has a practical application. Suppose a white dress has picked up a yellow tinge of color. To remove the yellow color, personnel at the local dry cleaners use a complementary bluing agent to restore the white color. Spotlights add colors together. Paints and pigments subtract colors.

Artists who paint with pigments use the process of ***subtractive color***. Suppose an artist brushes a yellow pigment on a piece of canvas. When white light strikes the yellow pigment on the canvas, all of the colors are absorbed except yellow. The yellow pigment subtracts all of the colors from light except yellow, which reflects to the eye. Each color on the canvas subtracts or eliminates all of the other colors. Red removes all colors but red; green removes all colors but green and so on. Color photographs in magazines and

newspapers use subtractive color, so does the output from color printers connected to personal computers. Tiny dots of colored ink are put on white paper to produce the color image. The three colors that are used in the subtractive process are magenta, yellow and cyan. Black ink is often used, too, because when pigments are mixed to give black, they sometimes become muddy brown. Where no ink is put on the paper, the image appears white. The white sheet reflects all of the colors. Where only black dots are put down, the image appears black.



All of the colors are absorbed or subtracted. Some mixture of magenta, yellow, cyan and black ink creates the other colors.

Suppose an artist needed to paint a green pepper but had no green pigment. The artist could achieve that color by mixing cyan and yellow. Cyan as a subtractive pigment absorbs all colors but blue and green. It reflects only those two colors. Yellow absorbs all colors but red and green. It reflects only those two colors. Cyan and yellow both reflect only green.



Integrated Physics & Chemistry

Lesson 9
Energy

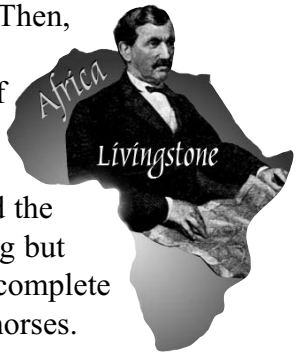
Chapter 6

LIGHT TRAVELING IN STRAIGHT LINES

Section 2

Lessons 6-10





David Livingstone, the great African explorer and missionary, once crossed the Kalahari Desert. While crossing the desert, Livingstone and the people with him ran out of water. Then, off in the distance, the wearied travelers saw the welcome sight of a lake. They dropped their packs and ran across the desert. As they topped a rise and ran down toward the lake, the travelers found nothing but sand. The illusion was so complete it had fooled even the horses. The oxen pulling the wagons depended on smell more than sight. The oxen did not smell water, so they were not fooled.

The human body has many sensory organs such as sight, sound, smell, taste and touch. Most people prize sight as the most important sensory organ. Much of our knowledge about our surroundings is brought to us through our eyes. If our eyes are less than perfect, we wear eyeglasses or contact lenses. Inventors have found ways to extend vision with the use of telescopes, microscopes, cameras, other optical instruments and surgery.

We depend so thoroughly on light that we are sometimes incapable of believing that our sense of vision is being fooled. One of the first rules we learn is that light travels in straight lines. Light which does not follow this rule can mislead our sense of vision. A ***mirage*** can create the illusion of water. On a hot day, a mirage can make water appear to be on a highway. A mirage is actually rays of light from the sky appearing to come from the ground. The effect can be so realistic that drivers slow to avoid splashing into the water at high speed.

VOCABULARY

Mirage: the illusion of water caused by the bending of light rays
Reflection: the bouncing of light rays back from a surface
Refraction: the bending of light rays as they enter a transparent medium such as glass lenses
Dispersion: the separation of light into the colors of the rainbow

For scientists, light has always been a surprising subject. When scientists think they understand light, new facts show that much is still to be learned. For instance, light sometimes acts as rays or particles. Observations such as ***reflection***, ***refraction*** (bending) and ***dispersion*** (separating into colors) are best explained by assuming that light travels in straight lines as particles. Other observations are explained by assuming that light travels as waves. Scientists have observed light acting in ways that can be explained by neither particles nor waves. Neither particles nor waves can explain the photoelectric effect and the scattering of light by crystals. Instead, scientists speak of light as quanta, tiny bundles of energy, that follow rules which combine both wave and particle natures.

Geometric optics represents the properties of light by using straight lines to show the path of light. Geometric optics include studies of light intensity, reflection, refraction and dispersion.

As a person reads a book, light arrives on the page from a variety of sources in the room. A reading lamp may be nearby, a light fixture may be overhead in the ceiling, or light may be emitted through windows. Light strikes the ceiling and walls, reflects and lands on the book. Under these circumstances, understanding how light grows weaker with distance is difficult.



VOCABULARY

Transparent: capable of transmitting light as if it were not there, clear
Opaque: does not let light pass
Translucent: transmits light but diffuses it so objects on the other side cannot be clearly seen

Scientists start with a point source of light. A point source of light is one in which light is free to radiate in all directions. A single bare bulb hanging in the middle of a large auditorium is an example of a point light source. As light leaves a point source, it expands outward and spreads over a larger surface. The light from a single bare bulb falling on a book four feet away may be bright enough for a person to read the type. At 20 feet, the light may become too dim for a person to read the type.

The Inverse Square Law explains the loss in intensity as light radiates outward. The surface of a sphere has an area proportional to the square of its radius. A sphere with a radius of 20 feet has an area 25 times greater than the sphere with a radius of four feet: $20^2/4^2 = 400/16 = 25$. The light is spread over the greater area, and intensity is reduced by a factor of 25. According to the Inverse Square Law, the intensity of light is inversely proportional to the square of the distance from the light source. In the previous example, the light intensity at 20 feet compared to four feet is: $(4/20)^2 = (1/5)^2 = 1/25$.

Although the sun is 860,000 miles across, it is an example of a point source of light. Light from the sun is free to radiate equally in all directions. One of the sun's planets, Pluto, is 31 times as far from the sun as the earth. The intensity of the light striking Pluto differs from the light falling on the surface of the earth. The intensity of light is inversely proportional to the square of the distance. The light's brightness on Pluto will be reduced by the ratio of $(1/31)^2$. The brightness will be only 1/961 times as bright as on earth.

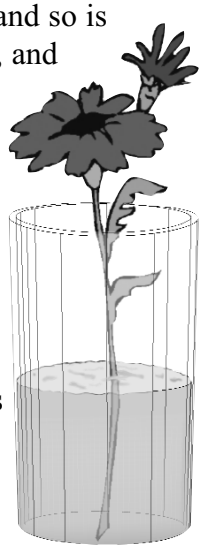
A practical application could be found in a small camera with a built-in flash. The camera may be perfectly capable of taking flash pictures at 8 feet, but with identical film

and the subject at 24 feet, pictures may be too dark to print. The light intensity at the greater distance is only 1/9th as much: $(8/24)^2 = (1/3)^2 = 1/9$. The camera may perform better than expected because the bulb is not a true point source of light. The bulb has a reflector behind the bulb and lens to direct the light toward the subject.

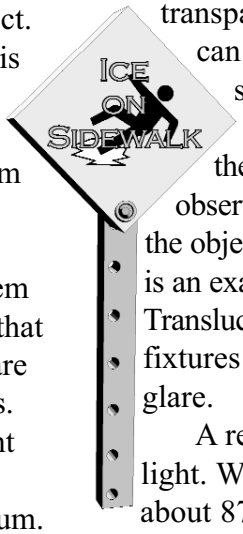


The inverse square is only true for rays of light that are free to expand in all directions. Rays beamed from an automobile headlight do not follow the Inverse Square Law because reflectors behind the bulb gather rays and reflect them forward. The light is sent in a tight beam that illuminates the roadway ahead. The rays are not free to expand equally in all directions. The Inverse Square Law assumes that light intensity falls off as it expands to cover a greater area. This would be true in a vacuum. However, when light strikes any surface, the light can be absorbed, bounced back or transmitted.

A surface that lets light pass unhindered is ***transparent***. Objects on the other side can be seen as if nothing was between the observer and the object. Clear glass is a transparent medium and so is pure water. A diamond is clear, and some crystals, such as quartz, are transparent. No substance is fully transparent. Although water is considered transparent, it does absorb some light. Water in a clean mountain stream may appear transparent; however, at greater depths, the water filters out the light. Sunlight cannot penetrate more than about 500 feet in the ocean. Below that distance, the ocean is totally dark. Even the vacuum of space is not completely transparent. A few gas molecules per cubic meter are enough to reduce the light from distant stars.



An ***opaque*** medium is one that light cannot penetrate. Most objects we see are opaque. They either absorb or reflect light. A sidewalk is opaque, but ice is transparent. A transparent medium on an opaque one can be deceptive, as any person who slips on an icy sidewalk knows.



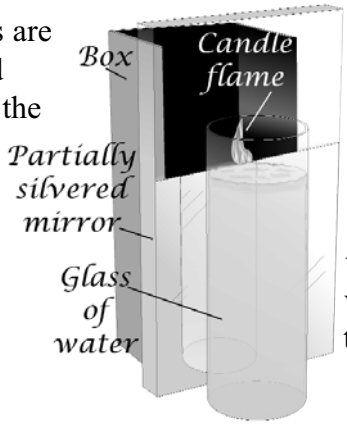
A ***translucent*** medium diffuses the light that enters the medium. The observer does not see a sharp image of the object on the other side. A frosted glass is an example of a translucent medium. Translucent globes are placed around light fixtures to diffuse the light and prevent glare.

A reflective surface can also diffuse light. White paper, for instance, reflects about 87 percent of the light that hits the paper. The white paper reflects light almost as well as a mirror. The difference is that the sheet of paper produces a *diffuse reflection*. Parallel rays that strike the paper do not keep their orientation upon reflection. The parallel rays reflect in every direction. To change the direction of light and prevent glare, diffuse reflectors are used. Most ceiling tiles are diffuse reflectors.

A mirror has a smooth, flat surface that produces a *regular reflection*. The rays reflect in the same order they arrive. The surface is smooth, and if the rays arrive equally spaced and parallel, they will reflect out that way. A mirror reflects light so well an image of the subject can be seen clearly.

Some magic tricks are done with mirrors. Objects can be hidden in trunks behind V-shaped mirrors. The mirrors reflect the sides of the trunk as if it were the back of the trunk. The appearance is given that the

trunk is empty. Some tricks are done with partially silvered mirrors. Despite the use of the name, most mirrors are coated with aluminum rather than silver.



The partially silvered mirror will reflect some light but lets some light pass through. Suppose a candle is hidden from view inside a black box that is open only on the side facing the half silvered mirror and a glass of water is on the other side of the mirror. An observer would see the candle as if it is burning in the glass of water.

LIFE PRINCIPLE



"Seeing is not always believing."

—Anonymous

Integrated Physics & Chemistry



Lesson 10
Inventions & Discoveries

Chapter 6

MIRRORS AND TELESCOPES

Section 2

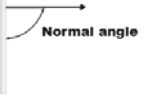
Lessons 6-10

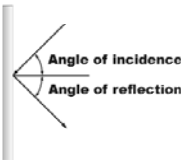


Before a talk show host such as Oprah Winfrey walks on stage, she pauses behind the curtain. She stands before a full-length mirror and looks herself over one last time before facing a live audience and the television audience of several million people. Some people who engage in public speaking daily travel with a full-length mirror enabling them to build their confidence before facing a crowd of people. Celebrities look in a mirror and so do ordinary people. We trust a mirror to reflect our images correctly and reveal any changes that need to be made.

One of the simplest laws of geometric optics is the *Law of Reflection.* Suppose a person is standing beside a smooth wall and throws a round ball at the wall. The ball hits the wall and bounces away. Providing the round ball does not have a spin, the ball will bounce away in a very predictable way. The angle it makes to a line drawn straight out from the wall equals the angle it makes to the line as it bounces away. Light follows the same law. Suppose the ball bounced from a mirror instead of a wall and you were to shine the beam from a flashlight along the path of the ball, it will reflect from the mirror along the same path that the ball took when it bounced.

The ray coming to the mirror is the incident ray. The ray reflecting from the mirror is the reflected ray. A line drawn straight out, perpendicular to the surface of a flat mirror, makes an angle of 90 degrees to the surface. A line that forms a right angle with the surface is *normal* to the surface at that point. The angle the incoming ray makes with the normal is the *angle of incidence*. The angle the reflected ray





VOCABULARY

Field of view: the amount of space that can be seen at one time

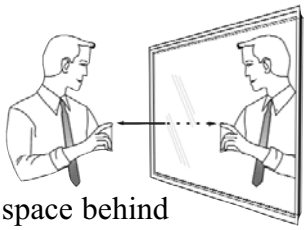
Focal point: the point at which parallel rays are brought to a focus, the image of an object at infinity is at the focal point

Focal length: the distance from the center of the surface of the mirror or lens to the focal point

Infinity: a distance beyond which all objects will be brought to a focus at the focal point, rays of light from objects at infinity are parallel

makes with the normal is the *angle of reflection*. The Law of Reflection of Light states that the angle of incidence equals the angle of reflection. The incident ray, the normal ray and the reflected ray all lie in the same plane.

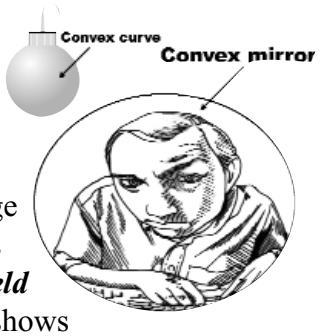
An image that appears to be in a location where it does not actually exist is a virtual image. The rays appear to diverge from the virtual image behind the mirror, when actually the mirror reflects the path of the rays from a real object. When you look into a flat mirror, your reflection appears to be as far behind the mirror as you are in front of the mirror. The image appears to be behind the mirror, although the space behind the mirror may be a solid wall. The viewer knows that the rays actually come from objects in front of the mirror.



Animals which do not normally see their reflections in mirrors are easily fooled. For example, grouper fish are territorial. Each fish claims as its own territory a certain area along the sea bottom. If a mirror is placed in the claimed territory, the grouper fish will attack the fish in the mirror.

A mirror can be curved rather than flat. Most curved mirrors are part of a sphere. If the mirrored surface is the outside of a sphere, then it is a convex mirror. Examples of convex mirrors include the outer silvered surface of Christmas tree ornaments and hubcaps on some cars. Some stores place convex mirrors high on walls or ceilings enabling store clerks to view aisles that are not visible from checkout stations.

A convex mirror always forms a virtual image that is smaller than the object. The backside of a spoon makes a convex surface. The image of a person's face is reduced when reflected from the back of a shiny spoon. The image appears to be behind the convex mirror, therefore, it is a virtual image.



One advantage of a convex mirror is that it has a wider ***field of view***. The mirror shows more than can be seen with the eyes alone. Photographing the northern lights, aurora borealis, is often done with cameras mounted over a convex mirror that reflects the whole sky. The camera can photograph the entire sky at once. The only defect is that the camera itself blots out some of the light.

Some exterior mirrors on automobiles are gently curved to improve the field of view, helping the driver to see objects that would otherwise be hidden. These mirrors have a warning that objects are closer than they appear. The convex mirror forms a smaller image that appears to be farther away.

A mirrored surface with the shape of the inside of a sphere, forms a concave mirror. The front or bowl side of a spoon makes a concave surface. Other examples of concave mirrors include those used for makeup and shaving. The image formed by a concave mirror can be virtual or real, depending upon how far away the object is placed.

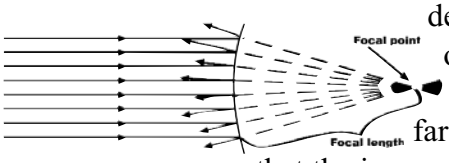


Concave mirrors have two interesting points regarding formation of images. One point is the center of curvature which is the center of the circle that fits the surface of the convex mirror. The ***focal point*** is the other point of interest regarding how concave mirrors form images. When an object is sufficiently far away, rays from it are parallel to one another. A convex mirror brings parallel rays of light to a focus at the mirrors focal point. The easiest way to

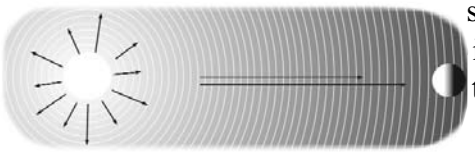
find the focal point is to turn the convex mirror toward a bright object that is very far away, and see where the image forms. The distance from the mirror to the focal point is the ***focal length*** of the mirror. If the image of a distant object forms three inches in front of the lens, then the focal length is three inches.

An object is at ***infinity*** if the rays of light coming from the object are parallel. In that case, the rays are brought to a focus at the focal point. Mathematicians speak of infinity as a number so great that it never can be achieved. Scientists who work with lenses and mirrors use the definition that objects are at infinity if they are far enough away so that the image forms at the focal point. The sun, for instance, is at infinity. Objects can be much closer and still be at infinity. The moon is at infinity, so is a street light that is several hundred yards away. For most lenses and mirrors of normal size, rays of light from an object that is 200 feet away appear to be coming from infinity.





Most large modern telescopes use a concave mirror to gather light and form a real image of outer space objects. One of the chief purposes of a telescope is to gather light. The primary fact about a telescope is not its focal length, but the size of the mirror. The size of a telescope refers to the diameter of the main or primary lens or mirror. An amateur astronomer who refers to an 8-inch telescope, refers to the diameter of the main mirror, rather than the focal length of the telescope.

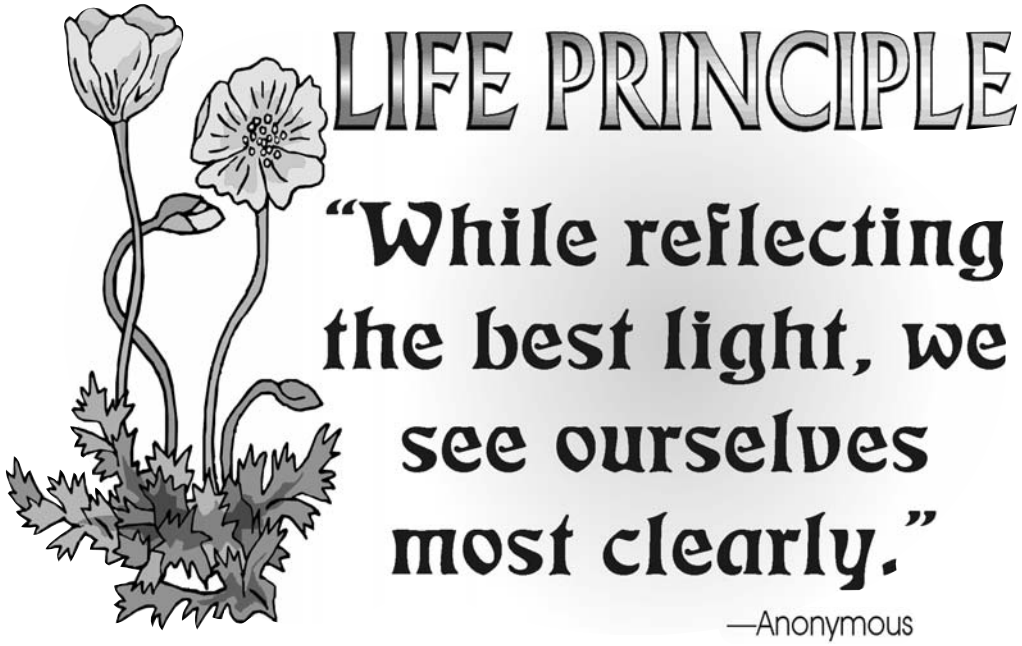


The United States has a National Observatory on Kitt Peak near Tucson, Arizona. The main telescopes are on the summit at an elevation of 6,882 feet, which puts the telescopes above much of the haze and air pollution. The largest telescope at the National Observatory has a convex mirror that is 4 meters across, about 13 feet.



For more than 50 years, the largest telescope that used a mirror to gather light and form an image was the glass giant on Mount Palomar in California. The glass giant has a main or primary mirror measuring 200 inches (5.08 meters, 16.7 feet) in diameter. It is no longer the champion in size. A pair of telescopes, each with a mirror 8.2 meters in diameter were built to study the heavens in 1998. One telescope is located at the summit of Mauna Kea on the Big Island of Hawaii at 13,796 feet in elevation. Another identical telescope is located in South America in Chile.

High mountains away from light and air pollution are usually chosen for telescope sites. The Hubble Space Telescope has the best location. It is 600 miles above the earth. The Hubble Space Telescope cost 1.85 billion dollars and has a mirror 2.4 meters (about 8 feet) across. The crew of the space shuttle Discovery deployed the Hubble Space Telescope in low-Earth orbit in 1990. The first photographs the telescope took showed a serious design flaw. In 1993, astronauts installed corrective optics to overcome the design defects.


LIFE PRINCIPLE
"While reflecting the best light, we see ourselves most clearly."
—Anonymous

Integrated Physics & Chemistry

Lesson 11
Energy

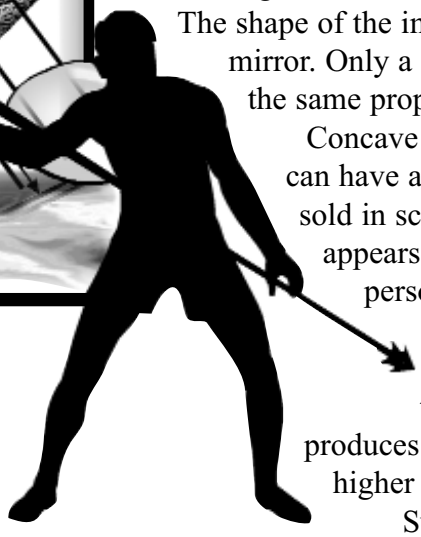
Chapter 6

BENDING LIGHT

Section 3

Lessons 11-15

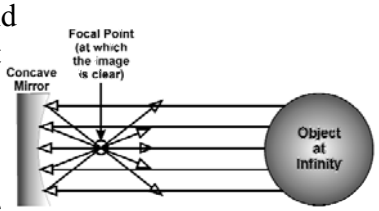




At an amusement park you will find individuals walking through a fun house stopping to look at themselves in mirrors that distort images. Some mirrors make people appear impossibly tall, with incredibly skinny legs. Other mirrors squeeze the image and make a person appear short and wide. The shape of the image depends on the shape of the mirror. Only a flat mirror gives an image with the same proportions as the viewer.

Concave mirrors form real images that can have a startling reality. One gadget sold in science stores is a dish that appears to have a coin in it. When a person tries to pick up the coin, his fingers pass right through it. The coin is actually deeper in the dish. A concave mirror produces a real image of the coin at a higher position.

Suppose you are standing far away from a concave mirror. As you look at the mirror, an image of your face, upside down and reduced, will float at the focal point of the mirror. The image can be projected by placing a small piece of paper at the focal point. An object at infinity forms a real image at the focal point of a concave mirror. As you walk closer to the mirror, the image will no longer be at the focal point. It would form farther away from the mirror and grow larger. When you reached the center of curvature of the mirror, the image would also have moved so that it forms at the center of curvature, too. For you to see the image of your face would be impossible because the image would be forming on your face itself. An



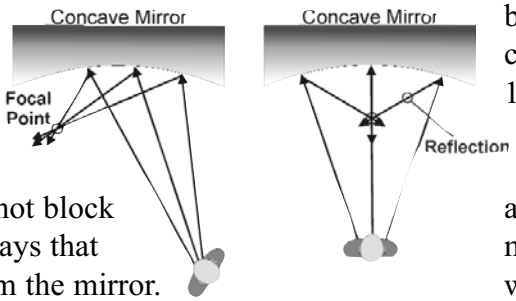
VOCABULARY

Refraction: the change in speed of light as it changes from one medium to another; in going from a vacuum to any other medium, the speed of light is reduced; if it enters the second medium at an angle, the rays of light will be bent toward the normal

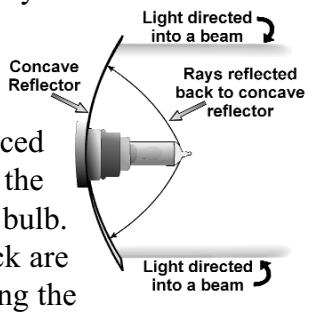
Index of refraction: of a medium is the ratio of speed of light in a vacuum compared to its speed in the medium

Mirage: the appearance of water caused by the refraction of light from the sky

object at the center of curvature of a concave mirror forms an image at the center of curvature. As you move still closer to the mirror, the image will form behind you, provided the mirror is large enough that your face does not block all of the rays that reflect from the mirror. As you move forward, the image continues to grow larger and form farther and farther away from the mirror. Finally, when you reach the focal point, the image is projected to infinity. The rays that leave your face will travel to the mirror and then reflect out in a nearly parallel bundle. An object at the focal point of a concave mirror sends out nearly parallel rays to infinity.



Automobile headlights take advantage of this fact. The bulb is placed at the focal point of the reflector behind the bulb. The rays that go back are then reflected, leaving the headlight in a tight, nearly parallel bundle. The rays are focused so they illuminate the road ahead of the car.



If your face is located between the focal point and the mirror, then an enlarged image is formed, but it is a virtual image behind the mirror. Shaving mirrors and makeup mirrors are concave mirrors with a focal point well back of where a person would normally sit. Those who use the mirror see an enlarged, right side up image of their faces. Should you stand far enough away from a shaving mirror or makeup mirror, the image forms upside down and is smaller.

Lenses can form images, too. Rather than reflecting light to give an image, lenses bend light. The ***refraction*** is caused by a change in speed of the light rays. Until the 1850s, measuring the speed of light except as it traveled through the vacuum of space was very difficult. However, with improved apparatus, the speed of light could be measured in a variety of media such as air, water, glass, clear crystals and even diamonds. In every situation, scientists found that light has the greatest speed in a vacuum and is slower in all other transparent media.

The ratio of the speed of light in a vacuum compared to its speed in some other medium is the ***index of refraction***: (index of refraction = speed of light in a vacuum / speed of light in the medium). Notice that the speed of light in the medium is in the denominator. The slower the speed of light, the greater is its index of refraction. The speed of light in a vacuum is 186,282 miles per second. Light in diamond travels at only 75,000 miles per second. The index of refraction for diamond = (speed of light in a vacuum) / (speed of light in diamond) = 186,282 / 75,000 = 2.47. Diamond has the highest index of refraction of any substance.

INDEX OF REFRACTION

medium	index of refraction	speed of light (m/sec)	speed of light (mi/sec)
vacuum	1.00000	299,792,458	186,282
air	1.00029	299,705,543	186,228
water	1.33	225,000,000	140,000
glass (crown)	1.50	200,000,000	124,000
glass (flint)	1.71	175,000,000	109,000
diamond	2.47	121,000,000	75,000

Windows are made of crown glass, as are most glass objects found in homes. Flint glass is more expensive and is used to make cut glass and lenses for some optical instruments.

Perhaps you have heard the statement that nothing can go faster than the speed of

light. That is true only in a vacuum. Electrons can go faster than light in water and other media.

The fact that light changes speed as it crosses from one substance to another causes both distances and direction to be misleading. As an example, place a coin in an empty cup. Lower your eyes until the coin is just hidden by the rim of the cup. Now slowly fill the cup with water. As the water fills the cup, the coin will become visible. The cup appears to be less deep, and the coin appears to be higher than it actually is. The depth of a very clear pool of water can be misleading. Water that looks 4.5 feet deep is actually 6.0 feet deep because of refraction.

A person who stands on a river bank will miss his target if he aims his spear directly at the fish. The spear must be aimed at a point closer to the fisherman for him to spear the fish.



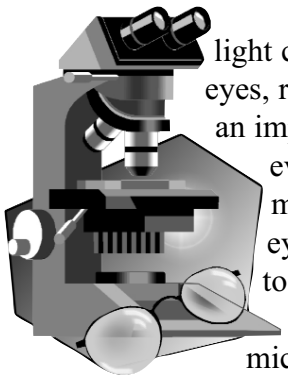
As light changes speed it also usually changes direction. Consider four friends with their arms interlocked walking along a boardwalk on a sandy beach . If the person on the end steps into the sand, that person will begin to walk slower causing the others to be pulled around. One by one, the other three people step into the sand. Not only do they go slower, but they also change direction.

As another example, place a pencil in a half full glass of water. When light leaves the water, light changes direction and makes the pencil appear broken. This is caused by the refraction of light. When light leaves air and enters a block of glass at an angle, light's path is bent toward the normal. The light changes direction. The only exception to this rule occurs when rays of light come straight into the glass or any other substance along the normal. In that case, the rays do not change direction but move slower.



Even the slight difference in the index of refraction of air and a vacuum become visible at sunset. When the sun is directly overhead, sunlight enters the atmosphere along a *normal* (perpendicular to Earth's surface), and the rays are not refracted. About two minutes are required for the sun to appear to move its width. At sunset, the rays enter the atmosphere at 90º from the normal, and refraction bends the rays so the image of the sun stays visible longer. From the time the lower edge of the sun first touches the horizon to the moment its upper edge disappears from sight, the sunset should take two minutes. However, because of refraction, the event takes six minutes. The sun seems to hang on the horizon. The same lifting effect is true of stars near the horizon. Astronomers must take into account the fact that the image of a star near the horizon is about three degrees higher than its actual position.

A ***mirage*** is due to the refraction of light over dry land. The surface appears blue due to the reflection of the sky. We see what appears to be a shimmery blue surface. A mirage is caused when the air presents the sky to our eyes. Normally, air is denser near the surface than it is higher in the sky. Any refraction is of objects on the ground. In the desert, heat reverses the situation. Air near the ground is hotter and less dense. The air higher in the sky is cooler and denser. The air refracts rays from the blue sky so they appear to be coming from the surface of the land. The shimmering blue image seen on the land in the distance, appears to be water. The image however, is merely a mirage.

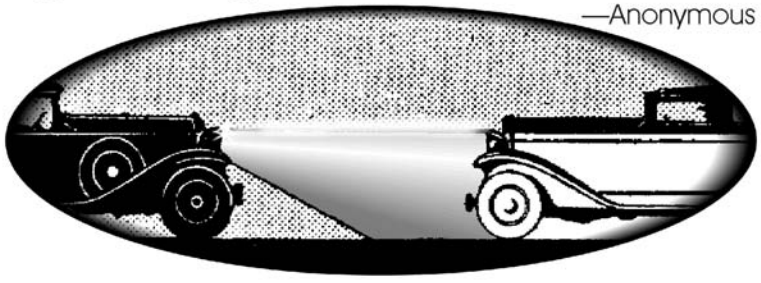


Although refraction of light can sometimes fool our eyes, refraction of light plays an important part in our everyday life. It is what makes possible eyeglasses and contacts to correct vision. Lenses in telescopes, microscopes, binoculars and cameras produce an image by refraction.

Life Principle

"The faults of others are like the lights of an oncoming automobile—they only seem more glaring than our own."

—Anonymous



Integrated Physics & Chemistry



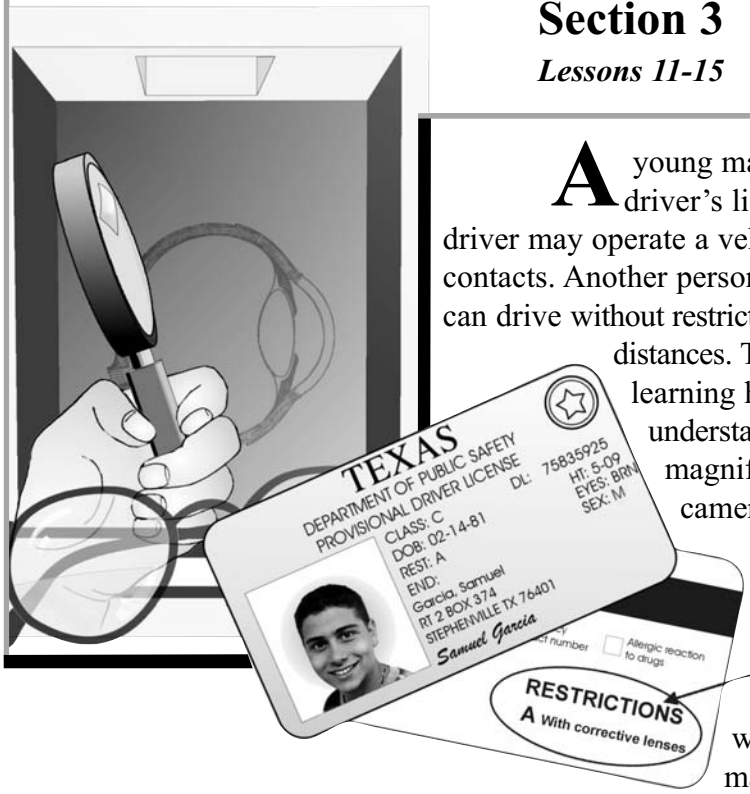
Lesson 12
Inventions & Discoveries

Chapter 6

CAMERAS AND EYEGLASSES

Section 3

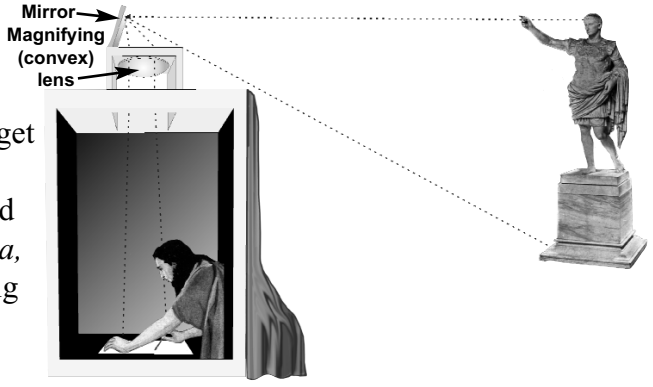
Lessons 11-15



A young man may pass his driver's test, but his driver's license may have a restriction that the driver may operate a vehicle only while wearing glasses or contacts. Another person must wear glasses to read a book but can drive without restriction. Another person can see clearly at all distances. The reason can be understood by learning how the eye works. Vision is easier to understand if a person first studies a simple magnifying lens and the operation of a camera.

A simple magnifying glass is a convex lens. It is a *converging lens* because it brings parallel rays of light to a focus. A magnifying glass can form a real image. Stand near the far wall in a darkened room and hold a magnifying glass so light from outside the room passes through the window and then to the magnifying glass. The magnifying glass causes the rays of light to converge and form an image on the wall. Using a white sheet of paper will make the image clearly visible. The image is upside down, real and smaller than the object.

In the Middle Ages, long before invention of modern cameras, artists used magnifying glasses to project images on pieces of frosted glass. An artist would place a piece of paper over frosted glass and trace out the magnified scene. This helped artists get proper perspective. This process, called the *camera obscura,* was a good learning tool for beginning



VOCABULARY

Diaphragm: a device that opens or closes to admit more or less light
Aperture: the opening through which light enters a camera
Shutter: a camera mechanism that allows light to enter the camera for a controlled amount of time

artists. In the 1800s, the camera obscura was replaced by a true camera when a French inventor learned to replace the sheet of paper with a photographic emulsion.

In addition to the lens and film, a camera also must focus the image and control the amount of light that strikes the film. The closer the subject is to the lens, the farther back the image forms. An inexpensive camera has its lens preset at a distance where the subject is likely to stand, usually five to eight feet. If the subject comes too close, the image tries to form behind the film and is out of focus. Expensive cameras can be adjusted to bring any subject into focus, from approximately one inch out to infinity. Focusing the camera on a nearby subject increases the distance between the lens and the film.

On overcast days in the shade, the film in a simple camera may not receive enough light, thus film will be underexposed.

VOCABULARY

Lens: a flexible crystalline material in the eye that changes shape to clearly focus an image on the retina

Iris: the colored part of the eye that controls the size of the pupil for admitting light to the eye

Pupil: the apparently dark opening that admits light to the eye, the pupil is surrounded by the iris

Farsightedness: distant object can be clearly seen, but not those that are nearby

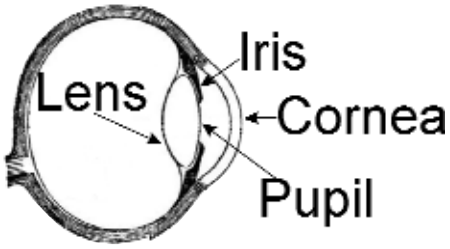
Meniscus: a crescent shaped lens that is convex on one side and concave on the other, it converges parallel rays if thicker in the middle than at the edges, it diverges parallel rays if thinner in the middle than at the edges

Nearsightedness: nearby objects can be clearly seen, but not those that are far away

On bright days, the film may receive too much light causing the film to be overexposed. A ***diaphragm*** changes the size of the opening in the camera lens so more or less light enters the camera. On a cloudy day, the diaphragm is opened wider to allow more light into the camera. On a bright day, the diaphragm is opened less to reduce the light that enters the camera. Rather than setting the diaphragm, photographers change the aperture. The ***aperture*** is the opening of the lens. The diaphragm adjusts the size of the aperture.

Another way to change the amount of light is with the ***shutter***. The click sound that a camera makes as it takes a photograph is the rapid opening and closing of the shutter. A high shutter speed, 1/250 seconds or shorter, will reduce the length of time the film is exposed to light. A slower shutter speed, such as 1/30 second, will keep film exposed to light for a greater length of time.

The human eye has been compared to a camera, but the comparison shows the eye vastly superior. For instance, the film in a camera is flat. The edges of the film are farther from the center of the lens than the rest of the film. Light must travel a longer distance to reach the corners of the film. Objects that are in focus at the middle of the film are not as sharp at the corners. The eye overcomes this by having a curved retina. Rays of light travel the same distance, whether going to the center of the eye or to the edge. Most people have better peripheral vision than does a camera lens.



The outer bulge of the human eye is the *cornea*. The cornea acts as a convex lens to bring light to a focus. The cornea is a converging lens that forms an image at the

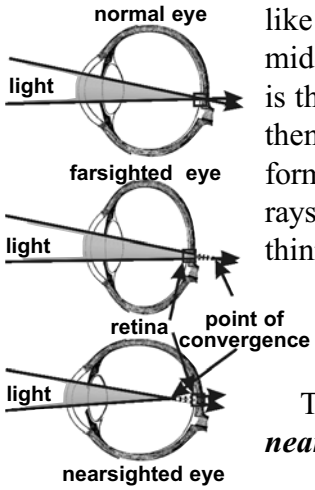
back of the eye. Fine focus is achieved by the ***lens***. The lens is held by muscles that contract or relax, causing the lens to become thinner or thicker. The lens changes its focal length by changing shape. The cornea is the stronger of the two in focusing rays, but it cannot change shape. The lens becomes thicker or thinner to ensure the image forms on the retina.

In front of the lens is the ***iris***, an automatic diaphragm that regulates the amount of light admitted to the eye. The iris opens or closes depending upon whether the person is in dim or bright light. The iris is the colored part of the eye – blue, brown, gray, black or in some cases, green. In the center of the iris is the ***pupil***, where the light enters the eye. The iris corresponds to the diaphragm of a camera, and the pupil corresponds to the aperture.

In very bright light, the iris closes so the pupil is only about 2 millimeters across. In very dim light, the iris opens so the pupil is about 7 millimeters across. Because the amount of light that enters the eye depends on the area of the pupil, 12 times as much light enters the eye when the iris is open to 7 millimeters compared to when it is open only 2 millimeters: $7^2 / 2^2 = 49 / 4 = 12$ (approximately).

The image forms on the retina. In bright light, the cones of the retina see in color. In dim light, the rods see in black and white. The eye seems to have two types of photographic film depending upon the amount of light that is available.

One common condition that reduces a person's ability to see clearly is ***farsightedness***. A farsighted person can see distant objects better than those that are nearby. A farsighted person can drive a car without glasses but must wear glasses or contacts to read a book.



Recall that as an object is brought closer to a convex lens the image falls farther and farther behind the lens. One cause for farsightedness could be that the eyeball is too short. The image of a nearby object does not converge before it strikes the retina. Or, the cornea and lens are too weak to converge rays of light quickly enough to form an image of a near object on the retina. Although distant objects are brought to sharp focus, rays from nearby objects are on their way to form an image behind the retina. The rays strike the retina before the image forms, and the object appears blurred.

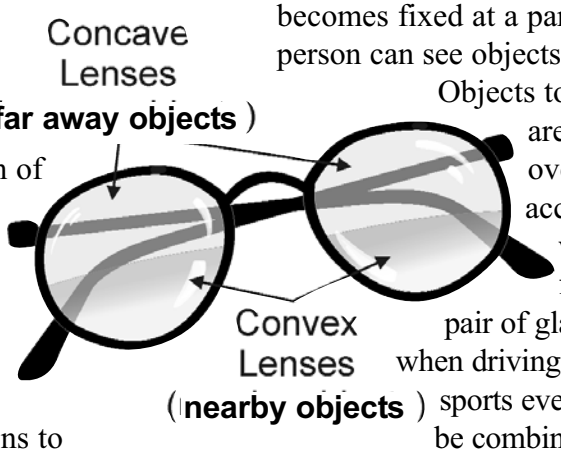
To correct farsightedness, the cornea and lens need help in forming the image of nearby objects. This is done with a convex lens to help the rays of light converge. Glasses for a farsighted person have convex lenses. If held up to the sun, a convex lens brings the rays together to form an image of the sun. Rays pass through the lens and form a spot of light that is smaller than the lens in the frame.

Eyeglasses and contacts are curved to follow more closely the curvature of the cornea. This is a ***meniscus***, or crescent, shape. On one side, a meniscus lens bulges as a convex lens does. On the other side, it bows as a concave lens does. A meniscus lens converges light like a convex lens or it diverges light like a concave lens. The thickness in the middle makes the difference. If the lens is thicker in the middle than at the edge, then the lens acts as a convex lens. It forms an image and causes the parallel rays of light to converge. If the lens is thinner in the middle than at the edge, then the lens acts as a concave lens. It will not form an image, and it causes parallel rays of light to diverge.

The opposite of farsightedness is ***nearsightedness***. A nearsighted person

can see near objects but is unable to see distant objects clearly. A nearsighted person may read a book without help but need glasses to drive a car or to see stop signs and signal lights. The image of nearby objects forms farther back from the eye. If nearby objects are seen clearly, then the eyeball is elongated. The distance from cornea to retina is longer than usual. Or, the cornea and lens may converge improperly. The cornea and lens form an image of a nearby object on the retina but can form images of far away objects before the rays reach the retina.

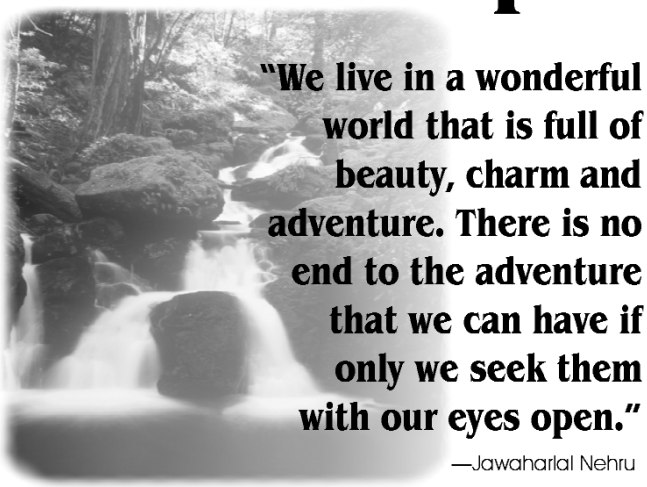
To correct nearsightedness, the strength of the cornea and lens needs to be weakened by a diverging lens. A concave lens diverges light. Rays of light from the distant object enters the concave lens, which causes the concave lens to diverge just enough to overcome the too powerful cornea and lens. Glasses for a nearsighted person have concave lenses. If held up to the Sun, a concave lens diverges the rays and no image forms. Rays pass through the lens and form a spot of light that is larger than the lens in the frame.



The third major condition that reduces a person's ability to see clearly is loss of accommodation. Normally the eye can focus on objects at any distance from about 10 centimeters to infinity. This automatic adjustment of the lens to varying focal lengths is accommodation. Usually, the loss of accommodation appears as a person ages. The eye lens is made of a crystalline substance that hardens with time. The lens becomes incapable of changing shape and becomes fixed at a particular distance. The person can see objects clearly at that distance.

Objects too close or too far away are fuzzy. A person can overcome the loss of accommodation by wearing reading glasses for close work. Another pair of glasses may be needed when driving a car or watching a sports event. The two lenses can be combined as bifocal glasses. The bottom part of the lens is convex, to help the eye focus on nearby objects. The top part of the lens is concave, to diverge light so the eye can focus on distant objects.

Life Principle



"We live in a wonderful world that is full of beauty, charm and adventure. There is no end to the adventure that we can have if only we seek them with our eyes open."

—Jawaharlal Nehru

Integrated Physics & Chemistry



Lesson 13
Inventions & Discoveries

Chapter 6

SINGLE LENS MICROSCOPES

Section 3
Lessons 11-15



People use binoculars to view distant objects. The people may be looking at birds, watching sporting events, observing indoor dramatizations or looking at star clusters in the night sky. When people look through binoculars for the first time, one of their first questions is about the ***magnification***.

Most binoculars have the magnification marked on the lens barrel. Simple, fold-up glasses for use in an auditorium are sometimes called *opera glasses*. Opera glasses have a low magnification of 2.5x. The little *x* means *magnification.* A pair of binoculars used for outdoor sporting events may have a magnification of 6x or 7x. A more powerful pair of binoculars for bird watching may be marked 8x or 10x.

Most people find binoculars with a magnification greater than 10x difficult to hold. Although 10x binoculars make an object appear 10 times closer, the glasses also magnify the holder's every movement. The slightest jiggle of unsteady hands is amplified 10 times. The subject being viewed seems to bounce around. Most people need to rest binoculars beyond 10x on something steady such as a tripod.

The definition of magnification is the size of the image divided by the size of the object: $m = Si/So$. For instance, suppose a person looks at a brick wall through a small telescope. Through the other eye, the person sees the brick wall normally. The person carefully counts that six of the normal bricks fill the same view as one of the enlarged bricks. The image in the binocular appears six times as large. The magnification is 6x.

As another example, if the image is 50 cm tall and the object is 5 cm tall, then the magnification is m = Si/So = 50 cm / 5 cm = 10x.

VOCABULARY

Magnification: the ratio of the size of an image to the size of the object, $m = Si/So$

Simple lens microscope: a microscope made of a single, convex lens of very short focal length, Anton van Leeuwenhoek made and used only simple lens microscopes

Microorganisms: a living organism, such as protozoan, that can be seen only with a microscope

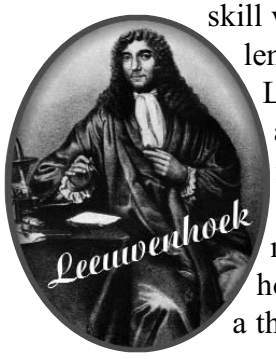
A *magnifying glass* forms a virtual image that is enlarged and right side up. Small print is placed closer to the lens than the focal point. Moving the print closer or farther back changes the size and location of the image. For the most useful magnification, the image should form at a distance that does not cause eyestrain. For most people the comfortable viewing distance is 25 cm or about 10 inches.

The magnifying power of a simple magnifying lens is given by the formula *m = (25 cm) / f,* with *m* the magnification, 25 cm the comfortable viewing distance, and *f* the focal length of the lens, stated in centimeters. Most magnifying glasses have a focal length of about 10 centimeters. The magnifying power is m = (25 cm) / f = (25 cm) / (10 cm) = 2.5x. The object will appear 2.5 times its actual size.

Sometimes a person needs to examine detail too small to be clearly seen in a 2.5x magnifying glass. For instance, a naturalist wants to examine an insect. A jeweler wants to see a diamond. A biologist wants to study the small animal life in a drop of water. Study the formula m = (25 cm) / f. The focal length is in the denominator. As the focal length decreases, the magnification increases. The magnification is inversely proportional to the focal length. To increase magnification, the focal length must become shorter. The naturalist, jeweler and biologist can increase the magnification by using lenses of smaller focal length.

Switching from a simple magnifying glass with a focal length of 10 cm to one with a focal length of 1.7 cm increases the magnification. The new magnification is m = (25 cm) / (1.7 cm) = 15x (approximately). The object will appear 15 times its actual size. A 15x lens is considered a strong magnifying lens. Although stronger lenses can be made, they become increasingly difficult to use.

The first person to make and use a microscope for scientific purposes was Anton van Leeuwenhoek. He was born in Holland in 1632. Anton van Leeuwenhoek worked most of his life at the Delft City Hall as a janitor. His hobby was making and using microscopes. Leeuwenhoek discovered that the magnifying power of a lens depends on its focal length. The shorter the focal length, the smaller the magnifying power of the lens. Exceptional skill was required to grind and polish these delicate little lenses. The most powerful of his ***simple lens microscopes*** was no larger than the head of a pin. Exceptional skill was needed to use the lenses, too. Anton van Leeuwenhoek had to hold a tiny lens at exactly the right distance and very close to the eye. He mounted the lens on a holder and the subject on a threaded bolt also on the



VOCABULARY

Bacteria: a small microscopic organism, some bacteria cause disease in plants, animals and humans

Compound microscope: has both an objective lens and an eye lens at opposite ends of a tube

Objective: a short focal length convex lens located next to the object to be magnified in a compound microscope, the objective forms a real image at the top of the microscope tube, magnification is *m = Di/Do* with *Di* the distance to the image and *Do* the distance to the object as measured from the objective

Eye lens: an eyepiece magnifying lens at the top of a microscope tube that enlarges the image formed by the objective

holder. This held the lens and subject at the right distance. By turning the bolt, Leeuwenhoek could move the subject in and out and achieve fine focus.

Along with patience and keen eyesight, Leeuwenhoek possessed a never-ending curiosity. He would analyze anything with his microscope: hair, skin, cork, ivory, blood, eyes and wings of insects, scales and fins of fish, muscle tissue — everything. Often, Leeuwenhoek would detect detail he had not seen before. He carefully recorded what he saw and made detailed drawings of his discoveries.

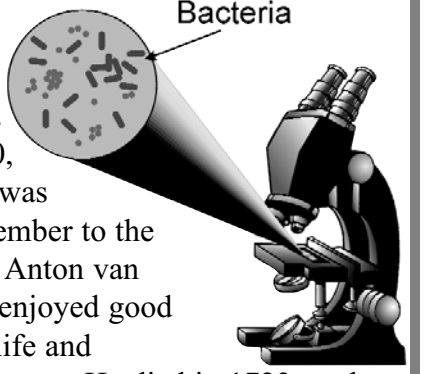


In 1673, Leeuwenhoek started sending letters to the Royal Society in London. Scientists usually corresponded in Latin, the language of scholars in those days, but Leeuwenhoek had only an elementary school education. He wrote in simple Dutch, the only language he knew.

Because of his experience and patience, Anton van Leeuwenhoek saw details that other scientists missed entirely. Many scientists did not believe the results Leeuwenhoek reported. Some scientists tried unsuccessfully to repeat Leeuwenhoek's work. The Royal Society asked for some of Leeuwenhoek's microscopes, which he sent. Finally, Robert Hooke, a scientist employed by the Royal Society, succeeded in repeating some of Leeuwenhoek's observations.

In 1674, Leeuwenhoek made one of the greatest scientific discoveries of all time. He found a world of living things inside a drop of canal water. Anton watched these very little animals with fascination, as they appeared to be everywhere — in water, in rain barrels, ponds and even in scrapings from inside his mouth. That discovery was totally unexpected. The small bodies were alive. They moved, ate, grew and reproduced offspring by splitting. When the temperature and food were right, the tiny bodies grew and split quickly. A single creature would fill a drop of water with teeming life in only a few hours. ***Microorganisms*** are living things that can be seen only with a microscope. The word *microorganism* means *small life.*

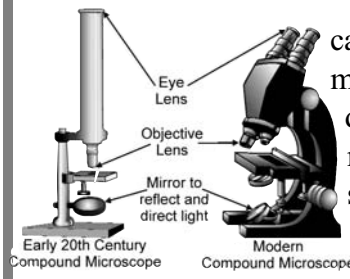
At the pinnacle of his skill with microscopes, Leeuwenhoek detected another category of life. These rod-like and ball-like microorganisms were far smaller than anything he had seen previously. Yet, they lived and grew, too. What he had seen were ***bacteria*** or germs. One hundred years would pass before another scientist succeeded in seeing germs. Another century would pass before scientists learned the importance of bacteria and germs. The bacteria that Leeuwenhoek saw are the causes of many diseases.



In 1680, Leeuwenhoek was elected as a member to the Royal Society. Anton van Leeuwenhoek enjoyed good health, a long life and considerable honors. He died in 1723, at the age of 90.

Leeuwenhoek's instruments were simple lens microscopes. He made them of a single small lens of very short focal length. An improved version of Leeuwenhoek's single lens microscope is the ***compound microscope*** still used today. A modern microscope is made of a main lens of short focal length, called the ***objective*** located near the object to be viewed. A second lens, the ***eye lens***, acts as a magnifying glass to enlarge the image formed by the objective lens.

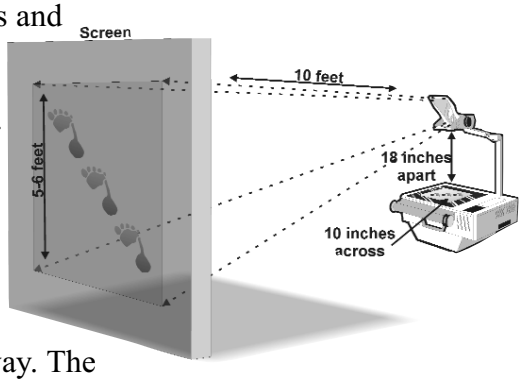
The advantage of a compound microscope is that the magnification can be done in two stages. The objective does part of the magnification while the eye lens does the rest. The field of view is larger, the eye lens does not have to be put as close to the lens, and focusing is easier.



Magnification can be measured in many ways. The definition of magnification is the size of the image divided by the size of the object: *m* = *Si/So*. Another formula is the one used for a magnifying lens: divide the comfortable viewing distance in centimeters by the focal length of the lens in centimeters: m = (25 cm) / f. A third way is to divide the distance of an image from the lens by the distance of the object from the lens: *m* = *Di/Do*. *Di* is the distance of the image from the lens and *Do* the distance of the object from the lens.

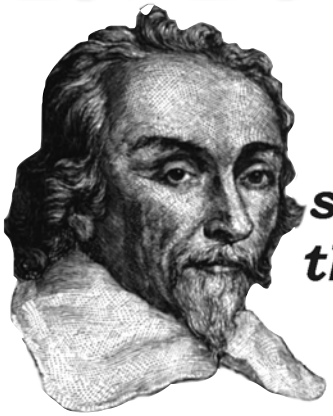
An object 3 inches from a lens is projected onto a screen 36 inches away. The magnification can be determined with the formula: m = Di/Do = 36 in / 3 in = 12x.

The formula *m* = *Di/Do* makes use of the fact that the further an image is cast, the larger it becomes. You have seen this when a person adjusts an overhead or slide projector. Moving the projector farther from the screen makes the image on the screen larger. Suppose an overhead transparency is 10 inches across and located 18 inches from the projector lens. The projector throws the image onto a screen that is 10 feet away. The magnification can be determined easily.



Solution: m = Di/Do = (10 feet * 12 in/ft) / (18 in) = (120 in) / (18 in) = 6.67x. Notice that all measurements are converted to inches. The transparency projected on the screen will be in feet. The 10 inch transparency is enlarged by a factor of 6.67x: 10 in * 6.67 = 66.7 in, or between five and six feet. (Divide 66.7 by 12.)

LIFE PRINCIPLE



"Great discoveries are made when we search out and study the secret(s) of nature by experiments."

—William Harvey

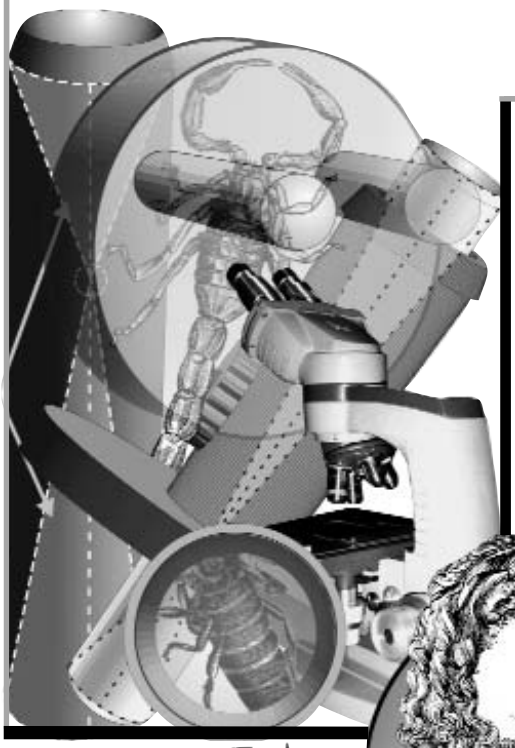
Chapter 6

Lesson 14
Inventions & Discoveries

MICROSCOPES AND TELESCOPES

Section 3

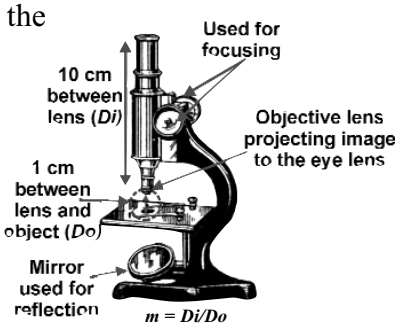
Lessons 11-15



A young person who receives a telescope as a present will be excited to observe the majesty of constellations. When the young person sets up the new telescope to view the moon, the lenses provided with the instrument may require adjustment The image of the moon may look fuzzy and indistinct. By trial and error, the young person learns that the maximum useful magnification is about 100x. Although not as high of a magnification as some telescopes, 100x still allows an inspiring view of Earth's nearest neighbor in space.

The experience of the amateur astronomer shows that the useful magnification for a telescope may be less than the maximum magnification possible. This is also true of microscopes.

Focusing the microscope requires raising and lowering the entire microscope tube to bring the objective at the lower end of the tube closer to or farther away from the subject. The objective projects a real image to the top of the tube. The magnification of the objective is given by the formula $m = Di / Do$, with *Di* the distance to the image and *Do* the distance to the object. The standard length for a microscope tube is 10 cm. Suppose the object is 1 cm away from the objective, and the image is 10 cm up the tube. The magnification is m = Di/Do = 10 cm / 1 cm = 10x.



Microscopes are equipped with a ***turret***, or rotating wheel, so that objective lenses with different powers can be rotated into place. A shorter focal

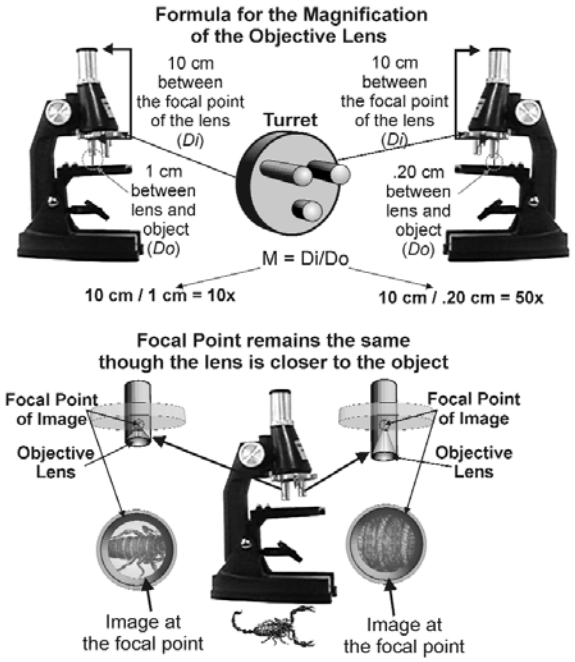
VOCABULARY

Turret: a rotating holder of microscope lenses that allows easy switching from one lens to another

Optical microscope: a microscope that uses lenses to focus light, maximum magnification of an optical microscope is about 2,000x

Electron microscopes: a microscope that illuminates an object with electrons and uses electric and magnetic fields to focus the electrons

length lens must be placed closer to the object. The equation *m = Di/Do* shows that reducing the distance to the object increases the magnification. If the distance to the object changes to 2.0 mm (0.20 cm), and the image is still formed 10 cm from the lens, then the magnification is m = Di/Do = 10 cm / 0.20 cm = 50x.



Going to the smallest lens at the bottom of the microscope tube just to increase the magnification eventually reaches a point where problems would arise. The image becomes extremely difficult to focus.

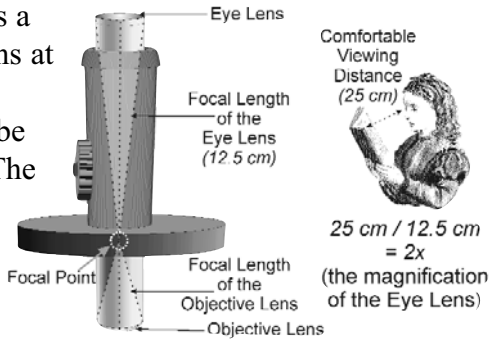
VOCABULARY

Telescope: a optical instrument to magnify distant objects, a telescope has a main objective that forms a real image that is then examined with an eyepiece

Resolution: a measure of the ability of an optical instrument to separate two objects that are very close together

The lens is nearly touching the microscope slide, and if the person using the microscope does not exercise care, he can break the slide while trying to focus. An objective that magnifies about 100 times is the limit. For this magnification, the objective is placed about 1.00 millimeter (0.10 cm) from the subject. The magnification is m = Di/Do = 10 cm / 0.1 cm = 100x.

A magnification of 100x is large but not large enough to show many very small structures or living things such as bacteria. Microscopes are not limited to 100x because the eye lens provides additional magnification. The eye lens is a magnifying lens at the top of the microscope tube near the eye. The eye lens enlarges the real image formed by the objective lens. The magnification of the eye lens is given by the formula m = (25 cm)/f with *m* the magnification, *25 cm* the comfortable viewing distance and *f* the focal length of the eye lens.



Suppose an eye lens has a focal length of 12.5 cm. Its magnifying power can be determined as: m = (25 cm)/f = (25 cm)/(12.5) = 2x. The size of whatever is viewed will double.

The total magnification of the microscope is equal to the product of the objective lens and the eye lens.

$$mt = mo * me$$

with *mt* the total magnification, *mo* the magnification of the objective lens and *me* the magnification of the eye lens.

For instance, if the objective lens gives a magnification of 100x, and the eye lens gives a magnification of 2x, then the total magnification is mt = mo * me = 100x * 2x = 200x.

Another example: a microscope has an objective lens that gives a magnification of 15x and an eyepiece with a magnification of 5x. The total magnification is mt = mo * me = 15x * 5x = 75x.

Suppose a person has a student microscope, and the objective is placed 2 mm (0.2 cm) from the subject. The student can select from several eyepieces, and the most powerful one has a focal length of 4 mm (0.4 cm).

Although the distance to the image is not given, most microscopes have a tube 10 cm long, and the image is formed at the top of the tube. Magnification of the objective: m = Di/Do = 10 cm / 0.2 cm = 20x.

Next, the eyepiece acts as a magnifier, and its magnification is given by the formula m = (25 cm)/f = (25 cm)/(0.4 cm) = 62.5x.



Finally, the overall magnification is given by the product of the magnification of the objective and the eye lens: mt = mo * me = 20x * 62.5x = 1,250x.

A magnification of 1,250x is far greater than would normally be used. With a variety of techniques, the best ***optical microscope*** in the hands of a skilled observer can achieve a maximum useful magnification of 2,000x.

An optical microscope is one that uses lenses to focus light. Greater magnification is possible with ***electron microscopes***. The electron microscope uses electrons and magnetic and electric fields to form an image. Electron microscopes can achieve a magnification of 100,000x and is capable of seeing details as small as individual molecules.

The magnification of a ***telescope*** depends on two factors: the focal length of the main objective and the focal length of the eyepiece. The size of the image is directly proportional to the focal length of the objective. If the focal length is longer, the image is larger. The main objective of one telescope has a focal length of 16 inches, while the main objective of a second telescope has a focal length of 64 inches. The second telescope will produce an image that is 4 times greater. In the first telescope, an image of the moon will be about 4 millimeters across. In the second telescope with the longer focal length, the image of the moon will be 16 millimeters across.

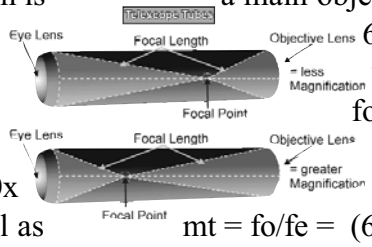
A telescope objective forms a real image of the moon. The image can be examined with a magnifying eyepiece to give an enlarged view. The formula is m = (25 cm)/f with *m* the magnification, *25 cm* the comfortable viewing distance and *f* the focal length of the eyepiece. A telescope eyepiece that is 6 mm (0.6 cm) in focal length gives a magnification of m = (25cm)/(0.6cm) = 13.2x.

The total magnification of a telescope is given by the ratio of the focal length of the objective to the focal length of the eye lens:

$$mt = fo/fe$$

with *mt* the magnification, *fo* the focal length of the objective and *fe* the focal length of the eye lens.

As an example, suppose a telescope has a main objective with a focal length of 64 inches, and it is used with an eyepiece with a focal length of 0.25 inch. The magnification solution will be:

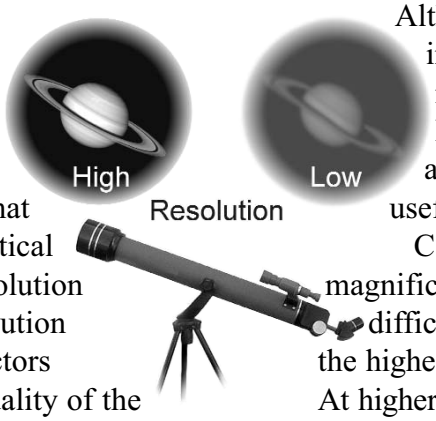


mt = fo/fe = (64 in) / (0.25 in) = 256x.

Examine the equation *mt = fo/fe*. The magnification is directly proportional to the focal length of the main lens, *fo*. To increase the magnification, a

person would make the focal length of the main lens or mirror as long as possible. The magnification is inversely proportional to the focal length of the eyepiece, *fe*. It should have as short a focal length as possible to increase magnification.

To increase the magnification beyond what is needed is called *empty magnification*. The magnification of any optical device, whether telescope or microscope should not exceed the resolution of the instrument.



Resolution is the ability to separate two objects that are close together. An optical instrument with high resolution can see fine detail. Resolution depends upon several factors including the size and quality of the instrument.

The resolution of a telescope increases as the diameter of its main lens or mirror increases. Even at the same magnification, a telescope 10 inches in diameter will show more detail than one that is two inches in diameter. If magnification exceeds the resolution of the telescope or microscope, the image becomes larger, but it also becomes blurred and indistinct. Magnification that exceeds the resolution is empty magnification.

Because of the nature of light, resolution of the lens is limited. For a telescope, this limit depends on the size of the objective, or main lens. A telescope objective of 50 mm (2 inches) can provide a maximum magnification of about 80x. Although eyepieces can be used to increase magnification to 200x or more, no additional detail is seen. Beyond the limit of the telescope, additional magnification is empty of useful information.

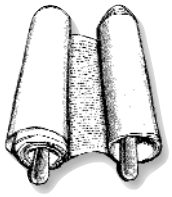
Calculating the useful maximum magnification of a microscope is more difficult. For most student microscopes, the highest useful magnification is about 300x. At higher magnification, no new detail is revealed, and the view becomes fuzzy and indistinct.

Life Principle

"It is best to view the faults of others with the naked eye while using a microscope to examine our own."

—Anonymous

Integrated Physics & Chemistry



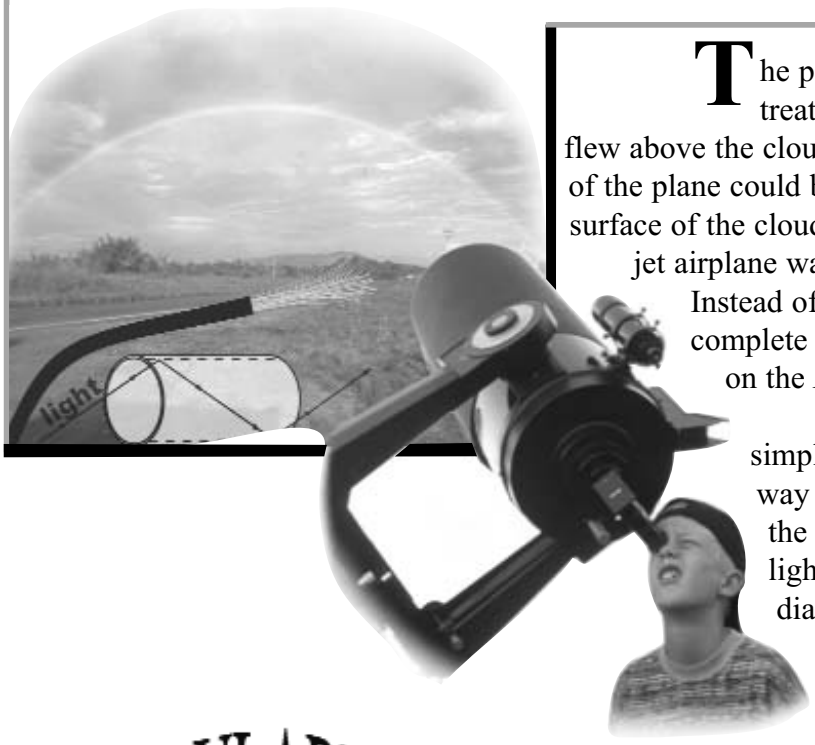
Lesson 15
Scientific Laws

Chapter 6

RAINBOWS

Section 3

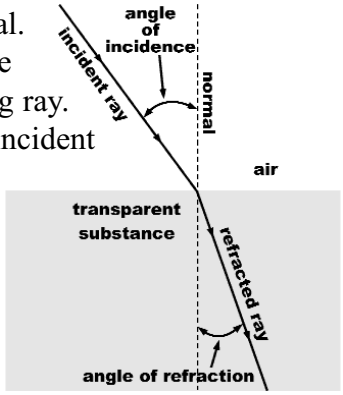
Lessons 11-15



The passengers of the jet airplane were treated to an amazing sight. As they flew above the clouds in bright sunlight, the shadow of the plane could be seen flitting along against the surface of the clouds. Surrounding the shadow of the jet airplane was a gloriously colored rainbow. Instead of an arc, the passengers saw a complete circle. The explanation is based on the *Law of Refraction*.

The Law of Refraction is not as simple as the Law of Reflection. The way a ray of light bends depends upon the transparent substance the ray of light enters. Air, water, glass and diamond all bend light by a different amount. The amount of bending also depends upon the ***angle of incidence***.

The direction light is bent is measured from the normal. The *normal* is a line perpendicular to the surface. The *incident ray* is the incoming ray. The angle of incidence is the angle the incident ray makes with the normal. The *refracted ray* is the ray after it enters the substance. The *angle of refraction* is the angle the refracted ray makes with the normal.

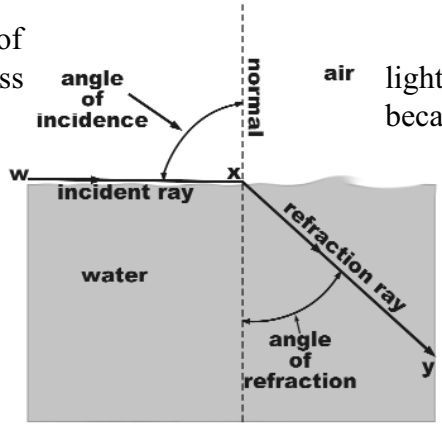


When going from a less dense substance such as air into a denser substance like water or glass, the ray is bent toward the normal. Consider the beam of a flashlight directed across a lake at almost 90 degrees to the normal. The light ray skims across the surface and then changes direction when it enters the water. The angle of incidence is 90

VOCABULARY

Angle of incidence: the angle an incoming ray makes with the normal
Dispersion: the separation of light into the colors
Prism: a solid geometric body, often of glass, usually with triangular ends, used for separating white light passing through into its rainbow spectrum of colors
Facet: one of the flat, polished surfaces on a gemstone

degrees. The angle of refraction will be less than 90 degrees because the light is going from the less dense air into the more dense water. Calculations show that the angle of refraction will be about 48 degrees.

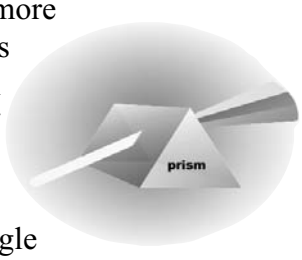


Suppose that instead of water, the beam of the flashlight strikes a different transparent surface such as glass. The angle of refraction will not be the same. The angle of refraction also changes with a change in the index of refraction. The higher the index of refraction, the more tightly the refracted ray is pulled toward the normal. If the pool of water is replaced with a block of glass, then the ray that strikes the block's surface at 90 degrees from the normal will be refracted to 41 degrees from the normal. Diamond has the highest index of refraction of any substance. A ray coming in at almost 90 degrees from the normal will have an angle of refraction of only 24 degrees.

Notice how differently the three media – water, glass and diamond – refract the same ray coming in at almost 90 degrees. Water refracts the ray at 48 degrees, glass at 41 degrees and diamond at 24 degrees. This illustrates the fact that the angle of refraction is directly related to the index of refraction. The greater the index of refraction, the more the ray is bent. Diamond bends light more than any other substance.

The index of refraction is the ratio of the speed of light in a substance such as air, water, glass or diamond compared with its speed in a vacuum. The speed of light in air is very nearly the same as its speed in a vacuum. In diamond, however, the speed of light is 2.42 times slower.

Dispersion is the separation of white light into its colors. Dispersion occurs because the index of refraction is not the same for all colors of light. A beam of violet light slows more upon entering glass than a beam of red light. The angle of refraction for violet light is greater than the angle of refraction for red light. Violet slows more and has its path bent more. Red slows less and is refracted less. The other colors fall between red and violet. A ***prism*** produces the rainbow of colors because of dispersion.



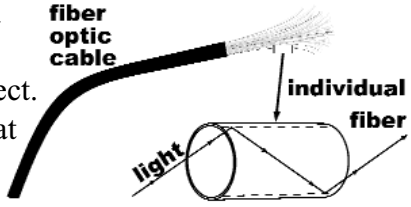
Any transparent substance can produce a rainbow when a beam of white light passes through the substance at an angle. Water, ice, plastic, glass and diamond all produce dispersion. However, the dispersion increases as the index of refraction increases. A prism of glass separates the colors better than a prism of ice. A prism of diamond does even better. The greatest separation of red and violet rays occurs with a prism of diamond.

Because each color changes speed by a slightly different amount when it enters diamond, the index of refraction is different for each color. Stating that diamond has an index of refraction of 2.42 is not entirely correct. That value is actually true only for yellow light. The index is a little less for red light and a little more for violet light. The index of refraction for diamond is 2.41 for red light and 2.46 for violet light. The other colors fall in between.

Diamonds sparkle as a result of their high dispersion and *total internal reflection*. A ray of light is bent toward the normal as it enters diamond or other transparent substance such as glass, plastic or water. A ray of light is bent away from the normal as it escapes from diamond or some other media into air.

If the ray inside the diamond has an angle of 24 degrees with the normal, the ray will leave the diamond at 90 degrees. An angle of 90 degrees is the largest angle a ray can make with the normal. If the ray inside the diamond has an angle greater than 24 degrees, then rather than being refracted, it will be reflected from the surface back into the diamond. The ray cannot escape unless it makes an angle of 24 degrees or less with the normal.

All transparent substances can produce total internal reflection. For water, the total internal reflection does not occur unless the angle is much greater. Rays must try to leave water at an angle greater than 48 degrees to be totally reflected. A swimmer who is underwater in a clear, still pool can see this effect. By looking up at the surface of the water at an angle of more than 48 degrees, the water presents a silvery surface as shiny as a mirror.



Fiber optics is an important application of total internal reflection. The fibers are so narrow that the light that enters at one end cannot escape because the light will strike the sides of the fiber with a glancing blow. Light is then kept inside the fiber by total internal reflection. The light can escape only at the other end. The strands of fiber optic plastic can carry light great distances. Strands of fiber optic plastic are used by medical researchers to look into a living heart. Telephone and cable companies use optics to transmit vast amounts of audio and video information on beams of light.

The colors in a beam of light become highly dispersed inside a diamond. Because of total internal reflection, the rays can escape from the prism only if they hit a ***facet*** nearly head on. Until that occurs, the rays are reflected around inside the diamond. Colors then become separated. When the rays do escape, they leave the diamond as individual colors. The diamond sparkles with each face showing vivid reds, yellows, greens and blues. Part of the skill in cutting a diamond is making its facets so that light escapes only after it has been thoroughly separated into colors.

A rainbow is caused by the combined dispersion of light by thousands of water droplets. Water produces far less dispersion than diamond or even glass. However, water droplets disperse light twice. The rays are separated once as they enter the water droplet. Then, the light rays are reflected from the far side and separated again as they leave. This doubles the dispersion. A rainbow can be seen when droplets are in the air, and the sun is at the observer's back. Rainbows are usually seen as arcs. However, from a high mountain or an airplane the entire circle of the rainbow is visible.

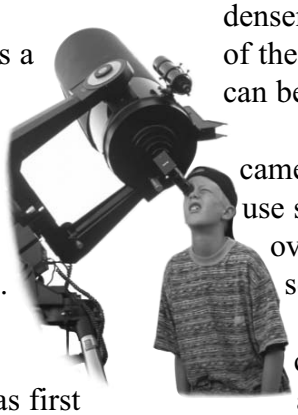


All optical instruments must overcome the fact that glass tends to separate light into colors. A convex lens is very similar to a prism. A convex lens does not bring all colors to the same focus. The lens forms a slightly different image for each of the colors. A telescope with a single convex lens, as the main objective, gives an image that is surrounded by a distracting color fringe.

Dispersion is another way that refraction differs from reflection. All colors reflect at the same angle. When a beam of light reflects from a mirror, each of the colors is then reflected by the same amount. A mirror cannot produce a rainbow by reflection. One solution is to use a mirror, rather than a lens as the main objective. The reflecting telescope

makes use of the law of reflection: the angle of incidence is equal to the angle of reflection. Rays of light strike the mirror and are reflected to a focus. Each color is then reflected by the same amount. When white light reflects from a mirror, it does not separate into colors.

A reflecting telescope has a concave mirror as its primary surface for forming an image. Isaac Newton invented the reflecting telescope as a solution to the color problem created by a refracting telescope. The primary objective of a refracting telescope is a convex lens. The refracting telescope was first used for scientific purposes by Galileo.



Two hundred years passed before scientists discovered how to eliminate the rainbow effect that was created by using a convex lens. The dispersion of light is not the same for all types of glass. Crown glass separates red and blue by a different amount than the denser flint glass. By combining lenses made of the two types of glass, the color problem can be overcome.

Today, all microscopes, telescopes, camera lenses and other optical instruments use several lenses in combination to overcome the tendency of glass lenses separating light into colors.

Congratulations! You have almost completed Volume II. Review your activity answers before taking the quiz over lessons 11-15. Then review your notes before taking the test over chapter six.

