Lesson Notes: Middle Grades—

SCIENCE CONCEPTS OF ELECTRICITY AND GENERATION AND DISTRIBUTION

Electric UNIVERSE

Magnetism and electricity are closely related. To understand electricity, you first need to know about magnets.

Magnets are objects which pull (attract) or push (repel) other magnets toward and from them. Magnets also attract objects containing the metal iron.

We call the forces of a magnet "magnetism".

The ends of magnets are called "poles". Magnets have a north pole and a south pole.

A magnet will have a north pole and a south pole no matter how many times you split it.

The north pole of one magnet attracts the south pole of another. Opposite poles attract.

Two north poles or two south poles repel each other. Like poles repel.

The Earth acts like a giant bar magnet. The north and south magnetic poles are near the top and bottom of the planet (the north geographic pole and the south geographic pole).

Have you ever observed a compass? The needle always points in the same direction—north. A compass needle is actually a magnet. It swivels freely on a tiny pin. The north pole of a compass magnet points toward the Earth's North Magnetic Pole, (The North Magnetic Pole is actually a south pole! Remember, opposite poles attract.)

A compass needle can be moved away from a northward direction when another magnet or piece of iron is placed nearby. This happens because the other object exerts a stronger magnetic attraction thanß the Earth's magnetic poles.

Iron is a material that is attracted to a magnet. The metals nickel and cobalt are attracted to magnets, but to a lesser extent. (Permanent magnets are commonly made from a combination of these metals.)

An object of pure iron or containing iron—like a paper clip— does not attract other iron objects. Yet, is attracted by a magnet. Once a paper clip touches a magnet, it will attract a second paper clip. Once the magnet is removed from the first paper clip, it no longer attracts the second paper clip.

This happens because the iron particles in the paper clip are composed of many small groups of magnetic atoms called domains. The domains are arranged in a random pattern—with the north and south poles pointing in all directions— so their magnetic effects are cancelled by each other. In this arrangement the object is unmagnetized.

When a magnet touches an iron object, the domains line up with all the north poles and all the south poles pointing in the same direction. When this happens, the object becomes magnetized. Remove the magnet and the domains return to their random pattern.

In permanent magnets, the poles of domains remain aligned in the same direction, thus the entire object exerts magnetic force.

Permanent magnets are usually composed of a mixture of iron, nickel or cobalt. This arrangement keeps the domains pointing in the same direction.

An object containing iron can be made into a temporary magnet by rubbing it against a permanent magnet. You can try this by using a pin or paper clip. By experimenting, you will notice that the magnetic effects wear off after a short time as the domains in the pin or paper clip return to their random pattern.

A magnetic field is the area around a magnet where its magnetic forces act.

A magnetic field passes through other objects. For example, a magnet will attract other magnetic objects through paper, wood, water, etc.

You can observe how this field affects other magnetic objects by moving a compass around a magnet. Notice that the compass needle moves in different directions, or not at all, depending on where it is.

Another way to visualize the magnetic field is to place a piece of stiff paper on top of a bar magnet. Then, sprinkle iron fillings on top of the paper. The filings will line up around the magnet. These lines of filings form a model of the magnetic field.

We said earlier that magnetism and electricity are related. To better understand this relationship, it is necessary to know about atoms.

In ancient times, the Greeks believed that everything was composed of tiny particles which could not be divided. They called these particles atoms.

Today, scientific research has shown that there are many types of atoms. Each different type composes an element. Elements exist on their own or they can combine with other atoms to form everything in the universe— all solids, gasses and liquids.

In modern times, scientists have identified smaller particles which make up the atoms. Chief among these are electrons, protons and neutrons. All atoms have a center, called a nucleus. The centers, or nuclei, of all atoms have one or more protons, and often, neutrons, too. Atoms also have at least one electron which moves around the nucleus.

The nuclei of some atoms are heavier (more protons and neutrons) than others. Heavier atoms have more electrons spinning around them.

Some materials allow electrons to move from one atom to the next. They are call conductors because they conduct electrons.

Atoms of conductors are said to be loosely held. This means that the nuclei of these atoms do not hold the electrons in a tight orbit, and the electrons fly away from the nucleus of one atom to the orbit of the next atom. This movement causes an electron from the orbit of the second atom to jump to a third, and so on.

We call a stream of moving electrons electricity.

Some good conductors of electricity include elements like gold, silver, iron, copper and aluminum. Combinations of atoms (molecules) which are good conductors include steel, and most types of water.

You are good conductor of electricity.

Materials that do not allow electrons to change orbits are said to be insulators. Their atoms are tightly held.

Plastics, cotton, glass, rubber and ceramics are all good insulators.

Other types of elements and molecules will conduct electrons under certain conditions. These are known as semiconductors. They are essential to the operation of the electronic devices we use every day, like mobile phones, CDs, televisions, radios and computers.

Electricity (moving electrons) can be produced by chemical energy in a device called a voltaic cell. We common call them "batteries"ß. Batteries most often produce a small amount of electricity, and we use them to power small appliances like portable radios, telephones, flashlights, small video games, and remote controls.

Strictly speaking, batteries are combinations of voltaic cells connected together, like a car or boat battery, to produce a stronger electrical current. Nowadays, most people call single voltaic cells batteries, too.

Most of the electricity we use at home or school is produced by machines and sent to us through wires.

The key to this method of making electricity is magnetism.

In 1820, the Danish scientist Hans Christian Oersted observed that electricity moving through a wire produced a magnetic field. He placed a copper wire carrying an electrical current on top of, and parallel, to a compass needle. He noticed that the needle turned away from the wire. Oerstead proved that a magnetic field exists around every wire carrying and electrical circuit.

Shortly after Oerstead's discovery, French scientist André Ampère found that a loop of wire which was carrying a current acted as a magnet, with north and south poles existing on either side of the loop. Increasing the number of loops increased the strength of the magnetic field.

A coil of current-carrying wire is called a "solenoid".

Five years later, William Sturgeon placed an iron core inside a solenoid and created an electromagnet. The core greatly increased the strength of the solenoid. The magnetic field of the solenoid aligned the magnetic domains in the iron.

When the current of an electromagnet is stopped, the magnetic property of the coil is turned off and the domains in the core return to their random pattern.

Can you think of reasons why an electromagnet could be more useful than a permanent magnet?

Mechanical Effects of Electricity

Just as Oerstead discovered the magnetic property of a wire carrying an electrical current, English scientist Michael Faraday discovered its mechanical properties.

Faraday stretched a flexible wire between the poles of a horseshoe magnet. When he placed a current through the wire, it moved toward one of the magnet's poles. When the direction of the current was reversed, the wire moved toward the opposite magnetic pole.

This discovery led to the invention of the electric motor. The design is much the same as Faraday's experiment. An electromagnet replaces the wire between the horseshoe magnet. The electromagnet has a fixed shaft through its center so it will spin. Here is how it works:

1. When current is sent through the electromagnet, it turns to align with the poles of the horseshoe magnet— north to south, south to north.

2. At the instant the poles align, a switch, called a "commentator" located on the shaft holding the electromagnet, reverses the flow of electricity through the electromagnet.

3 Instantly, the poles of the electromagnet reverse. Its momentum causes the electromagnet to turn in the same direction toward the opposite poles of the horseshoe magnet.

4. Switching the direction of the current each half revolution causes the electromagnet, and its shaft, to spin. It revolves many times a second.

5. The spinning shaft (connected to the electromagnet) is used to power a machine, thus converting the movement of electrons in a wire to do mechanical work.

Faraday continued experimenting and discovered perhaps the most useful property of electrical currents. He found that a moving magnet can actually cause electrons to move in a conductor. An American scientist, Joseph Henry, discovered this effect about the same time as Faraday.

The ability of a magnet to move electrons is called "induction". It is the principle of how most electricity is generated.

Faraday made a solenoid and connected it to a galvanometer, a device similar to Oerstead's wire and compass which could detect the movement of electrons in a wire by observing its magnetic field.

Faraday found when he moved the magnet one way through the solenoid (down) the electrons moved one way through the wire. When he moved the magnet the other way (up) electrons in the wire moved in the opposite direction.

A generator is a machine that produces an electrical current. Its principle is exactly the same as that of an electrical motor, except that some outside force spins the shaft turning the coils of the electromagnet.

As the coils spin, they pass through the magnetic field of the fixed magnet. This movement through the magnetic field induces an electrical current in the coil. (Remember Faraday's experiment?)

The current flows in one direction through the first half of a revolution and the opposite direction on the second half.

If the generator has a commentator to switch the direction of electrical flow (like the electrical motor we just described), the flow of electricity from the generator would be in one direction. We call this type of flow direct current or DC.

If the generator does not have a commentator, the current it produces switches direction each half revolution of the coil. We call this type of current alternating current or AC.

The electricity we use in our buildings is alternating current. AC generators in North America are designed to turn 60 times a second. This type of AC is called 60 Hz (Hertz). The direction changes 120 times each second (twice a revolution [2] x 60 revolutions a second = 120).

The shaft of a commercial generator is often connected to a fan, or turbine. The fan turns when wind, water or steam passes through it. This turning fan spins the coils, producing the electricity.

Some generating plants, fossil fuel plants, burn coal, oil or natural gas to heat water and produce steam. Others, called nuclear generating plants, use heat released by splitting atoms to produce steam. Still others, hydroelectric generating plants, use rushing water from behind dams to operate their turbines. In wind farms, generators are connected to huge windmills to power them. Wind generators are erected in places where the wind blows constantly, like mountain tops.

Electricity from generators is directed over large wires called transmission lines. These wires are easily recognizable by the tall towers that support them.

Transmission lines carry extremely large electrical currents. The current is too strong to operate our electric motors, heaters and lights. The current has to be reduced to a useful level, often more than once.

Devices called "transformers" are used to change the strength of alternating current. The current strength is often referred to as "voltage".

A transformer uses the principles of electromagnets and induction to do this job.

Transformers can either increase or decrease the voltage of a current.

Two coils are wrapped around an iron core— a kind of double electromagnet.
Current coming into the transformer goes to one coil. This is the primary coil.
Current leaving the transformer is connected to the second coil. This is the secondary coil.

Here is how a transformer works. Voltage coming into the primary coil turns the core into an electromagnet. Alternating current of the voltage in the primary coil changes the magnetic direction of the core 120 times a second. The changing electrical field of the core induces a new electrical current in the secondary coil.

If the secondary coil has fewer loops than the primary coil, a weaker electrical current is produced, This is called a step down transformer. Type is used to lower voltages from the transmission line to the user.

If the secondary coil has more loops than the primary coil, a stronger electrical current is produced. This is called a step up transformer.

Transmission lines are connected to one or more substations. These contain large step down transformers. Substations can be recognized by a high fence that surrounds them and "Danger High Voltage" signs. You can often hear a humming sound that these transformers produce.

Related safety rule: Never approach a substation. Don't touch the fence or attempt to climb in.

Smaller transformers reduce the power further before it enters a building.

These are often shaped like cans and mounted on utility poles (pole mount transformers.)

Other transformers sit on the ground. They rest on concrete pads and are enclosed in a metal box. These are called padmount transformers. Padmount transformers have a "Danger: High Voltage" sign on them. Wires coming into and coming out of padmount transformers are buried underground.

Safety rule: Never climb or play near a padmount transformer. Never dig near a padmount transformer. Never play with the lock or try to stick anything inside the metal cabinet.

Electrical wires enter a building through overhead wires, called a service drop, or through a buried cable.

Service drops and underground cables are connected to the building's electric meter. The meter records how much electricity is used at each location.