Teacher Resource Kit

Electricity and Magnetism Activities

for the Utah State Fifth Grade Science Core
STANDARD III & STANDARD IV

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Contents

Background Information - Electricity

Matter is made up of tiny particles called atoms. While there are over 100 different types of atoms, individual atoms are made up of only three different particles. These particles are called protons, neutrons and electrons. Protons and neutrons reside in the center of the atom (called the nucleus) and electrons surround the center.

Electric Forces and Static Electricity

Experiments have shown that all electrons repel each other; all protons repel each other; and all electrons attract all protons (this attraction holds electrons in the atom). Neutrons do not have any *electric* interactions with electrons, protons, or other neutrons. These interactions are called electric forces[1].

A useful way to classify interactions between these particles is to say that they have something called "electric charge." There are two kinds of electric charge. Electrons have one kind of charge which we call "negative" or "–". Protons have a different kind of charge which we call "positive" or "+", and all neutrons have no charge or "zero" charge. With this definition of electric charge, we can describe electric interactions among particles in the following way:
Particles with *like* charge *repel* each other (+ and +, or – and –)
Particles with *unlike* charge *attract* each other (+ and –)
Particles with zero charge don't interact electrically with any other particles

No other kinds of electric charge have ever been detected. For example, no one has ever found a particle that electrically repels both electrons and protons.

The **net charge** of an object is the sum of all positive charges minus the sum of all negative charges. Usually, matter has the same number of protons as electrons, so its net charge is zero. **Static electricity** results when an object has a net charge. When two dissimilar objects touch, particles with electric charge are transferred from one object to the other. One object ends up with more particles that have a negative charge than particles with a positive charge, so we say it has a net negative charge. The other object ends up with more particles that have a positive charge than particles with a negative charge, so we say it has a net positive charge.

Electric Fields

How can a proton attract an electron that is far away? An electric charge creates a "field" of influence around itself. This is called an electric field. If a particle with a charge is placed in an electric field, it will experience an electric force.

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[1] There is another interaction that holds protons and neutrons together in the center of an atom. It is called the strong force. The strong force results in an attraction between protons and protons, protons and neutrons and neutrons and neutrons. The strong force does not act on electrons and only acts over VERY short distances.

When an atom’s electrons are evenly distributed around its center, the electric fields and forces that result from its positively charged protons and negatively charged electrons exactly cancel each other *outside* the atom. However, if two or more atoms are very close to each other, the distribution of electrons can change and result in electric forces between atoms. Atoms can be bound together by these electric forces. A more detailed description of how atoms bind together requires an understanding of the principles or quantum mechanics. Two or more atoms bound together is called a molecule.

Conductors, Insulators and Electric Current

A material that contains electrons that are tightly bound to its atoms and are not free to move is called an **insulator**. Examples of insulators are; rubber, plastic, and dry wood.

Some materials contain particles with electric charge that are free to move through the material. We call this type of material a **conductor**. Examples of conductors are; metal, water with dissolved salts, humans, and plasma.

Table salt dissolves in water by separating into positively charged sodium atoms and negatively charged chlorine atoms. The reason water with dissolved salt is an electrical conductor is because it contains these mobile atoms with a net positive and negative charge. An electric current in water is not moving electrons, but is instead positively and negatively charged atoms moving in opposite directions.

Plasma is a mixture of negatively charged electrons and positively charged atoms. A gas will become a plasma at very high temperatures. Examples of plasma are; part of a candle’s flame (see a demonstration of this at https://www.youtube.com/watch?v=a7_8Gc_Llr8), the inside of fluorescent light bulbs, the ionosphere (a layer in Earth’s atmosphere), and the Sun and other stars.

Electric current is the flow of particles that have electric charge. A common definition of an electrical conductor is “a material that electric currents can easily move through.” While this definition is not wrong, it does not aid in understanding and it can contribute to a common misconception about electric current. This misconception is that a battery or generator introduces electrons into one end of the circuit and then the electrons move rapidly to the other end of the circuit.

In reality, the speed of electrons that make up an electric current is very slow. In the battery-and-bulb circuit in the Electric Current activity, their net speed is only about 2 millimeters per minute. At that speed it would take an electron nearly 90 minutes to move through the circuit.

If electrons move so slowly in a circuit, why does the light bulb light up as soon as the connection is made? It's energy in the circuit that flows quickly, not electrons. When a wire is connected to a battery (or a switch is closed), an electric field moves at nearly the speed of light through the circuit and forces all the mobile electrons that are *already in the wire* (including those in the light bulb filament) to start moving.

A common misconception is that in a circuit, moving electrons carry the energy throughout the circuit. In reality, most of the energy in a circuit is in the electric and magnetic fields that are in and surround the elements of the circuit (wires, light bulbs, etc.). These fields carry the energy from the battery or the generator to all the circuit elements.

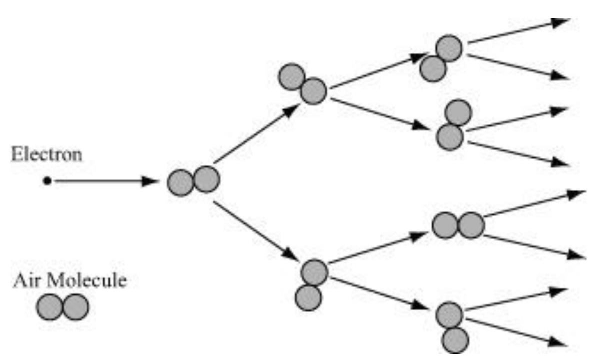
In contrast, even though electric fields are produced when charged particles are transferred between two insulators, giving each a net charge, there are no charges within insulators that are free to move in response to these electric fields. Therefore an electric current will not flow thorough an insulator under normal circumstances. However, if there are very large electrical fields present, this is not always true. Two common examples where a current flows through what was an insulator are sparks and lightning.

Sparks and Lightning

A spark will sometimes occur when you touch a piece of metal like a doorknob after moving your feet across carpet. This spark results from the movement of particles with electric charge through the air. How can that happen? Isn't air an insulator? A conductor is a material that has particles with electric charge that are free to move through the material. So, to turn a portion of the air into a conductor, we need to create particles in the air with electric charge that are free to move.

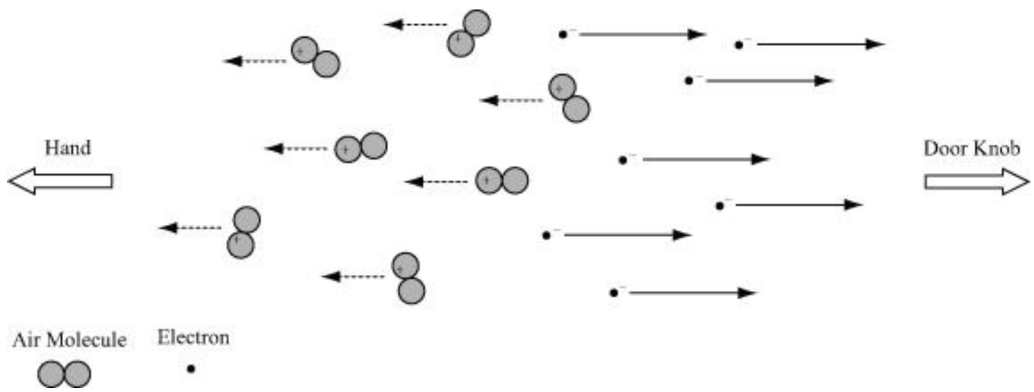
How could that happen? Walking on carpet can transfer electrons (or molecules with a negative charge) on to the bottom of your shoes. These attract positively charged molecules within your body towards your shoes, leaving the upper part of your body, including your hands, with a negative charge.

As your hand approaches a metal doorknob, your negatively charged hand repels electrons in the metal, so electrons in the metal move to the other side of the knob. This leaves the side of the knob closest to your hand positively charged. As your negatively charged hand gets very close to the positively charged side of the metal, there is VERY strong electric field in the air between your hand and the metal. Any free electrons in the air are strongly repelled by the negative charges in your hand and strongly attracted to the positive charges in the metal. If the electric field is strong enough (greater than about 3000 volts per millimeter), these electrons will move fast enough to knock electrons out of any air molecules they happen to run into.



If the electric field is strong enough, a free electron will gain enough energy to kick an electron out of an air molecule. There are now 2 free electrons, then 4, 8, 16, 32…a chain reaction.

These new electrons are also attracted to the metal doorknob and they collide with more molecules, eventually creating an avalanche of electrons moving quickly toward the metal and positively charged air molecules moving toward your hand. This sudden flow of particles with electric charge between your hand and the metal is called a static discharge or spark.



A small piece of air is now a conductor as it contains mobile charged particles; a spark is formed

As electrons recombine with positively charged air molecules, they give off light, which is the light you see in a spark.

In lightning, clouds develop regions of positive and negative charge due to a process that is not completely understood but involves the movement of air molecules, water drops, and ice particles. Electrons are usually concentrated at the base of the clouds, and positively charged particles are concentrated at the top. Electrons in the clouds repel electrons on the ground beneath them, so the ground below the clouds becomes positively charged. A conducting path through the air is created by a process similar to that in a spark except that it occurs in short steps, which is responsible for a lightning bolt's jagged shape. When this conducting path reaches the ground, a large and deadly current will flow between the cloud and the ground as a lightning bolt.

Direct Current and Alternating Current

Electric current in a circuit powered by a battery flows in one direction. This is called **direct current**. The following *incorrect* statement comes from a "Guide to Science" written for middle school aged students. "These metal wires enable electrons to flow from the power stations to and through our home wiring." What is wrong with this statement? Generators in power stations produce **alternating current**. In alternating current, electrons do not flow through the wires, but instead electrons already in the wire move rapidly back and forth (60 times per second) over very short distances. They do so in response to alternating electromagnetic fields that flow in and around the metal wires from the power plant's generators into our homes.

Background Information - Magnetism

Properties of Permanent Magnets

- Magnets attract iron (also nickel and cobalt).
- There are two points on opposite sides of the magnet called "poles", where these metals are attracted most strongly.
- When a magnet is free to move, one pole will turn to point north. The pole of a magnet that points north is called a "north pole". The pole of a magnet that points south is called a "south pole
- Opposite poles attract, like poles repel
- A magnet touching a piece of iron can turn it into a temporary magnet.
- When a magnet is cut into smaller pieces, each smaller piece has both a north and a south pole.

Magnets can attract objects made of iron or steel (which is mostly iron) that are short distances away with touching. The attraction can also pass through objects such as a wooden desktop, a book, or a person's hand. Two magnets also attract and repel each other without touching.

From the third property listed above we can conclude that:

- A compass is simply a magnetized needle that is placed on a pivot so that it can swing freely
- Earth itself must be a huge magnet

Magnetic Earth

Earth's magnetic poles are not in the same location as Earth's north and south poles (these are called geographic poles). One magnetic pole is located in northern Canada, several hundred miles south of the geographic north pole, and the other magnetic pole is on the Antarctic continent, several hundred miles north of the geographic south pole.

Because the north pole of a magnet points north, the magnetic pole near the north geographic pole must be a south magnetic pole! (Remember, opposite poles attract). The magnetic pole near the south geographic pole is a north magnetic pole. The location of the magnetic poles changes over time.

Magnetic Fields

How can a magnet attract or repel another magnet that is far away? A magnet creates a "field" of influence around itself. This is called a magnetic field. If a magnet or piece of iron is placed in a magnetic field, it will experience a magnetic force. If a magnet is free to move and it is placed in a magnetic field, it will turn and line up with the magnetic field.

The magnetic field of Earth has a pattern that looks similar to that of a bar magnet, although there are differences. Near the magnetic pole in the northern hemisphere, Earth's magnetic field dips downward toward the ground.

Electromagnets
In 1820, Hans Christian Ørsted discovered that an electric current can defect a compass needle. So, an electric current (or moving particles that have a net charge) creates a magnetic field. That discovery has allowed us to create magnets that can be tuned on and off. These are called electromagnets.

While the magnetic field from an electric current in a wire can change the direction of a compass needle, it is not normally strong enough to attract objects made of iron. The magnetic field from an electric current can be made MUCH stronger by having the current loop around a piece of iron. Electromagnets are made by wrapping an insulated wire around a piece of iron. The strength of the electromagnet depends on the amount of current in the wire, the number of coils of wire (and how close together the coils are wound), and how well the iron in the core responds to the magnetic field.

Evidence from seismic waves and other things suggest that Earth has a core made of iron. The inner part of the core is solid but the outer part of the core is liquid. Scientists think Earth's magnetic field is created by electric currents in Earth's liquid outer core, so Earth a giant electromagnet.

Magnetic Interactions and Electric Interactions
While there are similarities, magnetic interactions are different from electric interactions. Student interviews conducted by researchers reveal that many students do not distinguish clearly between electric and magnetic effects. For, example, many students will predict that north magnetic poles will repel positive electric charges. To clarify this you may wish to have students bring an "electrified" tape near both poles of a magnet so that they can discover that it is attracted to both poles, the same as it is with any other object with zero net charge.

It may also help to ask students if the magnetism of a permanent magnet is created or changed by rubbing it with another material or if its magnetism is "drained away" when it is handled (as charged particles are quickly drained away when a charged conductor is touched).

Magnetic Materials
Iron, nickel, and cobalt are elements that are strongly attracted to magnets. A piece of one of these metals (nickel and cobalt are much less common than iron) can also be turned into a temporary magnet when it touches a permanent magnet or when it is placed inside loops of wire that has an electric current. How does this happen?

<u>A Simplified Explanation</u>
In addition to having an electric charge, electrons also behave like tiny magnets. Inside a piece of iron, there are regions smaller than a grain of sand where the magnetism of some electrons in each iron atom line up in the same direction. This makes each tiny region behave like a magnet. Normally, the magnetism in regions next to each other arrange themselves to cancel each other's

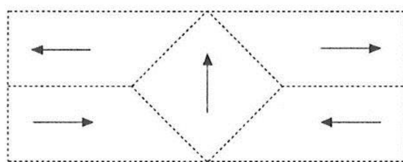
magnetism. However, if the iron is placed in a magnetic field (by placing it next to a permanent magnet or inside loops of a wire that has an electric current), the magnetism in many of the regions will change and line up with the outside field. This turns the iron into a magnet.

<u>A More Detailed Explanation</u>

In experiments, when electrons, protons and neutrons move through a magnetic field, they are deflected like they are tiny magnets. This inherent magnetism they possess is called a magnetic moment. The magnetic moment of an electron is much stronger than that of a proton or neutron*, so electrons are primarily responsible for magnetism in magnets. In most atoms, the magnetic moments of particles near each other line up in opposite directions so that the magnetism of one particle cancels the magnetism of the other. However, this is not the case in certain atoms like iron, nickel and cobalt when they combine to form a solid. For these atoms, the way they bind together causes the magnetic moments of the outermost electrons within an atom to line up in the same direction as the outermost electrons in the atoms next to it. This occurs throughout very small regions 0.001 to 0.1 mm across called magnetic domains.

This makes each domain behave like a tiny magnet with a north and south pole. Normally, domains within an object orient themselves to cancel one another's fields. So, an object like an iron nail has no overall magnetic field.

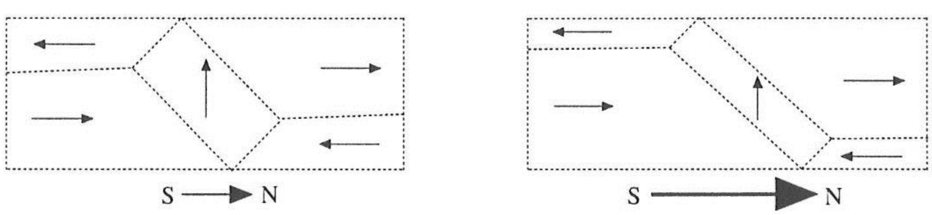
Domains in a Pure Single Crystal of Iron



Magnetic domains with no external magnetic field.
(Arrows show direction of each domain's magnetic field).

When exposed to an outside or external magnetic field, the magnetic moments of some electrons will change to align with the magnetic field. In the diagrams below, notice how domains aligned with the outside magnetic field grow, while domains aligned in other directions become smaller. This gives the whole object a magnetic field. The resulting magnetic field can be hundreds of times stronger than the field causing the alignment.

Domain Walls Move in Response to an External Magnetic Field



Magnetic domains in an external magnetic field   Magnetic domains in a stronger magnetic field.
(Large arrow shows direction of external field)

*The magnetic moment of an electron is 658 times larger than the magnetic moment of a proton and 961 times larger than the magnetic moment of a neutron.

Permanent Magnets

Examples of elements that combine to make strong permanent magnets are; Iron Oxide, Neodymium-Iron-Boron, Samarium-Cobalt or Aluminum-Nickel-Cobalt. During the manufacturing process, that materials that make up the magnet are exposed to a strong external magnetic field so the domains will align and give the magnet a permanent magnetic field.

Static Electricity

STANDARD IV: Students will understand features of static and current electricity.
Objective 1: Describe the behavior of static electricity as observed in nature and everyday occurrences.

Materials:

- "Invisible" Tape
- Static Electricity Worksheet
- Pencil

The worksheet has detailed instructions for this activity. While students could be asked to read and follow the instructions, experience in testing this activity in classrooms suggests that it works best if the teacher gives verbal instructions while also demonstrating each step.

<u>Below are some tips and more detailed information</u>.

Remind students to rub the base tape each time before placing another tape on it.

If a student group's experiment does not happen as expected, have them repeat it.

If a student is having difficulty "de-electrifying" an L-U combination tape, suggest rubbing it very slowly.

Why is it important to rub the base tape with your finger each time? How does rubbing the L-U combination tape "de-electrify" it?
Your skin is covered by a very thin layer of salt water (or a thicker layer if you are sweating). When you rub your finger on an "electrified" tape, atoms on your skin that have a net electric charge that is opposite to the charge on the tape are pulled on to the tape. This will continue until there are equal amounts of positive and negative charge on the tape and the tape becomes neutral or has zero net charge.

For the portion of the activity in which students (in groups of two) test the interactions of L and U tapes, it works well to have each student take one of the L-U combination tapes and, after making their predictions, separate their L and U tapes and immediately bring their L tapes together and then bring an L and U tape together.

After the students observe the interactions between all the tapes they are asked to "Figure out an explanation for the behavior of U and L tapes and then write it." Their explanation should account for the interaction of U tapes with each other, the interaction of L tapes with each other and the interaction between U and L tapes. It is important that they support their conclusions with evidence from their experimental observations. Hopefully they will conclude that "like" tapes repel and "unlike" tapes attract. If they have trouble with this, it may help to ask them to summarize what happened in each experiment. They should also note that both tapes are attracted to other objects.

In a discussion about their explanations, you may wish to ask if the L-U combination tape was 'charged" or "electrified" before it was pulled apart. [No] What do the experiments tell us about the charge on each tape after the L-U combination tape is pulled apart? [The charge is different on each tape]

Repulsion and attraction between tapes can be accounted for a property that we call "electric charge". When two dissimilar objects touch, particles with electric charge are transferred from one object to the other. The smooth and sticky sides of tape are dissimilar. So, when pulled apart, the L tape will end up with the opposite charge of the U tape.

How can we explain the attraction to other objects? Below are notes to help with a class discussion about this.

<u>Discussion Points (this information is in the notes section of the Static Electricity power point).</u>
Why are "electrified" or "charged" objects attracted to other objects?
When the "orbits" of an atom's electrons are centered on its protons, the electric forces that result from its positive protons and negative electrons exactly cancel each other <u>outside</u> the atom. (The word "orbits" is in quotes because electrons do not orbit the nucleus the same way that planets orbit the Sun).

Let's look at an example where the tape has a net negative charge. *How will the negative charge on the tape interact with the atom's protons? [Attract] How will the negative charge on the tape interact with the atom's electrons? [Repel]*

When a negatively charged tape is brought near an object, the electrons in the atoms of that object are repelled and shift away from the tape by a small amount. So, there is a slightly higher probability of finding them on the opposite side of the atom. Atoms in the object are slightly distorted as the electron "orbits" are centered on a point farther away from the tape than the atom's protons.

Because the atom's protons are now closer to the tape than the center of the electron "orbits", the attractive force (between the positively charged nucleus and the negative charges on the tape) is slightly stronger than the repulsive force (between all the atom's negatively charged electrons and the charges on the tape) and the tape is attracted to the object.

Electric Current and Circuits

STANDARD IV: Students will understand features of static and current electricity.
Objective 2: Analyze the behavior of current electricity.

Materials:

- Flashlight Bulb
- D-Cell Battery
- Copper Wire
- Aluminum Wire
- Plastic wire
- String
- Worksheet
- Pencil

Experiment 1: Lighting a light bulb

Using ONLY one battery, one light bulb, and one copper wire, students should experiment and figure out how to light the light bulb. Students should sketch each arrangement they try in the corresponding section of the worksheet. There are four different arrangements that light the bulb.

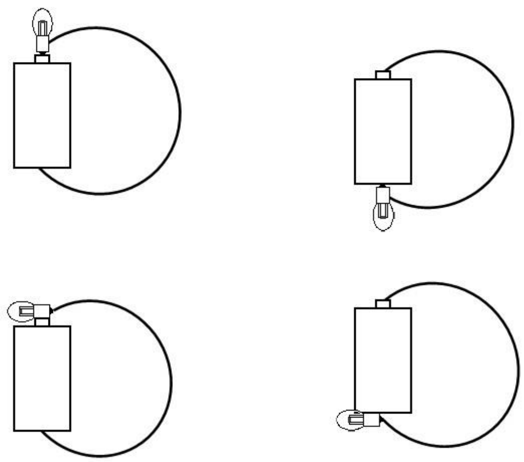
Instruct the students to make a careful enough drawing so that we can determine what parts of the light bulb and battery are touched by the wire.

It is important to warn students about short circuits. (A short circuit occurs when the wire touches both the positive and negative terminals of the battery). Tell them if they wish to try an arrangement where the wire touches both ends of the battery, they should leave it connected for no more than 5 seconds. A short circuit will drain the energy from the battery quickly and the battery will get hot.

It is important that students be allowed to struggle with the process of trial and error. Once one group has figured out one of the arrangements that light the bulb, it is up to the teacher if they may share that information with other groups.

The next part of the activity is designed to help students describe or explain observations carefully (ILO 4b). This will also hopefully reinforce in the minds of all students the details of each circuit.

When all the groups have found all four arrangements, draw four diagrams of a battery on the whiteboard, smartboard or chalkboard. Ask a student from one of the groups to describe verbally how specifically the wire, battery and bulb are touching each other in one of the arrangements. Questions to help a student that is struggling with this are; “What part of the bulb is touching the battery?” and “What part of the bulb does the wire touch?” Here is an example of a sufficiently detailed description: “The bulb is sideways with the side of the bulb touching the top of the battery. One end of the wire touches the bottom of the battery and the other end of the wire is touching the bottom of the light bulb.” As the student describes the arrangement, draw it on the board. Then repeat this with three other students so that all four arrangements are drawn correctly.



Ask, how are they similar? They are similar in that all four arrangements that light the bulb have one end of the wire touching one terminal of the battery and the other end touching one of the metal parts of the light bulb, while the other metal part of the light bulb touches the other terminal of the battery.

In Experiment 2 on the back of the worksheet, students are asked to use one of the arrangements they found that lights the bulb to test if other materials besides copper wire will light the bulb. Remind them to pick one of the arrangements that lights the light bulb and draw it on the worksheet and then make their predictions before conducting the experiments.

Using the slide in the PowerPoint presentation, discuss conductors and insulators with class. Then, have the students answer the question at the bottom of the worksheet.

Two things that the working circuits (light bulb, battery and wire) have in common:
1. There is a closed or complete circuit.
2. Each part of the circuit is a conductor.

Exploring Magnets

STANDARD III: Students will understand that magnetism can be observed when there is an interaction between the magnetic fields of magnets or between a magnet and materials made of iron.
Objective 1: Investigate and compare the behavior of magnetism using magnets.

Materials:

- Magnet
- Compass
- Iron Nail
- Copper Wire
- Aluminum Wire
- Plastic wire
- Paper Clips
- Paper
- Pencil

One of the goals of this activity is to have students plan and conduct simple experiments (ILO 1.f) that will allow them to discover some of the properties and behavior of magnets. Another goal is to help them develop the ability to record data accurately, choose an appropriate form to record it, and describe their observations carefully (ILO 4).

Before they begin the activity, students should be led to establish the north-south direction in the classroom.

Some students may hold the misconception that directions on Earth are defined by the direction of a compass. Directions are actually defined by Earth's rotation. Earth spins once each day around an imaginary line that passes through Earth's center. The two locations where this line intersects Earth's surface are called the North Pole and the South Pole. North and south are defined as the directions to each of these points. In the Northern Hemisphere, the north direction can be found as the direction to the North Star, Polaris, or as the direction of the shortest shadow cast by a vertical stick during the day time. Both of these phenomena are a consequence of Earth's rotation.

Each student should have a piece of paper to record the results of their experiments. There is no worksheet for this activity. Students are expected to select a format to record the results of their experiments. While two examples (full descriptive sentences or a chart) are given in the power point presentation for this activity, more examples may be helpful. The teacher could remind students of pervious activities where they recorded results and how that was done in each case. Regardless of the format used, what a successful student writes should provide a reasonably clear description of the experiments and observations.

Remind students to record only the results of their experiments. They should not write down what they think they already know about magnets.

Students will begin their experiments using a tiny magnet also known as a compass, an iron nail, a piece of copper wire, a piece of aluminum wire, a piece of plastic wire, and three paper clips made out of steel (steel is mostly iron). In the beginning, they should only use these objects. Later, they can use other objects in the room.

As steel in a student desks will attract the compass needle, it is important to point out to students that in order to make observations of what the tiny magnet (compass) will do when it is by itself, they should hold it horizontally in their hand away from other objects, including their desks. After observing what the tiny magnet (compass) will do when it is alone, they can then make observations of how other objects, like a desk with metal, will affect the magnet.

Warn students not to hook the paper clips together or bend them in any way.

It is important to allow students time to explore the behavior of the tiny magnet (compass) before giving them a cow magnet. **Warn students that the cow magnets should be kept away electronic equipment, computer monitors, cards with magnet stripes, etc.**

As they are experimenting and making observations, it is helpful to walk around and ask each student group if they have observed what the compass does when it is by itself.
Note: in many of the compasses the red half of the needle points north but in some, the white half of the needle points north.

It may be helpful as you are observing the students to ask an individual group what kind of interaction they observed between _______ and _________ (e.g. between the compass and the copper wire, the compass and each end of the cow magnets, a paperclip and the nail after the nail has been in contact with the cow magnet).

At the end of the exploration, have each group get with another group so they have access to two cow magnets. Have each student take one cow magnet in each hand and then experience what happens when they bring both magnets together. They should bring both magnets together again after turning one of the magnets around and continue until they have tried all four possible combinations.
"It is important for such students to feel for themselves the attraction between two magnets on being pulled apart in appropriate orientation or the repulsion when pushed toward each other." - Arnold B. Arons (a leader in physics education research)

How a Magnet Can Save a Cow's Life
Cows have four-chambered stomachs for digestion. A farmer will place a magnet down a cow's throat (with a device used for feeding cows pills) and the magnet will end up in a part of the stomach called the reticulum. If a cow happens to swallow a piece of metal such as a nail or a small piece of wire while eating, it will be attracted to the magnet and that will keep it from damaging the stomach wall. That will prevent the piece of metal from injuring or even killing the cow.

Mapping Magnetic Fields

STANDARD III: Students will understand that magnetism can be observed when there is an interaction between the magnetic fields of magnets or between a magnet and materials made of iron.
Objective 2: Describe how the magnetic field of Earth and a magnet are similar.

Materials:

- Magnet
- Compass or Magnaprobe
- Worksheet
- Pencil
- Tape

The goal of this activity is for students to conduct an investigation to gather evidence that a field exists surrounding a magnet and then create a model that describes a magnet's magnetic field.

Procedure

1. Place the worksheet on a table or desk. Make certain that you don't have any iron, steel or anything that will attract a magnet under the table or desk.

2. Tape the magnet in the center of the worksheet.

3. Place a compass at some location on the paper. Note the direction of the compass needle. If using the Magnaprobe, place the Magnaprobe at some location on the paper. Note the direction the red end of Magnaprobe is pointing. (It works best to hold the Magnaprobe with the handle pointing toward the ceiling and the large oval resting somewhere on the paper).
Note: Avoid touching other magnets with the Magnaprobe's test magnet. If you do so by accident, hold the Magnaprobe's test magnet while you pull it off the larger magnet. Do not simply pull back with the handle as parts of the device could be bent or damaged.

4. Draw a short (about 1 cm long) straight arrow at this location on the paper in the same direction as the compass needle or Magnaprobe magnet.

5. Move the compass or Magnaprobe to a different location on the paper and repeat the process.

Students should make at least as many measurements as there are dots on the worksheet (70). More than 70 measurements are encouraged. They should also, at minimum, make measurements throughout the region with the dots. Encourage students to make measurements at locations that will reveal the pattern of the magnetic field and not make all their measurements on the dots. Measurements can also be made anywhere on the paper outside the region of the dots. A pattern should be apparent. If any arrows don't seem to fit the pattern, test that place again.

After making their measurements, students should verify that their lines are correct by quickly moving the compass or probe all around the magnet again.

The Magnetic Field Demonstrator can also be used to reveal the shape of a magnet's magnetic field. A document camera is a good way to display this.

On slide 16 of the Magnetic Fields PowerPoint presentation, the diagram in the upper left is not a very accurate representation of a bar magnets magnetic field. If you use the PowerPoint presentation, you may wish to ask the students if they think that diagram is an accurate representation of a bar magnets magnetic field.

William Gilbert conducted investigations on magnetism from about 1581 to 1600 and published results in "De Magnete" in 1600. Gilbert observed that when a small compass needle was moved about the surface of a spherical magnet, it faithfully reproduced the behavior of a compass needle on Earth's surface. Gilbert's experiments convinced him that Earth itself was a giant magnet. The magnetic field of Earth has a pattern that looks similar to that of a bar magnet, although there are differences.

Electromagnets

STANDARD III: Students will understand that magnetism can be observed when there is an interaction between the magnetic fields of magnets or between a magnet and materials made of iron.
Objective 1: Investigate and compare the behavior of magnetism using magnets.

Materials:

- D-Cell Battery
- Battery Holder
- 3-inch Iron Nail
- Wire (2 feet long)
- Paperclips
- Worksheet
- Pencil
- Electromagnet or electromagnet video

Demonstrate an electromagnet or show video of an electromagnet.
http://www.youtube.com/watch?v=6yhNOXQkMpY

Asks students how they think it works.

Clarify students' ideas to be sure that students know that an electromagnet is a type of magnet that uses electricity. The electricity turns an iron core into a temporary magnet that can be turned on and off.

Explain that in order to turn an iron core into a magnet, electricity needs to flow around an iron core. This will make electrons in the iron core align, and turn the iron core into a magnet.

The challenge for student groups is to build a circuit that creates an electromagnet. Ask students how they can test that they have created an electromagnet? [It will attract paperclips]

It is important to warn students about short circuits. (A short circuit occurs when the wire touches both the positive and negative terminals of the battery with nothing else in the circuit). As they test a particular circuit, they should leave the wire connected to the battery for no more than 5 to 10 seconds. A short circuit will drain the energy from the battery quickly and the battery will get hot.

If a group of students struggles initially with what to do, remind them that electric current needs to flow around a piece if iron. Then ask, "Where is the current in a circuit?" [In the wire] "If current flows in the wire, what would you have to do to the wire to make the current go around the nail?" [Wrap the wire around the nail.]

After a group has successfully made an electromagnet, they should draw a diagram (with labels) of it on their worksheet.

Have groups share their observations.

Ask groups how many paperclips their electromagnet picked up. Discuss the variance.

Ask how could you make the electromagnet stronger? Record ideas on board.

Engineering Design Challenge

Although engineering design is similar to scientific inquiry, there are significant differences. For example, scientific inquiry involves the formulation of a question that can be answered through investigation, while engineering design involves the formulation of a problem that can be solved through design. – *Next Generation Science Standards* (http://www.nextgenscience.org/three-dimensions)

Science and Engineering Practices
(http://ngss.nsta.org/Practices.aspx?id=6)

The goal of engineering is to solve problems. Designing solutions to problems is a systematic process that involves defining the problem, then generating, testing, and improving solutions. This practice is described in the Framework as follows.

In engineering, the goal is a design rather than an explanation. The process of developing a design is iterative and systematic, as is the process of developing an explanation or a theory in science. Engineers' activities, however, have elements that are distinct from those of scientists. These elements include specifying constraints and criteria for desired qualities of the solution, developing a design plan, producing and testing models or prototypes, selecting among alternative design features to optimize the achievement of design criteria, and refining design ideas based on the performance of a prototype or simulation. (NRC Framework, 2012, p. 68-69)

Elementary School (3-5)
Constructing explanations and designing solutions in 3–5 builds on K–2 experiences and progresses to the use of evidence in constructing explanations that specify variables that describe and predict phenomena and in designing multiple solutions to design problems.

- Construct an explanation of observed relationships (e.g., the distribution of plants in the back yard).
- Use evidence (e.g., measurements, observations, patterns) to construct or support an explanation or design a solution to a problem.
- Identify the evidence that supports particular points in an explanation.
- Apply scientific ideas to solve design problems.
- Generate and compare multiple solutions to a problem based on how well they meet the criteria and constraints of the design solution

Electromagnet Background Information
The strength of an electromagnet depends on the amount of current in the wire, the number of coils of wire per unit length, and how well the iron in the core responds to the magnetic field. As

the iron cores in this activity are nails, it is likely that they will all respond in a similar way to a magnetic field. Therefore, the advantage of one over another is the ease with which the wire can be looped tightly around the nail in order to give the greatest number of turns for the length. Since what counts is the number of loops of wire, the wire length itself is only important if increased length allows for more loops around the nail.

To get the strongest magnetic field at one end of the nail, it helps to wrap all the turns near that end of the nail, building up multiple layers of windings. Adding additional batteries to increase the current will also increase the strength of the electromagnet.

Design Challenge for Student Groups:
Build an electromagnet that can pick up the largest number of paperclips.

Supplemental Materials:
- 4-inch Iron Nails
- 6-inch Iron Nails
- Wire (4 feet long)

Students can use the class's ideas from the end of the Electromagnet Activity to form a design hypothesis.

Things they could change or vary: length of wire, material of core, number of winds around core, how closely together the winds around core are, or number of batteries.

Discuss with the students the importance of changing only one thing at a time, so they can determine what each change does to the strength of the electromagnet. Everything else should be kept the same.

The following are steps that students might follow in the design challenge.

<u>Research</u>
Learn the science needed to know how a device works.

<u>Brainstorm, Select Ideas – Develop a Hypothesis</u>

<u>Build</u>
Actually building an early version of a product, called a prototype, is a first important step. As the prototype is being built, designers sometimes see how things could be arranged differently, or it may give them a new design idea.

<u>Test and Evaluate</u>
After the prototype is built, designers test their inventions. The prototype's performance is then compared to the list of design criteria. Ask, is the prototype is finished? Does it need any changes? What changes should be made? Or, should it be scrapped for a different idea?

Iterate – repeat the process

Designers are not afraid of failure early in their work because they can figure out how things failed, learn from those mistakes, and then make improvements. Iterate means to repeat this design cycle, making improvements each time.

Students should have the opportunity to make at least two or three changes to their design. The total number of iterations allowed is a decision best made by the classroom teacher.

At the conclusion of the activity, each student should summarize what they learned by making a claim about what design feature or features are most important in building an electromagnet that can pick up the greatest number of paperclips. They should state the evidence that backs up their claim and provide the reasoning that connects the claim to the evidence that supports it.

Here is an example:

The Case of the Missing Toy

A student returns home from school to find a favorite toy missing. After an investigation, they present the following claim to a parent.

Claim: The student's younger sibling has taken the student's toy.

Evidence: The student observed their toy in the drawer where it is normally kept before they left for school in the morning. A dirty handprint, the same size as the hand of the younger sibling was found on the outside of the drawer. The student's toy was found in the younger sibling's room.

Reasoning: The fact that the toy was in its proper place before school and not afterwards proved that someone must have taken it. Since there is a handprint from the younger sibling on the drawer where the toy is kept AND the toy was found in the sibling's room, the sibling must have committed the crime!

Claim – What do you know?

The claim is usually one sentence in length. It is a statement that answers the original question.

Evidence – How do you know that?

Evidence can come from their own group or another group in the class.

Reasoning – Why does you evidence support your claim?

It shows why the data they chose counts as evidence. It should also show an understanding of the scientific principles involved and use correct science vocabulary. The reasoning is usually a few sentences in length.

Claim, Reasoning and Evidence Statement Rubric
Component Level 0 1 2

Component	Level		
	0	1	2
Claim – statement or conclusion that answers the original question/problem.	Does not make a claim, or makes an inaccurate claim.	Makes an accurate but incomplete claim.	Makes an accurate and complete claim.
Evidence – scientific data that supports the claim. The data needs to be appropriate and sufficient to support the claim.	Does not provide evidence, or only provides inappropriate evidence (Evidence that does not support the claim.).	Provides appropriate, but insufficient evidence to support claim. May include some inappropriate evidence.	Provides appropriate and sufficient evidence to support claim.
Reasoning – justification that links the claim and evidence and includes appropriate and sufficient scientific principles to defend the claim and evidence.	Does not provide reasoning, or only provides recording that does not link evidence to claim.	Repeats evidence and links it to some scientific principles, but not sufficient.	Provides accurate and complete reasoning that links evidence to claim. Includes appropriate and sufficient scientific principles.