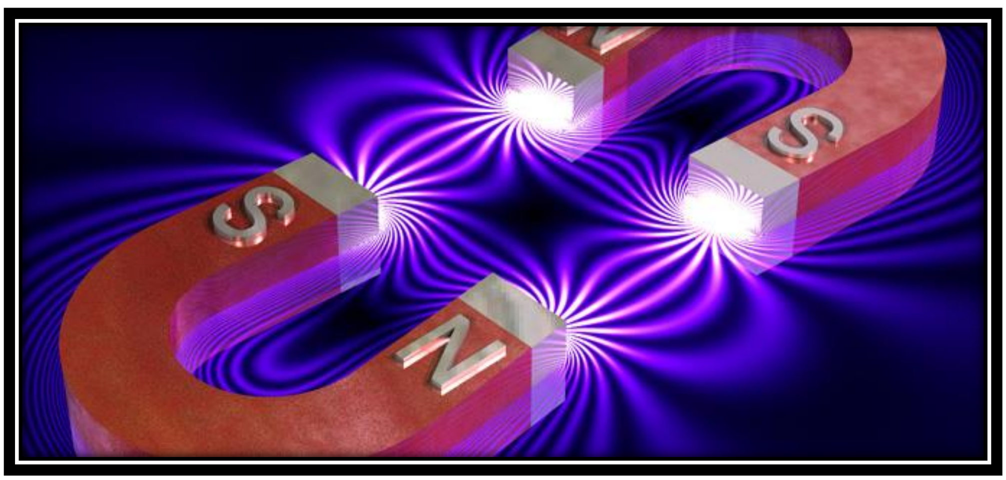
MAGNETISM

A comprehensive course that teaches the big ideas behind Maxwell's Principles. Students will discover how to detect magnetic poles and magnetic fields, learn about electromagnetism as they construct motors, generators, doorbells and earphones, and uncover the mysterious link between electricity and magnetism that marks one of the biggest discoveries of all science…ever.



Created by Aurora Lipper, Supercharged Science

www.SuperchargedScience.com

This curriculum is aligned with the National Standards and STEM for Science.

TABLE OF CONTENTS

Introduction

Greetings, and welcome to the study of Magnetism. This unit was created by a mechanical engineer, university instructor, airplane pilot, astronomer, robot-builder and real rocket scientist… me! I have the happy opportunity to teach you everything I know about electricity and magnetism over the next set of lessons. I promise to give you my best stuff so you can take it and run with it… or fly!

To get the most out of these labs, there are really only a couple of things to keep in mind. Since we are all here to have fun and learn something new, this shouldn't be too hard.

One of the best things you can do as the student is to cultivate your curiosity about things. *Why did that move? How did that spin? What's really going on here?*

This unit on magnetism is chock-full of demonstrations and experiments for two big reasons. First, they're fun. But more importantly, the reason we do experiments in science is to hone our observational skills. Science experiments really speak for themselves much better than I can ever put into words or show you on a video. And I'm going to hit you with a lot of these science demonstrations and experiments to help you develop your observing techniques.

Scientists not only learn to observe what's going on in the experiment, but they also learn how to observe what their experiment is telling them, which is found by looking at your data. It's not enough to invent some new kind of experiment if you don't know how it will perform when the conditions change a bit, like on Mars. We're going to learn how to predict what we think will happen, design experiments that will test this idea, and look over the results we got to figure out where to go from there. Science is a process, it's a way of thinking, and we're going to get plenty of practice at it.

Good luck with this magnetism unit!

For the Parent/Teacher:
Educational Goals for Magnetism

The scientific principles we're going to cover were first discovered by a host of scientists in the 19th century, each working on the ideas from each other, most prominently James Maxwell. This is one of the most exciting areas of science, because it includes one of the most important scientific discoveries of all time: how electricity and magnetism are connected. Before this discovery, people thought of electricity and magnetism as two separate things. When scientists realized that not only were they linked together, but that one causes the other, the field of physics really took off.

<u>Here are the scientific concepts:</u>

Magnets

- Magnetic fields are created by electrons moving in the same direction. Electrons can have a "left" or "right" spin. If an atom has more electrons spinning in one direction than in the other, that atom has a magnetic field.
- If an object is filled with atoms that have an abundance of electrons spinning in the same direction, and if those atoms are lined up in the same direction, that object will have a magnetic force.
- A field is an area around an electrical, magnetic or gravitational source that will create a force on another electrical, magnetic or gravitational source that comes within the reach of the field.
- In fields, the closer something gets to the source of the field, the stronger the force of the field gets. This is called the inverse square law.
- A magnetic field must come from a north pole of a magnet and go to a south pole of a magnet (or atoms that have turned to the magnetic field.)
- All magnets have two poles. Magnets are called dipolar, which means they have two poles. The two poles of a magnet are called north and south poles. The magnetic field comes from a north pole and goes to a south pole. Opposite poles will attract one another. Like poles will repel one another.
- Iron and a few other types of atoms will turn to align themselves with the magnetic field. Over time, iron atoms will align themselves with the force of the magnetic field.
- The Earth has a huge magnetic field. The Earth has a weak magnetic force. The magnetic field comes from the moving electrons in the currents of the Earth's molten core. The Earth has a north and a south magnetic pole which is different from the geographic North and South Pole.
- Compasses turn with the force of the magnetic field.

Electromagnetism

- Magnetism is caused by moving electrons.
- Electricity is moving electrons.
- Electricity causes magnetism.
- Moving magnetic fields can cause electrons to move.
- Electricity can be caused by moving magnetic fields.
- Electricity is a flow of electrons.
- A flow of electrons creates a magnetic field.
- Magnetic fields can cause a flow of electrons.
- Magnetic fields can cause electricity.

By the end of the labs in this unit, students will be able to:

- Build a simple compass and use it to detect magnetic effects, including Earth's magnetic field.
- Understand how electric currents produce magnetic fields.
- Know how to build and use an electromagnet.
- Construct electric motors, electric generators, and simple devices, such as doorbells and earphones.
- Understand that magnets have two poles (north and south) and that like poles repel each other while unlike poles attract each other.
- Differentiate observation from inference (interpretation) and know scientists' explanations come partly from what they observe and partly from how they interpret their observations.
- Measure and estimate the weight, length, or volume of objects.
- Formulate and justify predictions based on cause-and-effect relationships.
- Conduct multiple trials to test a prediction and draw conclusions about the relationships between predictions and results.
- Construct and interpret graphs from measurements.
- Follow a set of written instructions for a scientific investigation.

Master Materials List for All Labs

This is a brief list of the materials that you will need to do *all* of the activities, experiments and projects in each section. The set of materials listed below is just for one lab group. If you have a class of 10 lab groups, you'll need to get 10 sets of the materials listed below. For 10 lab groups, an easy way to keep track of your materials is to give each group a number from 1 to 10, and make up 10 separate lab kits using small plastic tubs or baskets. Put one number on each item and fill each tub with the materials listed below. Label the tubs with the section name, like *Magnetism Study Kit,* and you will have an easy way to keep track of the materials and build accountability into the program for the kids. Copy these lists and stick them in the bin for easy tracking. Feel free to reuse items between lessons and unit sections. Most materials are reusable year after year.

Materials for Standard Labs

- 9V battery with clip (RS#270-325)
- AA batteries (2)
- AA case (RS#270-408)
- Alligator wires (RS#278-1157)
- Bi-polar LED (RS #276-012)
- Chopstick
- Compass
- Donut magnet (RS#64-1888)
- Foam blocks
- Hair dryer
- Hammer
- Hobby motor, 9-18V DC (RS #273-256)
- Hot glue gun
- Insulated wire (1 foot)
- LED (Radio Shack (RS) #276-012)
- Magnet wire (RS#278-1345)
- Magnets (RS#64-1883)
- Metal screws (5 different sizes)
- Nails (9 2-3 inches long)
- Needle or pin
- Paperclip
- Plastic fork
- Propeller
- Rectangular magnet (RS#64-1879)
- Reed switch (www.sparkfun.com)
- Relay (RS#275-206)
- Rubber eraser
- Ruler
- Sandpaper
- Shallow dish or pie tin
- Small piece of foam (like a packing peanut)
- Straw
- String
- Tape
- Toilet paper or paper towel tube

Materials for Advanced Labs

- Aluminum block (the thicker the better)
- Baby oil or vegetable oil
- Candle (with adult help)
- Clean glass jar with lid
- Disposable plastic cup with lid
- Gloves and goggles
- Laser pointer (cheap key-chain work well)
- Magnet, tiny bead (www.KJmagnetics.com R211)
- Magnets, 4 donut (RS#64-1888)
- Magnet, large ceramic (RS#64-1877)
- Medicine dropper
- Metal bolt with nut and large washer
- Mirrors (2 small)
- Neodymium magnets, four ½" (www.KJmagnetics.com B888)
- Old toner cartridge from a laser printer or copy machine
- Paper or newspaper
- Pen or straw
- Plastic bag
- Popsicle stick
- Rare earth magnets, 2 (RS#64-1895)
- Rubber bands (8)
- Steel ball bearings, 9 (1/2" or 5/8")
- Thin copper wire
- Thread
- Wood or plastic ruler with a groove down the center, 12" long
- Wooden spring-type clothespin

Lab Safety

Goggles: These should be worn when working with chemicals, heat, fire, or projectiles. These protect your eyes from chemical splatter, explosions, and tiny fast-moving objects aimed at the eyes. If you wear glasses, you can find goggles that fit over them. Don't substitute eyeglasses for goggles, because of the lack of side protection. Eyeglasses don't provide this important side eye protection.

Clean up Messes: Your lab area should be neat, organized, and spotless before you start, during your experiment, and when you leave. Scientists waste more time hunting for lost papers, pieces of an experiment, and trying to reposition sensitive equipment… all of which could have easily been avoided had they been taught organizational skills from the start.

Dispose of Poisons: If a poisonous substance was used, created, or produced during your experiment, you must follow the proper handling procedures for disposal. You'll find details for this in the experiments as needed.

Special Notes on Batteries: Do not use alkaline batteries with your experiments. Find the super-cheap kind of batteries (usually labeled "Heavy Duty" or "Super Heavy Duty") because these types of batteries have a carbon-zinc core, which does not contain the acid that alkaline batteries have. This means when you wire up circuits incorrectly (which you should expect to do because you are learning), the circuits will not overheat or leak. If you use alkaline batteries (like Energizer and Duracell) and your students short a circuit, their wires and components will get super-hot and leak acid, which is very dangerous.

No Eating or Drinking in the Lab: All foods and drinks are banned from your classroom during science experimentation. When you eat or drink, you run the very real risk of ingesting part of your experiment. For electricity and magnetism labs, always wash your hands after the lab is over to rinse off the lead from the electrical components.

No Horse Play: When you goof around, accidents happen, which means chemicals spill, circuits short, and all kinds of hazards can occur that you weren't expecting. Never throw anything to another person and be careful where you put your hands – it could be in the middle of a sensitive experiment, especially with magnetism and electricity. You don't want to run the risk of getting shocked or electrified when it's not part of your experiment.

Fire: If you think there's a fire in the room (even if you're not sure), let your teacher know right away. If they are not around (they always should be), smother the fire with a fire blanket or use a fire extinguisher and send someone to find an adult. Stop, drop, and roll!

Questions: If you're not sure about something stop and ask, no matter what it's about. If you don't know how to properly handle a chemical, do part of an experiment, ask! If you're not comfortable doing part of the experiment, then don't do it.

Section 1: Magnets

What *IS* magnetism, anyway? You can feel how two north sides of a magnet push against each other when you bring magnets close together, but what IS that invisible force, and why is it there? And how come magnets stick to the fridge and not a soda can, even though *both* are magnetic? And when you run magnets down a metal ramp, they defy gravity and brake to a stop. And how come the grapes from your lunchbox twist around to align with magnets, even though there's no iron inside? There's *got* to be a reason behind this madness… would you like to find out what it is with me?

We're about to dive deeply into the mysterious world of magnetism. Although scientists are still trying to puzzle out some of its secrets, I'm going to get you up to speed on what they do know today.

Lesson #1: What's Magnetic?

Overview: Greetings and welcome to the study of magnetism! This first lesson is simply to get you to play with magnets and decide what it is that you want to learn about magnetism so we can do the really cool stuff later on.

What to Learn: Your job is to discover not only what "magnetic" means, but also what specific kinds of objects are magnetic. Magnetic fields are created by electrons moving in the same direction. Electrons can have a "left" or "right" spin. If an atom has more electrons spinning in one direction than in the other, that atom has a magnetic field. If an object is filled with atoms that have an abundance of electrons spinning in the same direction, and if those atoms are lined up in the same direction, that object will have a magnetic force.

Materials

- 1 rectangular magnet
- 1 circular disk magnet

Lab Time

1. You are to move around the room with your magnet and test several different objects to see if the magnet sticks to them. Fill out the data sheet as you go along, or do it after you've tested your different objects (your choice).

Object	What's it made of?	Does it stick to the magnet?

2. After you've completed the first data table, take a look at it. What did you find that is magnetic? What *types* of objects are magnetic?
3. Now move around again and test metallic materials and identify what kind of metal they are. Write your observations this in the second data table. Check to see if you are wearing metal.

What's Magnetic? Data Table

Metal Object	What kind of metal is it?	Does it stick to the magnet?

Reading

What Causes Magnetism? Believe it or not, electrons! Those wacky little fellows that we learned about several lessons ago are the key to magnetism. As you move further and further in your science education, you'll notice that electrons are responsible for a lot of stuff that goes on in science!

More accurately, a majority of electrons moving in a similar direction creates a magnetic field. This is how electromagnets work. Electrons are forced to move through a wire and the moving electrons cause a magnetic field. (We'll look deeper into magnetic fields in a future lesson.)

"But how are electrons moving in my magnet on my fridge? It isn't connected to any battery. What's going on there!? Don't I need electricity to have moving electrons?"

Electromagnets do have electricity flowing through them. Electricity is nothing more than moving electrons. So it's the electricity that causes the magnetic force in electromagnets.

However, most of the magnets you run across are not attached to any form of electricity. So how are the electrons moving?

Electrons move on their own. They move around the nucleus and they spin. It's the electron spin that tends to be responsible for the magnetic field in those "permanent" magnets (the magnets that maintain a magnetic field without electricity flowing).

"But don't electrons always spin? Shouldn't everything be magnetic?"

Yes, electrons are always spinning. The reason some things are magnetic and other things aren't is the balance of the spinning electrons.

Electrons are said to spin left or right. It's not quite that simple but it makes it easier to think and talk about. Most atoms have a fairly even number of left and right spinning atoms. If there's four spinning left, there's four spinning right. If there's nine spinning right, there's eight spinning left. Since they are fairly balanced, there's no net direction in which the electrons are moving. With no overall direction of movement there's no magnetic force.

However, there are a few atoms, iron being the most famous, that are not in balance. Iron has four more electrons that spin in one direction than in the other. This excess of same spinning electrons creates a net directional movement and thus a magnetic force! Nickel and cobalt are other fairly common magnetic metals.

"Aha, so everything that's made of iron is magnetic! Got it."

Well, not so fast. Yes, each iron atom is like a little magnet, but not all iron objects have a magnetic field. In fact, most don't. The reason that most objects that have iron in them are not magnetic is because the atoms are all jumbled up.

Imagine I gave you a shoe box filled with small magnets. Since I just threw the magnets in there, they are all jumbled up. Some are facing right, some left, some up and some down. Because of the jumble, the whole box may not have much magnetic force since the magnets inside are all canceling each other out.

Now, imagine what would happen if the magnets inside the box did all face the same way. If I stuck them all end to end and created a long string of magnets. Now the box would have a very powerful magnetic force, right? This is the difference between an iron nail and a magnet. The nail has iron atoms going every which way, while the magnet has iron atoms that are fairly lined up. The more lined up the iron atoms are, the stronger the magnetic force.

Diamagnetic materials (like bismuth, water, and graphite) have very weak magnetic fields. When the electrons have about the same number spinning left and spinning right, they cancel each other out and the atom has no magnetic poles. However, if you bring a magnet near, the magnetic field causes the individual electrons in the atom to move, and since moving electrons create a magnetic fields, the electrons create a magnetic field opposite to the original magnetic field and the atom moves away from the magnet. The effect is very weak, but with enough care you can see this effect in water (which is what a grape is mostly made up of).

Paramagnetic materials (like aluminum, helium, and platinum) need to be chilled in order for their magnetic fields to be noticeable. Here's why: What if the atom has more electrons spinning left than right? When this happens, the atom now has magnetic poles (north and south), and you can think of each atom like a little magnet. However, these magnets are not all lined up in the same direction, so their overall magnetic effect cancels out. If you bring in a magnet (or place the atoms in a magnetic field), the atoms start to line up in the same direction and the material starts to become magnetized. It doesn't happen quickly or easily, because the atoms still have so much energy that they keep bouncing around, even when in a solid state. So to magnetize something quickly, you need to bring down the temperature to reduce the motion of the atoms to get them to really line up. Paramagnetic materials are attracted to both ends of a magnet.

Ferromagnetic materials are the four elements (iron, nickel, cobalt, and gadolinium) that most permanent magnets are made up of. These atoms stay lined up together even when they are at temperatures that would cause other atoms to bounce out of alignment. The magnetic effects are mostly caused by the innermost electrons in the inner orbits, which all aligned the same way, and contribute the magnetic field. Some paramagnetic materials (like chromium and manganese) have atoms that pair up and cancel each other out. The north pole of one atom will line up with the south pole of another.

Exercises

1. Which objects are attracted to the magnet?
2. Are all metal objects attracted to the magnet?
3. Does the shape of the magnet matter?
4. Are things attracted to the magnet if they have to pass through something that isn't, like a piece of paper?
5. This evening, find an article or story that describes how magnetism improves our lives. Bring the article to school. If you bring in an article that no one else brings in, you get extra points.

Lesson #2: Breaking Magnets

Overview: Today, you get to break things and call it science as you investigate one of the fundamental concepts in magnetism that magnetic poles are inseparable.

What to Learn: All magnets have two poles. Magnets are called dipolar, which means they have two poles. The two poles of a magnet are called *north* and *south* poles. Opposite poles will attract one another. Like poles will repel one another.

Materials

- 2 rectangular magnets
- 1 circular magnet
- Hammer to break a magnet

Lab Time

1. Take two magnets and find the poles that repel. With a pencil, write **N** on the end of the magnets that repel each other. On the two opposite poles, write **S**. Put one **N** and one **S** end together to check to be sure they are attracted to each other. The magnets might have their poles on the top surface and bottom surface, or one at each end. How is the rectangular magnet different from the circular?

   ____

   ____

2. Grab a hammer and break one of the *rectangular* magnets. If it smashes into more than two pieces, that’s OK, but you want at least a couple of big pieces.

3. Try to piece the magnet back together. What happens?

   ____

   ____

4. Bring the unbroken magnet close to one of the pieces. Does it attract or repel? Which pole does that make this new end? Using the magnet you didn't break, label the new poles of the new smaller magnets with **N** and **S** as appropriate. What did you find?

____

____

5. Draw your broken magnet both before and after you smashed it, labeling *all* the poles with **N** or **S.**

Reading

Did you know that if you cut a magnet in half to try to separate the north pole from the south pole, you'll wind up with two magnets, each with their own north and south poles? Turns out that the poles are impossible to separate! Not only that, but if you try to puzzle-piece the magnet back together, the interlocking sections now repel each other, not attract. This lab will help you discover which part is responsible for magnets and magnetic fields.

Exercises

1. How many poles does a magnet have?
2. What happens when you try to separate the poles?
3. Were you able to put the magnet back together into one single magnet?
4. Where are the poles on the circular magnet? Is this different from your rectangular magnet?

Lesson #3: Which Way is North?

Overview: You're going to use a compass to figure out the magnetic lines of force from a magnet by mapping the two different poles and how the lines of force connect the two. A magnetic field must come from a north pole of a magnet and go to a south pole of a magnet (or atoms that have turned to the magnetic field.)

What to Learn: Compasses are influenced by magnetic lines of force. These lines are not necessarily straight. When they bend, the compass needle moves. The Earth has a huge magnetic field. The Earth has a weak magnetic force. The magnetic field comes from the moving electrons in the currents of the Earth's molten core. The Earth has a north and a south magnetic pole which is different from the geographic North and South Pole.

Materials

- Rectangular magnet
- Circular magnet
- Compass
- String
- Ruler

Lab Time

1. Tie a string around your magnet.
2. Bring it close to the compass.
3. Which end is the north end of your magnet? Label it with a pencil right on the magnet.
4. Flip the magnet around by twisting the string so that the compass flips to the opposite pole. Label the opposite site of the magnet with the appropriate letter (N or S).
5. Bring a second magnet close to the first one. What happens when you bring two opposite poles together? What if the poles are the same? Write down your observations here:

____

____

____

Now untie or cut the string for the next part of your lab.

6. Lay a piece of paper on your desk.
7. Place the magnet in the middle of the paper and trace the outline.

8. Draw 12 dots (just like on a clock) all the way around the magnet. These are the locations where you will place your compass, so make sure that they are close enough to the magnet so the magnet influences the compass.
9. Place your compass on one of the dots and look at the direction the arrow is pointing. Remove the compass and draw that exact arrow direction right over your dot. Do this for all twelve dots.
10. Draw another ring of dots an inch or two out from the first ring and repeat step 9.
11. Do this for a third ring of dots.
12. Repeat steps 6-10 with a circular magnet on a new sheet of paper.

Reading

Right under your feet, there's a magnet. Go ahead take a look. Lift up your feet and see what's under there. Do you see it? It's huge! In fact, it's the largest magnet on the Earth. As a matter of fact, it is the Earth! That's right; the Earth is one huge, gigantic, monolithic magnet! We're going to use a magnet to substitute for the Earth and plot out the magnetic field lines.

The magnetic pole which was attracted to the Earth's North Pole was labeled as the *Boreal* or "north-seeking pole" in the 1200s, which was later shortened to "North Pole". To add to the confusion, geologists call this pole the North Magnetic Pole.

You will use your compass to learn about the idea of the Earth's magnetic field. If you remember about magnets, you know that opposite attract. So the north tip of the compass will line up with the Earth's SOUTH Pole. So compasses are upside-down!

Exercises

1. How are the lines of force different for the two magnets?

2. How far out (in inches measured from the magnet) does the magnet affect the compass?

3. What makes the compass move around?

4. Do you think the compass's *north-south* indicator is flipped, or the Earth's North Pole where the South Pole is? How do you know?

Lesson #4: Flying Paperclip

Overview: In fields, the closer something gets to the source of the field, the stronger the force of the field gets. This is called the inverse square law. Those atoms are lined up in the same direction, that object will have a magnetic force.

What to Learn: The inverse-square law applies to quite a few phenomena in physics. When it comes to forces, it basically means that the closer an object comes to the source of a force, the stronger that force will be on that object. The farther that same object gets from the force's source, the weaker the effect of the force.

Materials

- Four different magnets
- Paperclip
- String
- Ruler
- Tape

Lab Time

1. Tie the string to one of the magnets.
2. Tape the end of the string to the table.
3. Bring your magnet close to the paperclip so the paperclip flies up to it.
4. Using a ruler, measure how far away your magnet is when the paperclip falls back to the table. Which part of your magnet is it most attracted to? Which part of the magnet is the strongest? That's the side of the magnet we want to use when you record your data.
5. Repeat steps 3 and 4 with all of your different magnets.
6. Complete the data table. (Don't forget your units in column 3! Did you measure in inches, feet, centimeters…?)

Flying Paper Clip Data Table

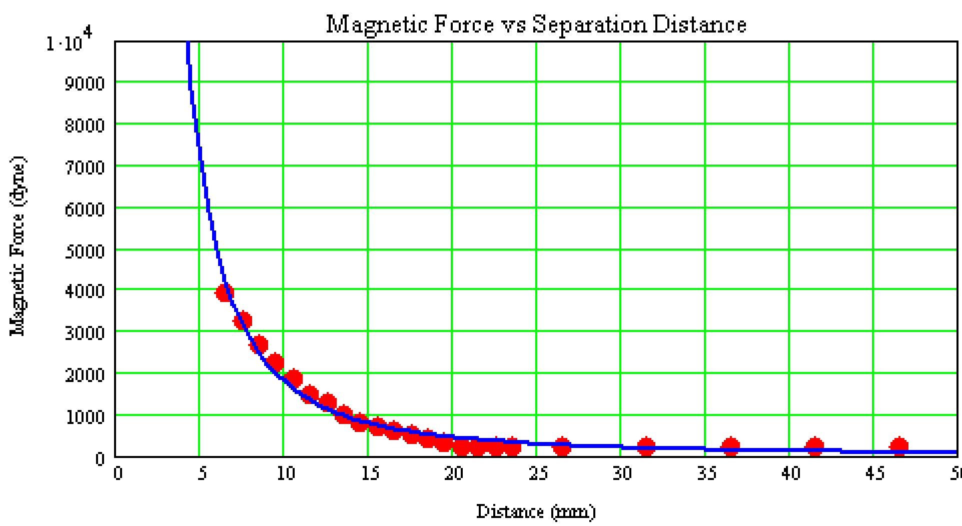
Type/Shape of Magnet	Which part is the strongest?	How far before the paperclip falls?

Reading

Have you ever been close to something that smells bad? Have you noticed that the farther you get from that something, the less it smells, and the closer you get, the more it smells? Well, forces sort of work in the same way.

Forces behave according to a fancy law called the inverse-square law. To be technical, an inverse-square law is any physical law stating that some physical quantity or strength is inversely proportional to the square of the distance from the source of that physical quantity.

The inverse-square law means that the closer an object comes to the source of a force, the stronger that force will be on that object. Mathematically, we can say that doubling the distance between the object and the source of the force makes the force 1/4th as strong. Tripling the distance makes the force 1/9th as strong.



Optional: You can see the inverse square law for yourself if you have a lightweight spring scale. Attach the scale directly to the magnet.

Place a ruler down on the table with the zero mark lined up with end of the paperclip. Take force measurements from the scale every half inch and write these down on paper. This is an excellent time to graph data by placing the force readings on the vertical scale (y-axis) and the distance measurements on the horizontal scale (x-axis). You'll see a graphical representation of the inverse square law.

Exercises:

1. Circle one: The closer you get to the magnet, the (stronger | weaker) the force of the magnetic field is on the paper clip.
2. Why does it matter which way you orient the magnet in this experiment?
3. Which magnet has the strongest magnetic field?
4. Is the north or south pole stronger on a magnet?

Lesson #5: Bouncing Magnets

Overview: Want to see a really neat way to get magnetic fields to interact with each other? While levitating objects is hard, bouncing them in invisible magnetic fields is easy. In this experiment, students will take two, three, or even four magnets and have them perform their antics.

What to Learn: We're putting together the ideas of the inverse square law and magnetic fields by having you play with the invisible magnetic lines of force.

Materials

- 3 identical magnets
- Optional: thick piece of aluminum metal

Lab Time

1. Stack two magnets on top of each other so they are all oriented in the correct direction.
2. Slide one off the top and find a magic spot where it hovers in mid-air. This takes patience, so work slowly.
3. Give the top of the floating magnet a *gentle* tap.
4. You should see the magnet vibrate in the air.
5. Using the clock or stopwatch, time how long it vibrates: ______________________________(unit of time?)
6. Now restack the two magnets and add a third. Slide the top one off and move it to the side, away from where you're working, but be sure not to flip it.
7. Slide the second magnet off and again find a magic spot where it hovers in mid-air.
8. Slowly move the magnet that's off to the side toward you. You want to add it very slowly to the other side of the non-moving magnet.
9. Give one of the floating magnets a *gentle* tap. You should not only see the magnet vibrate in the air, but the second magnet moving as well.
10. Do you notice how sometimes one floating magnet moves more, and then slows down as the other floating magnet starts to increase its movement? What do you think is going on? Write it here:

    ____

    ____

    ____

11. You can adjust your two bouncing magnets to have nearly the same "bounce" (frequency) by changing their distance apart. Notice that when one magnet starts bouncing, the magnetic field changes, which pushes and pulls on the other magnet. The two magnets interact with each other through their magnetic fields, pushing and pulling each other into resonance. How far apart are your magnets when it works best?

    ____ (units?)

12. What happens if you try floating three or four magnets?

13. If you have a sheet of metal, like an aluminum cookie sheet, hover it above your bouncing magnets. What happens? Write it here:

____

____

Reading

While this activity may seem a bit trivial (and a little fun), the idea of a magnetic field is one of the greatest leaps ever made in science.

Scientist Faraday imagined the idea that a magnet had not only a magnetic field, but that it could push and pull on other magnets ***and*** moving electric charges. This crazy idea was so wild that it took many scientists a lifetime to come to terms with it… as it replaced an older idea from Newton that had stood for centuries. And, as usually happens when someone has a new bright idea, others are quick to add to it.

Shortly after Faraday's idea about magnetic fields and electrical charges, Maxwell combined complicated mathematics (stuff you'll only see at a university) into his four famous equations (Maxwell's Equations) that describe all electric and magnetic fields.

We're going to cover eddy currents in a later lesson, but the basic idea in case your students are chomping at the bit to know about it now is that when a magnet moves near an object that conducts electricity (usually metal), it creates electric currents called *eddy currents* which start to flow in the conductor. These eddy currents create magnetic fields (electricity causes magnetism as we'll see in the next set of experiments in *Electromagnetism*) in the opposite direction of the moving magnet, slowing an object down so it appears to float. In our experiment today, the eddy currents created in the metal by the moving (floating) magnets create an opposing magnetic field that work to "brake" the moving magnet and stop it from bouncing.

Exercises

1. Why does the magnet float?

2. After you tap the floating magnet, does it vibrate for a short or long time? Why?

3. Why do we stack the magnets first before trying to levitate them?

4. How many magnets can you get to interact while floating?

5. When you float two magnets above the main magnet, how do the floating magnets interact with each other? Why do they do that?

Lesson #6: Magnetic Fields

Overview: Today you get to make your own compass to detect the Earth's magnetic field.

What to Learn: Not only how to build a simple compass and use it to detect magnetic effects, including Earth's magnetic field, but also how *not* to build a compass.

Materials

- Needle or pin
- Strongest magnet
- Small piece of foam (like a packing peanut)
- Disposable cup
- Water
- Compass

Lab Time

1. Fill a cup with water. You don't need much – just enough to float a piece of foam in.
2. Take your needle and wipe it several times on all sides with the magnet. Make sure you're only contacting the pin and stroking it in one direction. You're getting the electrons to all spin in the same direction, like lining up all those tiny magnets in the virtual shoebox we talked about before.
3. Pierce a piece of foam with the pin. Stick it right through the middle.
4. Place the needle carefully in the water. If you splash around, you're going to have to wait a while for the system to settle down before you take a reading.
5. Look at your homemade compass. Which way is the needle pointing?
6. Compare it with your ready-made store-bought compass. Are they both telling you the same thing? (If not, you'll need to remove the pin from the foam and repeat step 3 again.)
7. Fill out the data table.

Magnetic Fields Data Table

Magnetizing the Needle	**Does it align with the compass?**
Wiped in one direction for 20 strokes	
Wiped in one direction for 50 strokes	
Wiped in other direction for 50 strokes	
Rubbed back and forth in both directions for 20 strokes	
Laying it on the magnet for one minute (no wiping or stroking)	

Lesson Reading

Remember how we learned that the Earth is a gigantic magnet? We did an experiment where we mapped the magnetic field lines back in *Experiment 3.* Do you also recall how magnetism is caused by electron spin? So the question is… where does the Earth's magnetic field come from?

At this point, folks are still trying to figure that out. The most widely accepted theory is that the magnetic field comes from the Earth's core. The core of the Earth is solid, but around that core is a liquid. The liquid is basically molten iron, nickel and a few other elements. It is the flowing of the electrons in this liquid metal that probably causes the Earth's magnetic field.

So, yes, the Earth is a magnet, but not a very strong one. You probably couldn't even stick it to a sun-sized refrigerator. The Earth has a magnetic pull 100 times weaker then the magnets on your fridge. The Earth, by the way, is not the only giant magnet in the solar system. The Sun, Jupiter, Saturn, Uranus, Mercury and Neptune are also magnets.

"Oh, yeah. Now I remember. That's the deal with the North and South Poles right?"

Well, yes and no. To confuse things a bit, there are two sets of North and South Poles. There are the geographic North and South Poles and the magnetic North and South Poles. (To be completely honest, there are EIGHT magnetic poles on the Earth, but we'll just focus on the two strongest one for now to cut down on the confusion.)

The geographic poles are located at the axis of the Earth. The axis is where the Earth turns day after day. The magnetic poles are close to the geographic poles, but they are off by quite a bit. (The South Pole isn't even in Antarctica – it's in the ocean.) In fact, the north and south magnetic poles of the Earth move from year to year and have completely flipped a couple of times. If you were to connect the Earth's most prominent north and south poles, they wouldn't cut through the planet, since they are both on the same side.

In this experiment, we're going to make our own compass by magnetizing a needle so that it acts like a tiny magnet. By floating the needle in a cup, it will be able to easily turn to align itself with the magnetic field of the Earth.

The North Magnetic Pole in 2001 was near Ellesmere Island in northern Canada at 81.3°N 110.8°W. As of 2012, the pole is projected to have moved beyond the Canadian Arctic territorial claim to 85.9°N 147.0°W. This pole is moving toward Russia at a rate of 34-37 miles per year.

The South Magnetic Pole is constantly shifting due to changes in the Earth's magnetic field. As of 2005 it was calculated to lie at 64°31′48″S 137°51′36″E just off the coast of Adelie Land, French Antarctica. That point lies outside the Antarctic Circle. Due to polar drift, the pole is moving northwest by about 10 to 15 kilometers per year.

Exercises:

1. Why can't you simply rub the needle back and forth with the magnet? Why do you have to stroke it in one direction?
2. What other objects/materials can you use to make a compass?
3. How do you know that the needle is magnetized?
4. Why did we float the needle in water?

Lesson #7: Magnetic Sensors

Overview: Wouldn't it be cool to have an alarm sound each time someone opened your door, lunch box, or secret drawer? It's easy when you use a reed switch in your circuit! If you've built the burglar alarm from the unit on *Electricity,* this is a great addition to your stash of top-secret spy alarms.

What to Learn: Today, you get to learn how to wire up and utilize a magnetically-operated switch.

Materials

- Reed switch
- Magnet
- LED
- AA case
- 2 alligator wires
- 2 AA batteries

Lab Time

1. First, you need to light up the LED. If you haven't done this before, here are the steps:
   a. Use the materials to wire up a simple circuit and get the LED to light up:
      i. Insert your batteries into the case. Flat side (minus) goes to the spring.
      ii. Attach one alligator clip to each of the metal tips of the wires from the battery case. Make sure you've got a good metal-to-metal connection. You should now have two alligator clips attached to the battery pack.
      iii. Attach the end of the alligator clips that's connected to the black wire (negative) from the battery case to the flat side of the LED. It doesn't matter what color the alligator clip wire is.
      iv. Attach the other alligator clip that's connected to the red wire (positive) from the battery case to the longer LED wire. Again, it doesn't matter what color the alligator clip wire is.
      v. Your LED should light up!
   b. Troubleshooting a circuit that doesn't work:
      i. Batteries inserted into the case the wrong way? (Flat side of the battery should go to the metal spring inside the case.)
      ii. LED is in the circuit the wrong way? Remember, LEDs are picky about plus and minus, meaning that it matters which way they are in the circuit. If you choose a bipolar LED, then you don't have to worry about this one, since there are two LEDs, one in each direction, in one LED package which will illuminate no matter which way you have it in your circuit. LEDs are polarized.
      iii. Is there a metal-to-metal connection? You're not grabbing hold of the plastic insulation, are you? Not even a tiny bit? Sometimes kids have the edge of the alligator clip lead propped up on the edge of the plastic insulation, which will make your connection not work.
      iv. Once in a while, you'll get a bad alligator wire. There's an easy to check this: Remove your alligator clip leads from the circuit and touch each of the metal tips from the battery pack

wires to the LED wires. If the LED lights up, swap out your alligator clip lead wires for new ones and that should fix it.

2. Back to the lab… go ahead and light up your LED in a simple circuit. Don't put in the reed switch yet – we want to be sure everything works before introducing a new electronic element.
3. Remove one of the alligator clips from an LED wire and replace it with a third alligator clip lead.
4. Attach each one of the two free ends of alligator wires to either end of the reed switch. You should now have a complete circuit that looks a lot like a circle when you stretch it out.
5. Bring your magnet close to the switch. Where do you have to position your magnet so your LED lights up?
6. Draw a picture of how you can use this circuit in a door or drawer:

Reading

A reed switch is a switch that turns on and off, depending on if a magnet is close or not. A reed switch has two strips of metal that are close but not touching inside. When the magnet is close, the two strips of metal move closer together, until they touch which allows the current to flow and makes the LED light up.

Exercises

1. Where does the magnet need to be located in order for your circuit to work?
2. How does the switch work? Draw a picture and label the parts that make it work in the circuit.
3. Can the switch be activated through the side of a drawer, so that the switch is in the inside and the magnet is on the outside?
4. Which way does the magnet activate the switch the best? How are the poles oriented relative to the switch?

Lesson #8: Magnetic Boats

Overview: Today you get to splash around with several compasses at once as you discover how magnets can both repel and attract each other at the same time.

What to Learn: Notice how the magnet boats repel each other when they get too close, yet they hold each other in a pattern. Atoms do the same thing – they repel each other when you try to squish them together, yet hold together to form molecules.

Materials

- Shallow dish or pie tin
- Water
- Foam blocks
- 6-10 small magnets
- Large magnet
- Hot glue gun

Lab Time

1. Place the magnets in a tall stack.
2. Break the foam into small pieces, about 1-2" square.
3. Using the hot glue gun, place a dab of hot glue in the center of a foam block.
4. Working quickly, remove one magnet from the stack and place it right onto the foam. Glue the magnet to the foam.
5. Repeat for the rest of the magnets, making sure that they are all facing the same way (same pole facing up if the top surface is one pole).
6. Place three of the magnets in a shallow dish of water so they are free to float. What happens?
7. Now take a large magnet and move it toward the floating magnets. Can you keep them in a straight line using the large magnet?
8. Complete the data table.

Magnet Boats Data Table

Number of Magnets	How are magnets distributed? (What shape do they make?)
2	
3	
4	
5	
6	
7	
8	

Reading

What's a magnetic field? Well, I can't tell you. To be honest, nobody can. Magnetic fields, gravitational fields and electric fields are very mysterious, and at this point there are still lots of questions about each one.

A field is an area around an electrical, magnetic or gravitational source that will create a force on another electrical, magnetic or gravitational source that comes within the reach of the field. (Now you can see why there's still so much mystery about them!)

A gravitational field, for example, comes from a body of some sort. The larger the body, the greater the force will be. A planet, for example, is a large body with a large gravitational force. If another body gets within the gravitational field of the planet, it will be affected by the force.

What creates the force? What's pulling or pushing? Nobody knows! We just know that it happens.

Another thing about forces is that the farther something gets away from the source, the less and less the force works on that object. A fancy term for this is the inverse square law. Something quite far from the Earth will feel no tug from the Earth's gravitational pull. If it gets closer, it will feel a slight tug. Closer still, a stronger tug will be felt. The closer something gets to the source of a field (gravitational, magnetic or electric) the stronger the pull of the field force is. If you're standing on top of the Sears Tower in Chicago, you are actually going to weigh less than if you're standing in the street.

Weight depends on the pull of gravity. The farther you are from the Earth, the less gravity pulls on you and the less you will weigh! There's an instant diet plan for you!

When you build the little boats, remember that you kept all the poles the same (all north pointed up, for example). The floating magnets repel each other because they have the same pole oriented up.

But notice that when you bring the larger magnet close, they are all attracted to it and also make geometric patterns! When you bring the larger magnet in closer, the size of your pattern changes, doesn't it? Most patterns have at least one (sometimes two) stable patterns, each of which is a local minimum energy pattern. The patterns that the little boats make are very similar to the crystal structures in solids.

Notice how the magnet boats repel each other when they get too close, yet they hold each other in a pattern. Atoms do the same thing – they repel each other when you try to squish them together, yet hold together to form molecules.

Exercises

1. What shape do three magnets give? Why is this different from the shape that four magnets make?
2. Why do the magnets flip over when you first place them in the water?
3. How many magnets make a hexagon?
4. How is this experiment like the compass experiments we've done so far?
5. Why do the boats repel each other, yet still hold in a pattern?

Lesson #9: Curie Heat Engine

Overview: We're going to heat a magnet so that it temporarily loses its magnetic poles, and watch what happens as it cycles through cooling.

What to Learn: Magnetic material loses its ability to stick to a magnet when heated to a certain temperature called the *Curie temperature*. The Curie temperature for nickel is 380 ^{o}F, iron is 1,420^{o}F, cobalt is 2,070 ^{o}F, and for ceramic ferrite magnets it starts at 860^{o}F.

Materials

- Large ceramic magnet
- Tiny bead magnet
- Thin copper wire
- Smooth pen or straw
- Candle (with adult help)
- Framework to hold the setup

Lab Time **<u>Please be very careful with this lab! You will need adult help with the fire.</u>**

1. The video will show you how to create your frame. If you're using the two water bottle design, make sure they are full of water and space them approximately six inches apart and lay a smooth pen or straw across the caps. Tape the pen into place.
2. Insert the wire into your bead magnet and twist the wire end back on itself so the bead doesn't come off. I use a wire that doesn't have insulation so it won't burn when in the flame.
3. Straighten out your wire.
4. Place a votive candle on the table between the two water bottles. I like to do this on a cookie sheet to protect the desks.
5. Wrap your wire around the pen loosely several times so that it can still swing like a pendulum easily while hanging at a height at the top of the wick of the candle. You want the bead magnet to be just touching the top of the flame when you light the candle. Make sure the pen is supported well.
6. Lay the ceramic magnet on its side across one side of the votive candle so that the bead magnet is attracted to it and sticks. Move the large magnet so that the bead magnet is just touching the top of the flame while it's sticking to it.
7. You'll be adjusting it while the candle is lit, so **please be careful**! The ceramic magnet retains heat for a long time and will be hot to the touch, as will the wire and the bead magnet.
8. Have an adult light your candle and help you make the proper adjustments. Watching the video again may help.

Reading

We're going to use the idea that magnetic material loses its ability to stick to a magnet when heated to a certain temperature called the *Curie temperature*. At the end of the swinging wire, there's a tiny bead magnet, which is quite strong for its size. The magnet is attracted to the large ceramic magnet and moves toward it, almost touching it.

The candle heats up the tiny bead magnet, causing it to temporarily lose its magnetism by adding energy into the atoms and randomizing their orientation within the magnet. You'll notice that the magnet quickly regains its magnetism after it cools. While you can permanently destroy the magnetic field in the bead magnet, you'd need something hotter than a propane torch to do it.

The Curie temperature for the ceramic magnet is much higher than a candle can produce, which is why the permanent magnet isn't affected by the flame. The Curie temperature for the tiny bead magnet is about 600^{o}F, which is easily obtainable by your candle.

If you can't find a bead magnet, the Curie temperature for the Radio Shack rare earth magnets is just under 600^{o}F, which also within reach of your candle's heat. The magnets are also on the small size, so they tend to heat up faster. You can break a magnet if you need a smaller piece for this experiment.

Exercises

1. Why does the tiny magnet lose its attraction to the large magnet?

2. How long does it take for the attraction-repulsion cycle to repeat?

3. Draw out your experiment, explaining how it works and labeling each part:

Lesson #10: Linear Accelerator

Overview: Linear accelerators (also known as a "linac") use different methods to move particles to very high speeds. One way is through induction, which is basically a pulsed electromagnet. We're going to use a slow input speed and super-strong magnets and multiply the effect to cause a ball bearing to shoot across the floor at high speed.

What to Learn: Today you're going to do an award-winning project (yes, loads of students have used this experiment in science fairs and taken home first prize!) that will teach you how to measure, calculate, record data, and make steel ball bearings fly around the room using momentum and magnetism.

Materials

- Wood or plastic ruler with a groove down the center, 12" long
- Eight thick rubber bands or epoxy for a permanent mount
- Four super-strong magnets (try 12mm or ½" neodymium magnets)
- Nine steel ball bearings (1/2", 5/8", or other sizes)
- Measuring tape

Lab Time: This lab has two sections. Feel free to stop after the first part, or go on to the second. It's really up to you. The first lab is fairly easy and straightforward without a lot of fuss, since you do not need rubber bands or epoxy, and you only need one magnet and the setup doesn't need to be permanently mounted. The second part of the lab does require additional adult help to separate the magnets and get them under the stiff rubber bands. You can opt to make one of the advanced models

Construction note: If you plan on having a set of these to use for years, permanently stick the magnets to the ruler using epoxy or JB Weld. When you permanently mount the magnets, this experiment is safer to handle since the magnets can't slip out from under the rubber band and squash fingers or break into pieces.

<u>Part 1: Single-magnet design:</u>

1. Place the ruler on the table.
2. Put a magnet at the 6" mark on the ruler. If you've found a strong neodymium magnet, you only need one magnet, not the four as shown in the video.
3. Add four ball bearings in the groove on the ruler in a line, with one end touching the magnet. The balls should extend past the 7" mark.
4. Prop up the 0" mark slightly with a thin book or block (or just lift it a bit with your finger).
5. Place a fifth ball bearing on the 0" mark and let go. What happened?
6. Complete the data table.

Simple Linear Accelerator Data Table

You'll want to prop up your ruler at the same height for all the data you measure, or you'll have to record the ruler angle as well with each trial run. Also, note how far the initial ball has to travel. If your magnet is at 6" and you let go at the 2" mark, then it travels 4". So you'd write 4" in the "Distance Initial Ball Traveled".

Trial #	Distance Initial Ball Traveled	Distance Breakaway Ball Traveled
	(inches)	Circle one: (inches or feet)
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		

Part 2: Multiple-magnet design:

1. Take your ruler and find the 11" mark. Wrap your first rubber band strongly around the ruler at this mark.
2. Wrap a second rubber band at the 8" mark.
3. Wrap the third at the 5" mark.
4. Wrap the fourth at the 2" mark.
5. Carefully stack your magnets. Be very careful because if they snap together, they will break.
6. Take the first off the stack, keeping the orientation exactly the same as it was in the stack. We are going to separate the magnets from the stack but keep them in exactly the same direction they are in. If you mix up the north-south pole orientation, your linac (linear accelerator) won't work.
7. Slide the magnet under the first rubber band. Have the magnet straddle the 11" mark. This will be important later when we take measurements.
8. Slide the second magnet under the second rubber band. Keep the magnets facing the same way as you work!
9. Slide the third magnet under the third rubber band. Do the same with the fourth.
10. Add a second rubber band to each magnet to secure it into place.
11. Carefully place two ball bearings on one side of each magnet in a line in the groove of the ruler. Your last ball bearing should be at the 12" mark.
12. Look at your ruler. You should have a magnet at the 2" mark, followed by two ball bearings in the groove. Then you should have another magnet with two more ball bearings, a third magnet with another two ball bearings, and a fourth magnet with the last two ball bearings ending at the edge of the ruler.
13. Prop up the 0" mark on the ruler with a thin book, block, or your finger.
14. Take your very last, ninth ball bearing. Place it at the 0" mark, and let go. What happened? Write it here:

____

____

____

____

15. Draw what your ruler looks like before impact:

16. Draw what your ruler looks like after impact (where are the ball bearings now?):

17. Complete the data table.

Advanced Linear Accelerator Data Table

Note that we're measuring two things for the breakaway ball: how long it takes for the ball to travel six feet, which is measured in seconds, and also how far it goes until it stops on its own, measured in distance. Assign one person to each measurement task: distance or time.

For the time measurement, you'll want to use your tape measure to mark how far six feet is before you start, and then place the end of your ruler at the start line. As soon as the breakaway ball leaves the ruler, start timing. When it crosses the finish line six feet away, stop timing and record this number in the third column: 'Time Breakaway Ball Traveled 6 Feet'.

To figure out how fast your ball is going, divide 6 feet by the time you recorded. If it took your ball two seconds to go six feet, then the speed is 3 feet per second.

You'll want to prop up your ruler at the same height for all the data you measure, or you'll have to record the ruler angle as well with each trial run. Also note how far the initial ball has to travel. If your first magnet is at 2" and you let go at the 0.5" mark, then it travels 1.5". So you'd write 1.5" in the "Distance Initial Ball Traveled".

Trial #	**Distance Initial Ball Traveled**	**Time Breakaway Ball Traveled 6 feet**	**Total Distance Breakaway Ball Traveled**	**Calculated Average Speed: Speed = 6 feet / Time**
	(inches)	(seconds)	Circle one: (feet or inches)	(feet per second)
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				

Reading

There are several different types of magnets. Permanent magnets are materials that stay magnetized, no matter what you do to them… even if you whack them on the floor (which you can do with a magnetized nail to demagnetize it). You can temporarily magnetize certain materials, such as iron, nickel, and cobalt. And an electromagnet is basically a magnet that you can switch on and off and reverse the north and south poles.

The strength of a magnetic field is measured in "Gauss." The Earth's magnetic field measures 0.5 Gauss. Typical refrigerator magnets are 50 Gauss. Neodymium magnets (like the ones we're going to use in this project) measure at 2,000 Gauss. The largest magnetic fields have been found around distant magnetars (neutron stars with extremely powerful magnetic fields), measuring at 10 trillion Gauss. (A neutron star is what's left over from certain types of supernovae, and typically the size of Manhattan.)

In this experiment, the metal ball bearing is seriously attracted to your magnets, and this pull intensifies the closer the ball gets to the magnet (inverse-square law). When the ball smacks into the magnet, the energy wave from the impact zips through the magnet and attached ball bearings until it knocks the furthest ball free, which has the least magnetic pull on it because it's furthest from the magnet. If it wasn't, it would be slowed down and possibly reattached to the magnet it just broke away from.

With each impact, there's an increase in velocity. Imagine if you had a hundred of these things lined up… how fast could you get that last ball bearing going?

After each firing, you have to reset your system, and chances are it takes a bit of effort to pull the ball bearings from the magnets! You are providing the energy that gets released during each collision and adds to the velocity of the ball bearings.

Exercises

1. Does it really matter where you start the first ball bearing? If so, does it matter *much*?
2. Why does only the last ball go flying away? Why don't the others break away as well?
3. How many inches did the first initial ball (the one you let go of) travel?
4. How many inches did the last ball (the one that detached from the magnet) travel?
5. Why did we use four magnets in the second lab? What did that do?

Lesson #11: Earth Pulse

Overview: When you stare at a compass, the needle that indicates the magnetic field from the Earth appears to stand still, but we're going to find how it fluctuates and moves by creating a super-sensitive instrument using everyday materials (for comparison, you would spend more than $100 for a scientific instrument that does the same thing).

What to Learn: Today you get to learn how to amplify tiny pulses in the Earth's magnetic field using a laser and a couple of magnets. It's a very cool experiment, but it does take patience to make it work right.

Materials

- Index card or scrap of cardboard
- 2 small mirrors
- 2 rare earth magnets
- Nylon filament (thin nylon thread works, too)
- 4 doughnut magnets
- Laser pointer (any kind will work – even the cheap key-chain type)
- Clean glass jar (pickle, jam, mayo, etc… any kind of jar that's heavy so it won't knock over easily)
- Wooden spring-type clothespin
- Hot glue gun, scissors and tape

Lab Time

1. Sandwich the twine between the two rare earth magnets. These are the stronger magnets.
2. Use a tiny dab of glue on one of the magnets and attach a mirror to the magnet. Do this on the other side for the second magnet and mirror.
3. Lower the mirror-magnets into the container, leaving them hanging an inch above the bottom of the jar. Cut the twine at the mouth level of the container.
4. Glue the top of the twine to the bottom of the lid, right in the center.
5. When the glue has dried, place your mirror-magnets inside the jar and close the lid. Make sure that the mirror-magnets don't touch the side of the jar, and are free to rotate and move.
6. You've just built a compass! The small magnets will align with the earth's magnetic field. Slowly rotate the jar, and watch to see that the mirror-magnets inside always stay in the same configuration, just like the needle of a standard compass.
7. Set your new compass aside and don't touch it. You want the mirror-magnets to settle down and get very still.
8. You are going to build the magnet array now. Stack your four doughnut magnets together in a tall stack.
9. Fold your index card in half, and then open it back up. On one side of the crease, you're going to glue your magnets. When the magnets are attached, you'll fold the card over so that it sits on the table like a greeting card with the magnets facing your glass jar.
10. Tape your index card down to the table as you build your magnet array. (Otherwise the paper will jump up mid-way through and ruin your gluing while you are working.)

11. Place a strip of glue on the bottom magnet of your stack and press it down onto the paper, gluing it into place.
12. Lift the stack off (the bottom magnet should stay put on the paper) and place glue on the bottom magnet. Glue this one next to the first.
13. Continue with the array so you have a rectangle (or square) arrangement of magnets with their poles oriented the same way. Don't flip the magnets as you glue them, or you'll have to start over to make sure they are lined up right.

Since we live in a gigantic magnetic field that is 10,000 times more powerful than what the instrument is designed to measure, we have to "zero out" the instrument. It's like using the "tare" or "zero" function on a scale. When you put a box on a scale and push "tare," then the scale reads zero so it only measures what you put in the box, not including the weight of the box, because it's subtracting the weight of the box out of the measurement. That's what we're going to do with our instrument: We need to subtract out the Earth's magnetic field so we just get the tiny fluctuations in the field.

14. Place your instrument away from anything that might affect it, like magnets or anything made from metal.
15. Fold the card back in half and stand it on the table. We're normally going to keep the array away from the jar, or the magnet array will influence the mirror-magnets just like bringing a magnet close to a compass does. But to zero out our instrument, we need to figure out what the distance is that the array needs to be in order to cancel out the Earth's field.
16. Bring the array close to your jar. You should see the mirror-magnets align with the array.
17. Slowly pull the magnet array away from the compass to a point where if it were any closer, the mirror-magnets would start to follow it, but any further away and nothing happens. It's about 12 inches away. Measure this for your experiment and write it on your array or jar so you can quickly realign if needed in the future.
18. Insert your laser pointer into the clothespin so that the jaws push the button and keep the laser on. Place it at least the same distance away as the array. You might have to prop the laser up on something to get the height just right so you can aim the laser so that it hits the mirror inside. (Note that you'll have a reflection from the glass as well, but it won't be nearly as bright.)
19. Find where the laser beam is reflected off the mirror and hits the wall in your room. Walk over and tape a sheet of paper so that the dot is in the middle of the paper. Use a pen and draw right on top of the dot, and mark it with today's date.
20. Do you notice if it moves or if it stays put? Sometimes the dot will move over time, and other times the dot will wiggle and move back and forth. The wiggles will last a couple of seconds to a couple of minutes, and those are the oscillations and fluctuations you are looking for!
21. Tape a ruler next to the dot so you can measure the amount of motion that the dot makes. Does it move a lot or a little when it wiggles? Two inches or six?

Reading

The reason this project works is because of tiny magnetic disturbances caused by the ripples in the Earth's ionosphere. Although these disturbances happen all the time and on a very small scale (usually only 1/10,000th of the Earth's magnetism strength), we'll be able to pick them up using this incredibly simple project. Your reflected laser beam acts like an amplifier and picks up the movement from the magnet in the glass.

You need to use a filament that doesn't care how hot or humid it is outside, so using one of the hairs from your head definitely won't work. Cotton tends to be too stretchy as well. Professionals use fine quartz fibers (which are amazingly strong and really don't care about temperature or humidity). Try extracting a single filament from a multi-stranded nylon twine length about 30″ long. If you happen to have a fine selection of nylon twine handy, grab the one that is about 25 microns (0.01″) thick. Otherwise, just get the thinnest one you can find.

Also note that big, powerful magnets will not respond quickly, so you need a lightweight, powerful magnet. Try finding a set of rare earth magnets from Radio Shack or the hardware store.

You can walk around with your new instrument and you'll find that it's as accurate as a compass and will indicate north. You probably won't see much oscillation as you do this. Because the Earth has a large magnetic field, you have to "tare" the instrument (set it to "zero") so it can show you the smaller stuff. Use the doughnut magnets about 30 centimeters away as shown in the video.

Construction Notes:

You can tape a wooden clothespin down to the table and insert your laser pointer inside – the jaws will push the button of the laser down so you can watch your instrument and take your measurements. When you're ready, tape a sheet of paper to the wall where your reflected beam (reflected from the mirror, not the glass… there will be two reflected beams!) hits the wall and mark where it hits. Over periods of seconds to minutes, you'll see deflections and oscillations (wiggles back and forth) – you are taking the Earth's magnetic pulse!

In order for this experiment to work properly, ALL magnets (including the penny described below) need to be in the same plane. That is, they all need to be the same height from the ground. You can, of course, rotate the entire setup 90 degrees to investigate the magnetic ripples in the other planes as well!

To make this instrument even *more* sensitive, glue a copper penny (make sure it's minted before 1982, or you'll get an alloy, not copper, penny) to the glass jar just *behind* the magnets (opposite the laser). When your magnets move now, they will induce eddy currents in the penny that will induce a (small) magnetic field opposite the rotation of the magnets to dampen out "noise" oscillation. In short, add a penny to the glass to make your instrument easier to read.

Exercises

1. Does the instrument work without the magnet array?
2. Why did we use the stronger magnets inside the instrument?
3. Which planet would this instrument probably not work on?

Lesson #12: Ferrofluid

Overview: Today going to learn about liquid magnets, also known as ferrofluids. Ferrofluids are what scientists call "colloidal suspensions," which means that the substance has properties of both solid metal and liquid water (or oil), and it can change phase easily between the two. And make a total mess.

What to Learn: Ferrofluids are what scientists call "colloidal suspensions," which means that the substance has properties of both solid metal and liquid water (or oil), and it can change phase easily between the two. Because ferrofluids can change phases when a magnetic field is applied, you'll find ferrofluids used as seals, lubricants, and for many other engineering-related uses.

Materials:

- Old toner cartridge from a laser printer or copy machine
- Strong magnet (neodymium magnets work best)
- Paper or newspaper
- Baby oil or vegetable oil
- Plastic bag
- Metal bolt with nut and large washer
- Disposable plastic cup with lid
- Popsicle stick
- Medicine dropper
- Gloves and goggles
- Adult help

Lab Time

If you work with toner, you will make an absolute mess. It will get in places you never thought possible, which is why this lab is perfect as a parent-kid activity. Wear old clothes, goggles, gloves, and be prepared to have a lot of fun.

1. Watch the video and see where you need to punch holes (if needed) in your toner.
2. Wearing gloves, remove as much of the powdered ink as you possibly can onto a sheet of paper.
3. Funnel the powder into the cup. You might want to save some for later in case you'd like to experiment with different solvents. You can use baby oil, water, or alcohol to mix the fluid with. The experiment in the video uses oil.
4. Add a little baby oil to the cup and stir with a popsicle stick.
5. Bring a magnet to the outside of the cup and watch the magnetic liquid stick to the side of the cup!
6. Don't get the magnet above the rim of the cup, or the ferrofluid will stick to the magnet and you'll never get it off again.
7. Play with the ferrofluid:
    a. You can thicken it up by adding more powder to the mix. This will form a magnetic putty you can play with as long as you have gloves on your hands. If you leave it on the table close to a magnet, it

will slowly creep toward the magnet. Add a tiny bit more liquid if it doesn't appear to move over the course of 10-20 minutes.

b. Thin it out with more oil to make it more like the commercially available ferrofluid. You'll get more spikes, especially if you let it sit for a couple of hours to completely immerse in the oil.
c. Bring a magnet close but not touching the cup. What happens?
d. Make a larger magnetic surface for the ferrofluid to interact with:
    i. Place 1-2 strong magnets (neodymium work best) under your plastic cup. If it's not stable, add a large washer to the bottom of the magnets to make a stand.
    ii. Thread a nut onto a bolt a few turns (not all the way – leave it near the base) and upright in the cup so that the bolt is standing up on its own. The magnets will keep it stable.
    iii. Using a medicine dropper, slowly drip the ferrofluid onto the top of the bolt. If you pour it too quickly, the fluid will splatter and be very messy to work with. Make sure your ferrofluid is relatively thin for this process. You can use the ferrofluid you created or the stuff from a store.
    iv. Bring a magnet close (not close enough for it to jump onto the bolt, or you'll make a huge mess) and observe what happens. What is the furthest you can move the magnet and still influence the ferrofluid?
    v. What happens if you try a different magnet?

Reading

The ink inside your toner cartridge is powdered ink. Even an empty cartridge will have extra powdered ink inside. The ink has little bits of iron mixed in with the ink. If you extract the ink and mix it with oil, you can make your own ferrofluid.

A ferrofluid becomes strongly magnetized when placed in a magnetic field. This liquid is made up of very tiny (10 nanometers or less) particles coated with anti-clumping surfactants and then mixed with water (or solvents). These particles don't "settle out" but rather remain suspended in the fluid. The particles themselves are made up of magnetite, hematite or iron-type substance.

Ferrofluids don't stay magnetized when you remove the magnetic field, which makes them "super-paramagnets" rather than ferro-magnets. Ferrofluids also lose their magnetic properties at and above their Curie temperature points.

Engineering and scientists use ferrofluids to make a liquid seal in hard drives around the spinning disks to keep out dust and grit (hard drives must be kept exceptionally clean!). They do this by adding a layer of ferrofluid between the rotating shaft and magnets which surround the shaft.

You can also use ferrofluids to reduce friction, the way ice and water are used in ice skating rinks. If you coat a strong magnet with ferrofluid, you can get it to glide across a smooth surface like a hockey puck. NASA uses ferrofluids in the flight instruments for spacecraft, also!

Each particle of ferrofluid is like a each grain or a micro-magnet, which not only interacts with magnetic fields, but also with light.

With loudspeakers, the large magnets that interact with the coil often heat up. If we replace the magnet with ferrofluid (which is a liquid, remember!) it will actively conduct the heat away from the coil and cool it down because cold ferrofluid is more strongly attracted than hot, and thus the cooler fluid flows toward the coil, and the warmer fluid moves away from the coil.

Notes on the Lab: If you prefer, you can purchase a premade ferrofluid kit, but I prefer to show the kids where the fluid itself really comes from so it's not such a mystery after we're done. I usually have commercially available ferrofluid also to play with and compare after we've made our own. Feel free to skip this lab if the materials are out of your budget, or save it as a treat for a special time. You'll get lots of ooh-ahhs if you perform this for an adult.

Exercises

1. Is the ferrofluid a solid or a liquid?
2. Does the strength of a magnet matter?
3. What would happen if the magnet went over the rim of the cup?
4. Does the ferrofluid have a north and south pole?
5. What happens if you bring a compass near the ferrofluid?
6. Name three specific ways ferrofluid makes our lives easier. How might you use a ferrofluid if you were inventing something?

Lesson #13: Braking Magnets

Overview: Today you get to measure, calculate, and be amazed at how magnetism and electricity work together.

What to Learn Eddy currents defy gravity and let you float a magnet in midair. Think of eddy currents as brakes for magnets. Roller coasters use them to slow down fast-moving cars on tracks and in free-fall elevator-type rides. This is a great introduction to the next segment, which is all about how electricity and magnetism are linked together.

Materials

- Aluminum block (the thicker the better)
- Neodymium magnets (get different sizes and/or shapes for each lab group so they can swap and compare)
- Ruler
- Stopwatch or clock with a second hand

Lab Time

1. Lift up one end of the metal sheet.
2. Place your magnets at the top of the ramp and let go.
3. What happened? Write it here:

____

____

____

4. Trade magnets with another lab group that's ready to swap and redo the experiment as you complete the data table.

Braking Magnets Data Table

Length of Ramp:____________________ (units?) Height of Ramp at Start:________________________ (units?)

Example for what to put in the *Number of/Size/Shape of Magnet* column: If your experiment used two magnets that each were ½" in diameter (use your ruler to measure!), then write: '2 round ½" magnets'

Trial #	Number/Shape/Size of Magnet	Time to Reach the Bottom of Ramp (seconds)
1		
2		
3		
4		
5		
6		
7		

Reading

When a magnet moves near an object that conducts electricity (like metal), it creates electric currents in the metal. These are called *eddy currents* and they start to flow in the metal. These eddy currents also create magnetic fields (We're going to learn how electricity causes magnetism very soon!) in the opposite direction of the moving magnet, slowing an object down so it appears to float down the ramp slowly. Eddy currents are brakes for moving magnets.

Exercises

1. What is the average speed of your fastest magnet?
2. What makes the magnet slow down the most? Is it the size of the magnet, the strength of the magnet, number of magnets, or something else?
3. What if you stack two aluminum plates on top of each other and use this for a ramp? How would this affect your data?
4. Does the angle of the ramp matter?

Magnets Evaluation

Student Worksheet

Overview: Today you're going to take two different tests: the quiz and the lab practical. You're going to take the written quiz first, and the lab practical at the end of this test. The lab practical isn't a paper test – it's where you get to show your teacher that you know how to do something.

Lab Test & Homework

1. Your teacher will call you up so you can share how much you understand about magnets and how they interact with each other. Since science is so much more than just reading a book or circling the right answer, this is an important part of the test to find out what you really understand.
2. While you are waiting for your turn to show your teacher how much of this stuff you already know, you get to choose which homework assignment you want to complete. The assignment is due tomorrow, and half the credit is for creativity and the other half is for content, so really let your imagination fly as you work through it. Choose one:
    a. Write a short story or skit about magnetism from the perspective of the electron or the magnet itself. You'll read this aloud to your class.
    b. Make a poster that teaches the main concepts to magnetism. When you're finished, you'll use it to teach a class in the younger grades and demonstrate each of the principles that you've learned.
    c. Write and perform a poem or song about magnetism. This will be performed to your class.

Magnets Quiz

Name____

1. How many poles do magnets have, and what are they?

2. What happens when you bring two like poles together?

3. How do I know which pole is which on a magnet?

4. Is the magnetic force stronger or weaker the closer a magnet gets to another magnet?

5. What kinds of materials are magnets made from?

6. Name three objects that stick to a magnet.

7. Name three that don't stick to a magnet.

8. What does a compass detect? How do you know when it's detected it?

9. Circle the correct answer in the parenthesis:

    a. The Earth has a (tiny | huge) magnetic field.

    b. The Earth has a (strong | weak) magnetic force.

    c. The magnetic field comes from the moving electrons in the currents of the Earth's (molten core | rocky core).

    d. The Earth has a north and a south magnetic pole which is (the same | different) from the geographic north and south pole.

Magnets Lab Practical

Student Worksheet

This is your chance to show how much you have picked up on important key concepts, and if there are any holes. You also will be working on a homework assignment as you do this test individually with a teacher.

Materials:

- Needle
- Foam
- 2 different kinds of magnets (round or square, N-S pole locations different, etc.)
- Cup of water
- Paperclip
- Penny
- Quarter

Lab Practical:

- Design and build an experiment that shows how to detect a magnetic field.

- Using all the materials, even the cup and the foam (remove the needle), separate the objects into two piles: one pile for things that are not magnetically attracted and another that are magnetically attracted.

Section 2: Electromagnetism

One of the four fundamental forces of nature, the electromagnetic force is the one that binds atoms together, allows you to walk down the street, and is solely responsible for bad hair days worldwide. One of the greatest leaps in science was the discovery that the electricity and magnetism were a part of each other, not separate things. By the time you're through with this lesson, you'll have created particle accelerators, galvanometers, uni-polar motors, *listened* to a magnet (no kidding!), and built a working DC motor. Are you ready to dive in?

Lesson #14: Galvanometers

Overview Today is a very important day in your magnetism studies. You will begin to discover how electricity and magnetism cause each other. In the second half of this lab, they'll get to re-enact one of the most important scientific discoveries of all time: how magnetism causes electricity.

What to Learn Galvanometers are coils of wire connected to a battery. When current flows through the wire, it creates a magnetic field. Since the wire is bundled up, it multiplies this electromagnetic effect to create a simple electromagnet that you can detect with your compass.

Materials

- Magnet wire
- Sandpaper
- Scissors
- Compass
- AA battery case
- 2 AA batteries
- 2 alligator clip wires
- Strong magnet
- Toilet paper or paper towel tube

Lab Time

1. Wrap the wire 30-50 times around your fingers, making sure your coil is large enough to slide the compass through. Take one of the ends of the wire and wrap it a couple of times around a section of the circle to keep the wire from unwinding. Do this for both sides.
2. Remove the insulation from about an inch of each end of the wire. Use sandpaper if you're using magnet wire.
3. Connect one end of the wire to the battery case wire.
4. While looking at the compass, repeatedly tap the other end of the wire to the battery. You should see the compass react to the tapping.
5. Switch the wires from one terminal of the battery to the other. Now tap again. Do you see a difference in the way the compass moves? Write it here:

   ____

6. You just made a simple galvanometer. *"Oh boy, that's great! Hey Bob, take a look! I just made a….a what?!?"* I thought you might ask that question. A galvanometer is a device that is used to find and measure electric current. *"But, it made a compass needle move…isn't that a magnetic field, not electricity?"* Ah, yes, but hold on a minute. What is electric current…moving electrons. What do moving electrons create…a magnetic field! By the galvanometer detecting a change in the magnetic field, it is actually measuring electrical current! So, now that you've made one let's use it!

7. Take your new piece of wire and wrap this wire tightly and carefully around the end of the paper towel tube. Do as many wraps as you can while still leaving about 4 inches of wire on both sides of the coil. You may want to put a piece of tape on the coil to keep it from unwinding. Pull the coil from the paper towel tube, keeping the coil tightly wrapped. Take one of the ends of the wire and wrap it a couple of times around a section of the circle to keep the wire from unwinding. Do this for both sides.
8. Remove about an inch of insulation from both ends of the wire using sandpaper.
9. Hook up your new coil with your galvanometer. One wire of the coil should be connected to one wire of the galvanometer and the other wire should be connected to the other end of the galvanometer.
10. Now move your magnet in and out of the coil. Can you see the compass move? Does a stronger or weaker magnet make the compass move more? Does it matter how fast you move the magnet in and out of the coil?
11. Taa Daa!!! Ladies and gentlemen you just made electricity!!!!! You also just re-created one of the most important scientific discoveries of all time.
12. Now, we know that you can't have an electric field without a magnetic field. You also cannot have a moving magnetic field without causing electricity in objects that electrons can move in (like wires). Moving electrons create a magnetic field, and moving magnetic fields can create electric currents.
13. *"So, if I just made electricity, can I power a light bulb by moving a magnet around?"* Yes, if you moved that magnet back and forth fast enough you could power a light bulb. However, by fast enough, I mean like 1,000 times a second or more! If you had a stronger magnet, or many more coils in your wire, then you could make a greater amount of electricity each time you moved the magnet through the wire.
14. Believe it or not, most of the electricity you use comes from moving magnets around coils of wire! Electrical power plants either spin HUGE coils of wire around very powerful magnets or they spin very powerful magnets around HUGE coils of wire. The electricity to power your computer, your lights, your air conditioning, your radio or whatever, comes from spinning magnets or wires!
15. *"But what about all those nuclear and coal power plants I hear about all the time?"* Good question. Do you know what that nuclear and coal stuff does? It gets really hot. When it gets really hot, it boils water. When it boils water, it makes steam and do you know what the steam does? It causes giant wheels to turn. Guess what's on those giant wheels. That's right, a huge coil of wire or very powerful magnets! Coal and nuclear energy basically do little more than boil water. With the exception of solar energy almost all electrical production comes from something huge spinning really fast!

16. Draw out your experiment, showing how the magnet creates electricity and where/how that electricity creates magnetism. Label all the different parts of your experiment:

Reading

Now we've covered the fact that magnetic fields are caused by electrons moving in the same direction. Up to this point, we've been focusing on magnetism being caused by an unequal number of electrons spinning in the same direction in an atom.

If an atom has more electrons spinning in one direction than in the other direction, that atom will have a magnetic field. When bunches of these atoms get together, we have a permanent magnet. Now we're going to talk about what happens if we force electrons to move.

This is one of the most important scientific discoveries of all time. One story about this discovery goes like this:

A science teacher doing a demonstration for his students (Can you see why I like this story?) noticed that as he moved a magnet, he caused one of his instruments to register the flow of electricity. He experimented a bit further with this and noticed that a moving magnetic field can actually create electrical current, thus tying the magnetism and the electricity together.

Before that, they were seen as two completely different phenomena! Now we know that you can't have an electric field without a magnetic field. You also cannot have a moving magnetic field without causing electricity in objects that electrons can move in (like wires). Moving electrons create a magnetic field and moving magnetic fields can create electric currents.

"So, if I just made electricity, can I power a light bulb by moving a magnet around?"

Yes, if you moved that magnet back and forth fast enough you could power a light bulb. However, by fast enough, I mean like 1000 times a second or more! If you had a stronger magnet, or many more coils in your wire, then you could make a greater amount of electricity each time you moved the magnet through the wire.

Believe it or not, most of the electricity you use comes from moving magnets around coils of wire! Electrical power plants either spin HUGE coils of wire around very powerful magnets or they spin very powerful magnets around HUGE coils of wire. The electricity to power your computer, your lights, your air conditioning, your radio or whatever, comes from spinning magnets or wires!

"But, what about all those nuclear and coal power plants I hear about all the time?"

Good question. Do you know what that nuclear and coal stuff does? It gets really hot. When it gets really hot, it boils water. When it boils water, it makes steam and do you know what the steam does? It causes giant wheels to turn. Guess what's on those giant wheels. That's right, a huge coil of wire or very powerful magnets!

Coal and nuclear energy basically do little more than boil water. With the exception of solar energy almost all electrical production comes from something huge spinning really fast!

Exercises

1. Why didn't the coil of wire work when it wasn't hooked up to a battery? What does the battery do to the coil of wire?
2. How does a moving magnet make electricity?
3. What makes the compass needle deflect in the second coil?
4. Does a stronger or weaker magnet make the compass move more?
5. Does it matter how fast you move the magnet in and out of the coil?

Lesson #15: Electromagnets

Overview We're going to make a magnet (several, actually) that turn on and off using electricity. Today, you get to discover how electric currents produce magnetic fields and how to build a simple electromagnet.

What to Learn An electromagnet is a magnet you can turn on and off using electricity. By hooking up a coil of wire up to a battery, you will create an electromagnet. When you disconnect it, it turns back into a coil of wire. Since moving electrons cause a magnetic field, when connecting the two ends of your wire up to the battery, you caused the electrons in the wire to move through the wire in one direction. Since many electrons are moving in one direction, you get a magnetic field!

Materials

- AA battery case
- 2 AA batteries
- 2 alligator clip wires
- 5 nails (2-3" long, rust-free)
- Magnet wire
- Paperclips
- Pencil
- Chopstick
- Straw
- Plastic fork
- Rubber eraser
- Tape
- Compass

Lab Time

1. Wrap your wire 20 times around the nail. Be sure to always wrap in the same direction. If you start wrapping clockwise, for example, be sure to keep wrapping clockwise.
2. Clip the ends off, leaving 4" tails for both wires.
3. Take your wire and remove about an inch of insulation from both ends using sandpaper.
4. Now, connect one end of your wire to one terminal of the battery using an alligator clip.
5. Lastly, connect the other end of the wire to the other terminal of the battery using a second alligator clip lead to connect the electromagnet wire to the battery wire. This is where the wire may begin to heat up, so be careful.
6. Move your compass around your electromagnet. Does it affect the compass?
7. Bring your electromagnet next to a pile of paperclips. See if your electromagnet can pick up paper clips.
8. Switch the wires from one terminal of the battery to the other. Electricity is now moving in the opposite direction from the direction it was moving in before. Try the compass again. Do you see a change in which end of the nail the north side of the compass points to? Write it here:

____

9. Repeat these steps with a new nail for each as you complete the table. You will be making five nail electromagnets for Data Table #1.

Electromagnet Data Table #1

Number of Wraps Around the Nail	How Many Paperclips Picked Up?
20	
40	
60	
80	
100	

Electromagnet Data Table #2

Make sure you wrap the same number of turns around each object!
Don't forget to sand the ends of the wires before connecting it to your battery.

Object Used to Wrap Wire Around 40 times	How Many Paperclips Picked Up?
Pencil	
Chopstick	
Straw	
Plastic fork	
Rubber eraser	

10. Rank each object from best (1) electromagnet to worst (6):

____ Nail electromagnet

____ Pencil electromagnet

____ Chopstick electromagnet

____ Straw electromagnet

____ Plastic fork electromagnet

____ Rubber eraser electromagnet

Reading

An electromagnet is a magnet you can turn on and off using electricity. By hooking up a coil of wire up to a battery, you will create an electromagnet. When you disconnect it, it turns back into a coil of wire. Since moving electrons cause a magnetic field, when connecting the two ends of your wire up to the battery, you caused the electrons in the wire to move through the wire in one direction. Since many electrons are moving in one direction, you get a magnetic field!

The nail helps to focus the field and strengthen it. In fact, if you could see the atoms inside the nail, you would be able to see them turn to align themselves with the magnetic field created by the electrons moving through the wire. You can test the nail by itself (with the wire removed) after you've done the experiment, because you may have caused it to become a permanent magnet.

Exercises

1. How does the number of wraps affect the electromagnet?
2. Does it matter if you wrap neat and tight, or loose and messy?
3. When you unclip the electromagnet from the battery, does it still pick up paperclips? Why or why not?
4. How do you demagnetize the nail?
5. Why is this thing called an electromagnet and not just a magnet?
6. Which object made the best electromagnet?
7. Where specifically on the nail did the paperclips get picked up?

Lesson #16: Motors and Generators

Overview Inside your motor are permanent magnets and an electromagnet (the copper thing wrapped around the middle). Normally, you'd hook up a battery to the two tabs (terminals) at the back of the motor, and your shaft would spin. However, if you spin the motor shaft with your fingers, you'll generate electricity at the terminals. But how is that possible? That's what this lab experiment is all about.

What to Learn Students will learn the role of electromagnets in the construction of electric motors and electric generators.

Materials

- 9-18V DC hobby motor
- Bi-polar LED
- 2 alligator wires
- Propeller
- Hair dryer (You brought one from home, right?)
- Optional: Digital Multimeter (DMM) from previous *Electricity unit*

Lab Time

1. Take your motor and open up the tabs on the end (if they are down).
2. Insert one leg of the LED into the small hole in the back of the motor on the terminal. Bend the wire back up and secure it tightly around itself so it won't come off.
3. Do this for the other leg and second motor terminal.
4. Give your shaft a spin. What happened? Write it here:

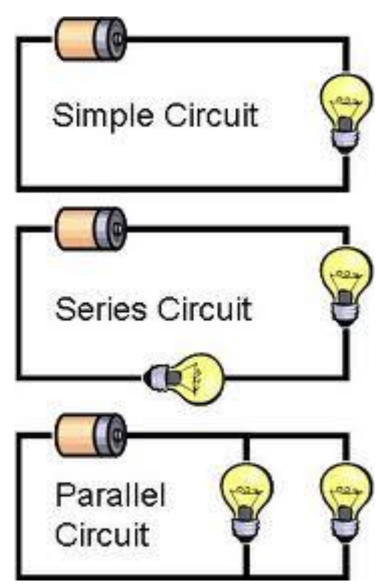
   ____

5. Can you use your alligator wires and work with another lab group's motor to see if you can get your LED to light up brighter and longer? If you don't have a DMM, complete data table #1 to finish up the lab. If you do have a DMM, skip this step and move onto the next step to complete data tables #2 and 3.

Motors & Generators Data Table #1

Move around the room to find additional lab partners to work with.

Number of Motors Connected *(ex: "2 motors in series" or "3 motors in parallel")*	**Brightness** *(Use a scale of 1-10 where 10 = brightest)*



Exercises

1. How and why does the LED change colors?

2. Why does it matter which way the air flows over the propeller (at the front or the back)?

3. Which set of conditions gave you the most energy from your generator?

6. Complete the data table #2.

Motors & Generators Data Table #2

Remove the LED and clip on a DMM probe to each terminal to measure the peak voltage.
Use the 20 VDC setting on the DMM.

Lab Partner Name	Number of Volts Generated When they Spin

7. Attach the propeller to the motor shaft securely.
8. Have one student hold the motor (or mount it on the edge of a stack of books and secure with tape).
9. Remove the DMM probes and attach the LED to the back of the motor.
10. Plug in your hair dryer.
11. Aim the hair dryer at the propeller. What happens to the LED?
12. Play with the distance and angle of the hair dryer. What is the best place to blow air over the propellers so the LED lights up the brightest? Write it here:

____

13. Remove the LED and attach the DMM probes to the motor terminals.
14. Complete the data table #3.

Motors & Generators Data Table #3

Hair Dryer Setting *(Low, Med, High…?)*	**Location from Propeller** *(Example: 4" behind, 6" in front…)*	**Voltage Generated** *(Don't forget units!)*

Reading

If you move a magnet along the length of a wire, it will create a very faint bit of electricity inside the wire. If you moved that magnet back and forth fast enough you could power a light bulb. However, by fast enough, I mean like 1,000 times a second or more! If you had a stronger magnet, or many more coils in your wire, then you could make a greater amount of electricity each time you moved the magnet past the wire.

A motor has a coil of wire wrapped around a central axis, so instead of rubbing back and forth (which is tough to get going fast enough, because you have to stop, reverse direction, and start moving again every so often), it rotates past a set of magnets continuously.

When you add a battery pack to the motor terminals at the back, you energize the coil inside the motor, and it begins to rotate to attempt to line up its north and south poles. But the magnets are lined up in a way that it will continually 'miss' and overshoot, which keeps the shaft spinning over and over, faster and faster.

When you remove the batteries from the motor and attach an LED instead, you transform the motor into a generator. When you spin the shaft with your fingers, you are converting rotation energy into electrical energy, which is seen when the LED lights up. The coil spins inside, moving past a set of magnets. Remember from *Experiment 13: Galvanometers* that when you move a magnet past a coil of wire, it creates electricity? That's exactly what's happening to light up your LED when you spin the shaft.

Exercises

1. How and why does the LED change colors?
2. Why does it matter which way the air flows over the propeller (at the front or the back)?
3. Which set of conditions gave you the most energy from your generator?

Lesson #17: Quick 'n' Easy DC Motor

Overview One of the big mysteries of the universe is why we can't separate the north from the south end of a magnet. No matter how small you break that magnet down, you'll still get one side that's attracted to the north and the other that's repelled. There's just no way around this! Or is there?

What to Learn Today, you get to find out how magnetic fields interact with each other and cause things to rotate. In this case, we're using an electromagnet and a permanent magnet so we can turn our motor on and off.

Materials

- AA battery
- 5 different sizes of metal screws
- 6" insulated wire
- Very strong metal magnet

Lab Time

Watch your fingers on this experiment – if you're not careful and leave your wire contacting the magnet too long, you'll roast your battery (and that's really bad).

1. Place your magnet on the head of the screw.
2. Put the point of the screw on the plus end of the battery. Everything should hold together if you've got a nice, strong magnet.
3. Fan the ends of one end of the wire out to make it look like a little paintbrush.
4. Hold the battery in your hand with the negative side up.
5. Take the other end of the wire and press it on the negative end of the battery with your finger. Hold the battery with the rest of your fingers so that the magnet dangles an inch or two above the table.
6. Take the little wire paintbrush end and barely touch the top of the magnet. The magnet and screw should start to spin!
7. **Note: Do not leave the paintbrush wire attached to the magnet or you will roast your battery (which may explode).**
8. You may need to re-center your screw, especially once you really get it going.
9. Complete the table for all the screws, trying each one on either the positive or negative terminal.

Quick DC Motor Data Table

Screw Size/Description *(Example: 2" brass screw)*	**Which Terminal is the Screw Attached to?** *(positive or negative)*	**Spin Rate** *Rate on scale: (very slow/slow/medium/fast/very fast)*

Reading

If you COULD separate the north from the south pole, you could point a magnet's south pole toward your now-separated north pole, and it would always be repelled, no matter what orientation it rotated to. Normally, as soon as the magnet is repelled, it twists around and lines up the opposite pole and SNAP! (*there go your fingers*.) But if it were always repelled, you could chase it around the room or stick a pin through it so it would constantly move and rotate.

Well, what if we sneakily use electromagnetism? Note that you can use a metal screw, ball bearing, or other metal object that easily rotates. If your metal ball bearing is also magnetic, you can combine both the screw and the magnet together.

Famous scientist Michael Faraday built the first one of these while studying magnetism and electricity, and how they both fit together. Here's what he figured out:

The current from the battery is flowing through the wire, creating a magnetic field around the wire, which interacts with the magnetic field in the gold disk magnet. Since the wire creates a magnetic field that is perpendicular to the field in the gold magnet, the magnet feels a push, which causes it to rotate.

Exercises

1. How does this experiment work?
2. What happens if you reverse the polarity and attach the screw to the negative side of the battery?
3. How do you get your motor to spin the fastest?

Lesson #18: Homemade Relay Shockers

Overview Today, you get to learn how to use an electrical switch that uses magnetism in order to operate. And you can shock yourself silly with this experiment at the end when you turn it into a buzzer.

What to Learn Relays are switches that turn on and off with electricity. They can be NO (normally open) or NC (normally closed), depending on how you hook them up. This relay experiment will actually give a nice blue spark when fired up, along with a nice zap to the hand that touches it in just the right spot. You can also use this relay in your electricity experiments as a switch you can use to turn things on and off using electricity (instead of your fingers moving a switch).

Materials

- Relay
- AA battery case
- 2 AA batteries
- LED
- Motor
- 9V battery with clip
- Alligator wires

Lab Time

This lab has two parts. The first walks you through how to use the relay as a switch, and the second shows how to wire up the relay so it's a buzzer/shocker.

Using the relay as a switch:

1. Snap the clip onto the 9V battery.
2. Connect the red positive wire from the 9V battery to an alligator clip lead. Connect the other end of the alligator clip lead to one side of the coil (the video will show you how to find out which tab on your relay this is).
3. Connect the black negative wire from the 9V battery to another alligator clip lead.
4. Tap the other end of this alligator clip lead to the other side of the coil (again, the video will show you how to find out which tab on your relay this is). Your relay should *click*. *Don't connect this wire permanently to the relay. Just tap it.*
5. Set this circuit aside. Leave the alligator clip from step 5 next to but not touching the relay terminal.
6. Insert your AA batteries into the case. Flat side (minus) goes to the spring.
7. Attach one alligator clip to each of the metal tips of the wires from the battery case. Make sure you've got a good metal-to-metal connection. You should now have two alligator clips attached to the battery pack.
8. Attach the end of the alligator clips that's connected to the black wire (negative) from the battery case to the flat side of the LED. It doesn't matter what color the alligator clip wire is.

9. Attach the other alligator clip that's connected to the red wire (positive) from the battery case to the longer LED wire. Again, it doesn't matter what color the alligator clip wire is.
10. Your LED should light up!
11. Once your LED is illuminated, what happens if you take it out and insert it in the opposite way into the circuit? (Reverse the polarity.) Does it still work?
12. You now have two circuits – one that lights up the LED and one that makes the relay click. Let's combine them so that when the relay clicks, it turns on the LED.
13. Remove one of the wires from the LED and replace it with a third wire. Spread this out in a big circle on your desk. When you touch the two free alligator clip leads together, the LED should still light up.
14. Now pull over your relay circuit. Clip one of the free alligator clip leads to the second and third contact of the relay on the same row of contacts of your relay.
15. Energize your coil by taping the alligator clip from step 5 to the terminal so it clicks. What happens? Write it here:

    ____

16. Move the alligator clip from terminal 3 to terminal 1 and then tap the coil to click the relay. How does this change your circuit? Write it here:

    ____

17. Can you replace the LED with a motor? Can you switch on the motor using the relay?
18. Can you figure out a circuit that will make both motor and LED work at the same time?
19. Draw one of the relay circuits that worked here, labeling all the parts:

Using the relay as a buzzer/shocker:

1. Remove all of the alligator leads from the previous steps.
2. We want to wire the relay so it energizes itself, because we want it to do it very quickly.
3. Clip one alligator clip lead to the coil, and the other end goes to the positive wire of the 9V battery.
4. Clip a second alligator clip to one of the contacts that the internal switch is normally touching when it's not energized. The other side of the alligator clip wire goes to the negative wire of the 9V battery.
5. Connect a third alligator clip lead to the bottom contact in the same row of contacts as the lead from step 3. (find the contact that is normally touching when the coil is *not* energized), and the other end of the alligator clip lead goes to the other side of the coil.
6. The relay should be buzzing! Can you find the blue spark? You can touch it – the amps are low so it's a nice, safe little zap.
7. How does this work? Why does the relay engage itself and disengage?
8. Draw the circuit with the three wires and battery and relay here (also indicate where to touch to receive a zap):

Reading

A relay is switch you can turn on and off using electricity. It uses an electromagnet to active the switch inside it. Relays are operated with a lower-power signal, but can switch a circuit of a high-power signal. They are often used when multiple circuits need to be controlled by one signal. The first relays used were in long-distance telegraph circuits as repeaters. They would repeat the incoming signal from one circuit and retransmit it to another circuit. The next lab, *Experiment 19: Telegraphs and Relays,* shows this very experiment.

There are many different types of relays: latching relays (shown in this video and also in the *Electricity* unit *Experiment 18: Latching Circuits*), reed relays (refer to *Experiment 7: Magnetic Sensors*), mercury switches (where the contacts are wetted with mercury, contactor (used for heavy-duty electric motor circuits), solid-state (which doesn't have any moving components), and more. In addition, some relays are SPST (single-pole single-throw) while others are DPDT (double-pole double-throw).

Exercises

1. Is there a permanent magnet and/or an electromagnet inside a relay?

2. What makes the relay a switch?

3. What makes the relay turn on and off (*click*)?

4. Is the same power source that activates the relay also used for the circuit it's switching?

Lesson #19: Relays and Telegraphs

Overview In this lab, we're going to build our own relay that will attract a strip of metal to make our telegraph 'click' each time we energize the coil.

What to Learn Relays *are* telegraphs, and they both are basically "electrical switches." This means you can turn something on and off without touching it – you can use electricity to switch something else on or off, as we did in the last experiment.

Materials

- Block of foam about 6" square
- Sandpaper
- Alligator wires
- Battery case
- AA batteries
- Film canister or similar
- 2-4" nail
- Magnet wire
- Brass fasteners
- 1/2″ strip from a steel soup can for the clicker
- Paper clip
- Hot glue gun
- Scissors
- Tape

Lab Time

IMPORTANT! This experiment is very tricky to get working right. You'll want to pair up with someone who's handy in the workshop and has a keen eye and a feather touch for adjusting the clicker in the final step. Someone who is a patient, fix-it type of person will be able to help you get this project working well.

1. Review the instructions on their worksheets and then break the students into their lab groups. Hand each group their materials.
2. Watch the video as you walk through these steps:
3. Make the electromagnet first. Wrap the magnet wire around the nail. (More wraps mean more power for your magnet, so use a lot!) You can insert a nail into a drill and wind it on slow speed.
4. Sand the insulation off the end leads.
5. Insert the AA batteries into their case.
6. Stick the electromagnet, pointy-end down, into the foam. If it wiggles around, you will need to hot glue it into place later (not now).
7. Hot glue one end of the clicker (the steel soup can piece) to the top of a film canister.

8. Attach the bottom of the film canister to the foam with hot glue, making sure the tip of the clicker is over the nail head. Do not glue the lid to the canister! It's a big plus to have it rotate and be adjustable.
9. Adjust and bend the clicker so that the electromagnet and nail have a *tiny* clearance between the nail head and the metal strip. You'll be adjusting this constantly as you play with your relay.
10. Hot glue the battery case to the foam off to one side.
11. Remove some of the insulation from the wires from the battery case. You need more wire exposed to wrap it around a brass fastener.
12. Wind the free end of the exposed wire from the negative black wire of the battery case around a brass fastener and insert it into the foam. Make sure you're only wrapping the part you've stripped or it won't make a good connection.
13. Bend a paperclip into a "V" shape.
14. Insert the brass fastener through the tip of the "V" shape and then into the foam. Do not use glue.
15. Wrap one of the electromagnet wires around a second brass fastener, making sure to only wrap the part of the wire that you sanded, and insert the fastener into the foam within reach of the paperclip. Be sure the smaller side of the "V" rests on the foam such that it does not reach the brass fastener; but the larger side of the "V", when pressed down, does. This is your switch.
16. Clip an alligator clip wire onto the positive battery wire, the other end connected to the last electromagnet wire. Again, make sure you're connecting to the part of the electromagnet wire that is sanded or it won't make a good connection.
17. Push your switch to the "ON" position (make it touch the second brass fastener), and the electromagnet should *click*.
18. ***Troubleshooting:*** If it doesn't click, move your electromagnet up or down, changing the nail-head-to-clicker distance until it clicks. If it sticks, it's too close. If it doesn't move at all, it's too far away. Hot glue the nail into the right position. Note that the clicker is bendable. Take your time – this is a project that requires patience and observation to figure out what's going on. If you're frustrated, STOP, take a breath, help someone else, and return later.

Reading

Why does this work? Anytime you run electricity through a wire, a magnetic field shows up. We're multiplying this effect when we coil the wire around a nail. A nail with wire wrapped around it is called an electromagnet. Think of it like a magnet you can turn on and off.

Using a paper-clip switch, we can turn the electricity on and send it through the electromagnet, turning the ordinary nail and wire into a magnet. When we release the paper-clip switch, the current (electricity) stops flowing and our electromagnet turns back into ordinary nail and wire.

When the electromagnet is energized (magnetized), it attracts the metal strip, which causes it to click downwards. Release the paper-clip switch, and the strip is no longer attracted to the nail (because it's no longer a magnet).

When the switch is on, it's a magnet. When it's off, it's not a magnet. Magnets attract steel, and that's why the strip bends and clicks. It's amazing we could communicate over thousands of miles this way, but we did, using telegraphs and repeaters!

Exercises

1. Why does the soup can clicker move?
2. Does this circuit use a permanent or electromagnet?
3. Why do we need multiple turns around a nail? Why not just a couple wraps?
4. What is the paper-clip switch used for?
5. How can a relay be used in real life? Give three examples.

Lesson #20: DC Motor

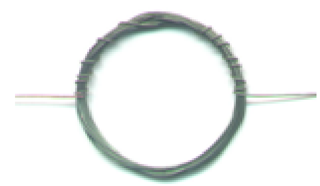
Overview Today, you get to baffle most adults by making a simple motor that really looks like it's impossible to explain. There's a sneaky trick to it that makes it work, and will make you look like a genius.

What to Learn You are about to make a simple electric motor that uses both permanent and electromagnets to rotate by interacting with each other.

Materials

- Magnet
- Magnet wire (26g works well)
- D cell battery
- Two paper clips (try to find the ones shown in the video, or else bend your own with pliers)
- Sandpaper
- Fat rubber band

Lab Time



1. Wind the magnet wire around a D-cell battery 15 times. Carefully remove the coil, holding it with your hands so it doesn't spring open.
2. Unwrap about 3 inches from each end of the wire.
3. Coil the end of the wire around the loop a couple of times to keep the wires together. Be sure that the "ears" are straight (see image right). This is now your 'rotor'.
4. IMPORTANT! Remove the insulation from 3 of the 4 sides. Sand the entire length of both ears, flip the rotor over, and sand only one ear side, leaving the insulation untouched on the side of the remaining ear.
5. Wrap the rubber band around the battery lenthwise twice.
6. Untwist a paper clip to make the shape:.

7. Make two of these paper clip shapes (above). Use pliers to make the shape if you're having trouble.
8. Place the left end under the rubber band in the center of the each end.
9. The loop on the right end is where the rotor ear will slip through. Slide the rotor into the loops.

10. Spin the rotor *gently.* It should spin without wobbling. Readjust and balance the rotor until it's centered and spinning freely.
11. Place the magnet on the battery. If it doesn't stick to the battery, slide it under a rubber band.
12. You want the rotor to be as close to the magnet as possible without hitting it.
13. Give it a spin, and adjust the distance as needed to keep the rotor spinning.
14. Troubleshooting: Usually problems arise between the connection of the battery terminals and paper clips. Hold the battery with the fingertips in the center of each battery end and squeeze to make a good connection. If it still fails to spin, check your rotor: one ear should be completely sanded and the other should have a strip of insulation down its length. If you're still having trouble, check the ears to be sure they are straight. The rotor needs to be able to spin nicely, so ensure it is well-balanced. Egg-shaped rotors just won't turn.

Reading

How does this work? When you run electricity through a wire, it turns the wire slightly into a magnet. When you stack wires on top of each other (as you did with the coil of wire), you multiply this effect and get a bigger magnet.

The coil of wire is the O-shaped ring. When the sanded parts of the "ears" are connected to the paper clip, current flows through the circuit. When this happens, everything connects together and turns the coil wire into an electromagnet, which is then attracted to the magnet on the battery.

When the O-ring rotates, it moves around until the un-sanded portion breaks the connection and turns it back into just a coil of wire. The coil continues to float around in a circle until it hits the sanded parts again, which re-energizes the coil, turning it back into an electromagnet, which is now attracted to the magnet on the battery, which pulls it around again…and 'round it goes!

Exercises

1. Will the DC motor work without the magnet?
2. Where is the electromagnet?
3. Why does this work?

Lesson #21: Hearing Magnetism

Overview Want to *hear* your magnets? We're going to use electromagnetism to learn how you can listen to your physics lesson, and you'll be surprised at how common this principle is in your everyday life.

What to Learn When a magnet moves next to a coil, it creates an electrical current in the coil. In a microphone, a magnet moves at the frequency of your voice next to a coil, which transmits your sound vibrations to an electrical signal.

Materials

- Magnet wire
- Sandpaper
- 3 nails
- 4 different magnets
- Audio amplifier (RS #277-1008)
- Audio plug (RS #42-2420)

Lab Time

1. Wind the magnet wire around the nail to make the electromagnet. Use a drill if you want to speed this up.
2. Use sandpaper to strip off the enamel coating of both ends of the magnet wire.
3. Take the audio plug apart by untwisting the casing from the metal pin.
4. Thread the metal wires from the electromagnet through the metal casing, narrow end first.
5. Thread one of the wires through the bottom hole of the metal plug and fold it back over into itself, twisting to secure it into place. Make sure you've sanded well to make a good metal connection.
6. Put the second electromagnet wire through two of the side tab holes, twist to secure.
7. Wrap each connection with a piece of tape to insulate them from each other. Since these wires are exposed in a tight space, it's easy for them to touch each other and short circuit.
8. Twist the casing back onto the metal plug.
9. Plug this into your audio amplifier. You should have an electromagnet plugged into the amplifier.
10. Make sure you have a 9V battery in your amplifier!
11. Turn on the amplifier. Turn the volume all the way up!
12. Bring a magnet close to the electromagnet, rubbing it along its length. What happened? Write it here:

____

____

13. Cover the electromagnet loosely with a sheet of aluminum. Now wave the magnet around. What happened?

____

14. Complete the data table.

Hearing Magnetism Data Table

Which electromagnet?	**Which magnet did you use?**	**What did you do?**	**What did it sound like?** *Loud, soft, rough, scratchy, clicky, etc.*
100 turns	*2" rectangle*	*Rubbed a magnet close to electromagnet*	*Loud and scratchy*

Reading

We're going to invert the ideas used in an experiment (*Homemade Speakers*) into a basic microphone. Although you won't be able to record with this microphone, it will show you how the basics of a microphone and amplifier work, and how to turn sound waves back into electrical signals.

An amplifier's job is to take small electrical voltages (AKA the 'input') and make them bigger (*amplify* them). Then, we usually plug a speaker or headphones into the amplifier and those turn the bigger electrical signal (AKA the 'output') into sound. So any small voltage that we plug into the amplifier's input will get larger and then turn into sound through the built-in speaker.

One way to show this is to use a coil of wire and a magnet. If you take a coil of wire and move a magnet past, around, or through it, you will create a small electrical voltage (and current) in the wire. In fact, if you have enough wire and a big enough magnet, and move the magnet fast enough, the electricity coming out of the coil of wire can light up a light bulb (this is how an electric generator works).

So back to the amplifier: If we take the voltage from our little coil/magnet generator, and we put it into the amplifier, we'll hear the sound from the speaker each time it makes a voltage. If we move the magnet back and forth really fast, we'll hear a fast clicking sound. And if we were to move it super-incredibly-fast (faster than you could with your hands), then those clicks would blend together into a tone. Tones like this are what all sounds are made of.

In fact, this is exactly what a microphone does. Many microphones have a magnet and a coil of wire attached to a very thin piece of plastic or metal that vibrates when sound waves hit it. The plastic (or metal) in turn moves the coil of wire next to the magnet super-fast. Then this causes the electric voltage to come out of the coil, and if you plug it into an amplifier it will make the same sound that the microphone heard, only louder.

Exercises

1. Why does the electromagnet make sound when you bring the permanent magnet close to it?
2. How is this like a microphone?
3. What did the aluminum do to the electromagnet?

Lesson #22: Rail Accelerator

Overview We're going to be making a tiny set of wheel zip down a track. This is how roller coasters and fast trains move down the rail, powered only by magnetism.

What to Learn Two magnetic fields at right angles (perpendicular) interact to each other to causes things to move, spin, rotate, and roll out of the way.

Materials

- Cardboard or poster board
- Aluminum foil
- Hot glue or double-sided sticky tape
- Scissors
- Wire coat hanger
- Two very tiny, neodymium metal-coated disc magnets (www.kjmagnetics.com Part #D21)
- 9V battery with clip
- 2 alligator clip leads
- Stopwatch
- Ruler or measuring tape

Lab Time

1. You can experiment with different length of track as shown in the data table, or just make one (in that case, you won't be using the data table).
2. Cut out two strips of aluminum foil (refer to data table for length). The width is approx 2-3" wide.
3. Using glue or tape, stick the aluminum strips down on your poster board a finger's-width apart (about a half inch). If you're using tape, tape only to the underside of the foil, not the topside.
4. Cut a 2" long straight piece from your wire coat hanger using vise grips.
5. Place the wheel at each end, placing the wire in the center. They should stick by themselves. Make them as centered as possible.
6. Attach the clip to your battery.
7. Attach one alligator wire to the wire from your 9V battery. The other end of this wire clips onto one side of the aluminum track.
8. Attach a second alligator wire to the other wire from your 9V battery. The end of this wire clips onto the other side of the aluminum track.
9. Set your wheels gently on the track and see if they take off. If they don't, try these things:
   a. If you drop your wheels from too high up, you'll knock the axle off-center and the wheels won't roll.
   b. If your wheels still don't roll, flip one of the magnets around. The magnets must be in opposite directions for this to work.
   c. Make sure you've got a fresh 9V battery.
   d. Do you have a good electrical connection between your clips and the track? No tape in the way?

10. **Do NOT** leave the wheels on the track if they are not moving. This will short circuit your battery and toast it (not a good thing).
11. Complete the table if you're trying different track lengths.

Rail Accelerator Data Table

Lab Group Name	Length of Track *(feet, cm, inches…?)*	Time to Travel Length *(seconds)*	Average Speed *(Speed = Length ÷ Time)*

Reading

This rail accelerator is really just two of the motors from *Quick 'n' Easy DC Motor* connected together. Instead of wire, we are using an aluminum rail. The magnetic field in the rail creates a force perpendicular to the tiny magnet's magnetic field. These two magnetic fields interact, causing the little wheels to roll.

If you have the wheels on 'backwards' (or your battery connected backwards), your wheels will roll toward (instead of away) from you.

Troubleshooting: If you drop your wheels from too high up, you'll knock the axle off-center and the wheels won't roll. If your wheels still don't roll, flip one of the magnets around (they must be in opposite directions for this to work!). Also, make sure you've got a fresh 9V battery and good electrical connection between your clips and the track.

Exercises

1. Do the magnets need to be opposite in order for this to work?
2. Why do the wheels move?
3. Which track works the best?

Lesson #23: Homemade Speakers

Overview We'll be making different kinds of speakers using household materials (like plastic cups, foam plates, and business cards!), but before we begin, we need to make sure you really understand a few basic principles.

What to Learn An electrical signal (like music) zings through the coil (which is also allowed to move and attached to your speaker cone), which is attracted or repulsed by the permanent magnet. The coil vibrates, taking the cone with it. The cone vibrates the air around it and sends sounds waves to reach your ear.

Materials

- Foam plate (paper and plastic don't work as well)
- Sheet of copy paper
- 3 business cards
- Magnet wire AWG 30 or 32 (RS#278-1345)
- 2-4 neodymium or similar (rare earth) magnets
- Disc magnet (1" donut-shaped magnet) (RS#64-1888)
- Index cards or stiff paper
- Plastic disposable cup
- Tape
- Hot glue gun
- Scissors
- 1 audio plug (RS #42-2420) or other cable that fits into your stereo (iPODs and other small devices are not recommended for this project – you need something with built-in amplifier)

Lab Time

1. Cut a business card in half lengthwise. Fold each strip in half, and then fold the lengths in half again so you have a W-shape.
2. Stack your magnets together and roll a small strip of copy paper around the magnets. Tape the paper into place. Do this one more time, so you now have two paper cylinder sleeves around your magnets.
3. Wrap the magnet wire 20-50 times around the paper tube (keep the magnets inside so this step is easier). Secure with tape.
4. Carefully remove only the *inside* paper sleeve and discard (you can take the magnets out when you do this).
5. Trim one side of the paper so one side of the coil is near the paper edge.
6. Hot glue the uncut side of the paper tube to the bottom of a foam plate.
7. Hot glue one side of the W-shape of the business card to the bottom of the foam plate. You want a W-shape on either side of the paper tube, an inch or two away.
8. Hot glue your magnets to the center of a stiff piece of cardboard.
9. Place your paper tube over the magnets and glue the W-shapes to the cardboard. These are your 'springs' .
10. Tap the plate lightly with your finger. Make sure the foam plate is free to bounce up and down.

11. Sand the ends of each magnet wire to strip away the insulation.
12. Unscrew the plastic insulation from the audio plug and wrap one wire around each terminal. Make sure the two contacts and wires don't touch each other, or your speaker won't work. You can secure each connection with tape.
13. Plug it into your boom box and play your music on the highest volume. You should hear the music coming from your speaker!

Lesson Reading

We've come a long way with this magnetism thing and hopefully you're feeling pretty good about how magnetism works and what it does. Now we're going to use what we've learned to make simple versions of two gadgets that you use every day.

Let's talk about a telegraph, since that's something you probably have experience with. A telegraph is a small electromagnet that you can switch on and off. The electromagnet is a simple little thing made by wrapping insulated wire around a nail. An electromagnet is a magnet you can turn on and off with electricity, and it only works when you plug it into a battery.

Anytime you run electricity through a wire, you also get a magnetic field**.** You can amplify this effect by having lots of wire in a small space (hence wrapping the wire around a nail) to concentrate the magnetic effect. The opposite is true also – if you rub a permanent magnet along the length of the electromagnet, you'll get an electric current flowing through the wire. Magnetic fields cause electric fields, and electric fields cause magnetic fields. So how does that translate into sound?

Sound is vibrations. If something vibrates between a frequency of 20-20,000 Hz our ears can detect it as sound.To make a speaker, we need to somehow make something vibrate. You should be thinking: *"Hmmm, I wonder if this magnetism/electricity could somehow be useful here."*

So what's going on with a speaker? What makes it work? Okay, here's the deal. The radio provides the electricity that gets pumped through the wires. The radio very quickly pumps electricity in one direction and then switches to pump it in the other direction. This movement of electrons back and forth creates a magnetic field in the coil of wire.

Since the electricity keeps reversing, the magnetic field keeps reversing. Basically, the poles on the electromagnet formed by the coil go from north to south and back again. Since the poles keep reversing, the permanent magnet you have taped to the cup keeps getting attracted, then repelled, attracted, then repelled. This causes vibrations.

The speaker cone (or cup, as in the speaker we're going to make) that's strapped to the coil and magnet acts as a sound cone. The magnet causes the sound cone to vibrate and since it's relatively large, it causes air to vibrate. This is the sound that you hear.

Almost all speakers work just like the one you are going to create now. They just use fancier materials so that the sound is louder and clearer.

These speakers we are making in this experiment are created from cheap materials and are for demonstration purposes only… they do not have an amplifier, so you'll need to place your ear close to the speaker to detect the sound. **DO NOT connect these speakers up to your iPOD or other expensive stereo equipment**, as these speakers are very low resistance (less than 2 ohms) and can damage your sound equipment if you're not careful. The best source of music for these speakers is an old boom box with a place to plug in your headphones.

Just to clarify: a microphone has a small electromagnet next to a permanent magnet, separated by a thin space. The coil is allowed to move a bit (because it's lighter than the permanent magnet). When you speak into a microphone, your voice sends sound waves that vibrate the coil, and each time the coil moves, it causes an electrical signal to flow through the wires, which gets picked up by your recording system.

A loudspeaker works the opposite way. An electrical signal (like music) zings through the coil (which is also allowed to move and attached to your speaker cone), which is attracted or repulsed by the permanent magnet. The coil vibrates, taking the cone with it. The cone vibrates the air around it and sends sound waves to reach your ear.

If you placed your hand over the speaker as it was booming out sound, you felt something against your hand, right? That's the sound waves being generated by the speaker cone. Each time the speaker cone moves around, it create a vibration in the air that you can detect with your ears. For deep notes, the cone moves the most, and a lot of air gets shoved at once, so you hear a low note. This is why you can easily blow out your speakers if your bass is cranked up too much.

Exercises

1. Does it matter how strong the magnets are?
2. What else can you use besides a foam plate?
3. Which works better: a larger or smaller magnet wire coil?
4. How can you detect magnetic fields?
5. How does an electromagnet work?
6. How does your speaker work?
7. Is a speaker the same as a microphone?
8. Does the shape and size of the plate matter? What if you use a plastic cup?

Electromagnetism Evaluation

Student Worksheet

Overview: Today, you're going to take two different tests: the quiz and the lab practical. You're going to take the written quiz first, and the lab practical at the end of this lab. The lab practical isn't a paper test – it's where you get to show your teacher that you know how to do something.

Lab Test & Homework

1. Your teacher will call you up so you can share how much you understand about electromagnetism and how it works. Since science is so much more than just reading a book or circling the right answer, this is an important part of the test to find out what you really understand.
2. While you are waiting for your turn to show your teacher how much of this stuff you already know, you get to get started on your homework assignment. The assignment is due next week, and half the credit is for creativity and the other half is for content, so really let your imagination fly as you work through it.

   Here it is: Your classroom is going to be converted into an interactive science museum next week. You will be in charge of one of the stations. Your audience knows nothing about magnetism. Your job is to design and build an experiment that teaches the students in lower levels an important concept in one of the following areas: magnetism or electromagnetism. You will get to explain to your students what's going on as you demonstrate your experiment. You can have them watch or actively do something at your station. You will be graded based on content and creativity, so really let your mind go wild. (Hint: If you were the audience, what would *you* want to learn about most?)

Electromagnetism Quiz

Name____

1. Why didn't the coil of wire on an electromagnet work when it wasn't hooked up to a battery? What does the battery do to the coil of wire?

2. Why is it called an 'electromagnet' and not just a 'magnet'?

3. What's inside a DC motor?

4. How can we use electromagnets to make things move? Give an example.

5. Give an example of how electricity causes magnetism.

6. Give an example of how magnetism causes electricity.

Electromagnetism Lab Practical

Student Worksheet

This is your chance to show how much you have picked up on important key concepts, and if there are any holes. You also will be working on a homework assignment as you do this test individually with a teacher.

Materials:

- AA battery case
- 2 AA batteries
- Alligator clip leads
- Plain nail (not wrapped in wire)
- Electromagnet (nail already wrapped in wire), ends *not* sanded
- Electromagnet (nail already wrapped in wire), ends sanded down
- Paper clips
- 9-18 VDC motor
- LED

Lab Practical:

- Design and build an electromagnet that picks up paperclips.

- Design and build an experiment that shows how magnetism creates electricity.

Answers to Exercises and Quizzes

Lesson #1: What's Magnetic

1. Which objects are attracted to the magnet? (Objects containing iron, nickel, cobalt, or gadolinium)
2. Are all metal objects attracted to the magnet? (No. See #1 above)
3. Does the shape of the magnet matter? (No, but we'll explore where the poles are on different magnets next time.)
4. Are things attracted to the magnet if they have to pass through something that isn't, like a piece of paper? (Yes – magnetic force can travel through materials that are not attracted to the magnet.)

Lesson #2: Breaking Magnets

1. How many poles does a magnet have? (Two.)
2. What happens when you try to separate the poles? (The magnet sprouts two like poles at the break point, making two magnets each with two opposing poles.)
3. Were you able to put the magnet back together into one single magnet? (No. They are permanently separate magnets with their own poles.)
4. Where are the poles on the circular magnet? Is this different from your rectangular magnet? (This is going to vary depending on your magnet, but most circular magnets have a top-bottom pole location while some rectangular magnets have the poles at either end.)

Lesson #3: Which Way is North?

1. How are the lines of force different for the two magnets? (Since this is going to depend on the kind of magnets you use, refer to the data collected.)
2. How far out (in inches measured from the magnet) does the magnet affect the compass? (Since this is going to depend on the kind of magnets you use, refer to the data collected.)
3. What makes the compass move around? (The magnetic lines of force that are invisible to your eye.)
4. Do you think the compass's *north-south* indicator is flipped, or the Earth's North Pole is where the South Pole should be? How do you know? (It's an arbitrary denotation, but the Earth's North Pole is deemed to be north.)

Lesson #4: Flying Paperclip

1. Circle one: The closer you get to the magnet, the (**stronger** weaker) the force of the magnetic field is on the paper clip.
2. Why does it matter which way you orient the magnet in this experiment? (The magnetic force is strongest at the magnetic poles.)
3. Which magnet has the strongest magnetic field? (Refer to your data.)
4. Is the north or south pole stronger on a magnet? (Neither – they are identical in force.)

Lesson #5: Bouncing Magnets

1. Why does the magnet float? (Like poles repel each other, right? But there's one more step in understanding this experiment – it's not just the poles we are dealing with, it's the magnetic fields. Remember that a magnet has field lines that connect the two poles, and it's the magnetic fields that are doing the repelling.)
2. After you tap the floating magnet, does it vibrate for a short or long time? Why? (Loooong because there's little friction in the experiment.)
3. Why do we stack the magnets first before trying to levitate them? (Initially your magnets stack up because they are north on the top surface and south be the entire bottom surface. The poles are all facing the same way so the like poles will repel and levitate the magnet.)

4. How many magnets can you get to interact while floating? (My personal record is six.)
5. When you float two magnets above the main magnet, how do the floating magnets interact with each other? Why do they do that? (When one magnet starts bouncing, the magnetic field changes, which pushes and pulls on the other magnet. The two magnets interact with each other through their magnetic fields, pushing and pulling each other into resonance. There's an energy transfer going on between the magnets.)

Lesson #6: Magnetic Fields
1. Why can't you simply rub the needle back and forth with the magnet? Why do you have to stroke it in one direction? (When you rub the needle with the magnet, you line up the iron atoms all in the same direction. If you rub in both directions, then the atoms get lined up every which way.)
2. What other objects/materials can you use to make a compass? (Anything with iron, nickel, or cobalt in it, and put it in a low-friction environment like the end of a pin or floating in water.)
3. How do you know that the needle is magnetized? (When it's aligned with the compass needle.)
4. Why did we float the needle in water? (To keep the friction low, so the needle is free to move and align with the Earth's magnetic field.)

Lesson #7: Magnetic Sensors
1. Where does the magnet need to be located in order for your circuit to work? (You need to have the switch lined up so that the magnet is hovering over the top of one of the strips.)
2. How does the switch work? Draw a picture and label the parts that make it work in the circuit.
3. Can the switch be activated through the side of a drawer, so that the switch is in the inside and the magnet is on the outside? (Yes, magnetic forces can go through materials like paper, plastic and wood as long as they are thin enough for the magnetic field to penetrate.)
4. Which way does the magnet activate the switch the best? How are the poles oriented relative to the switch? (One pole will be pointing to the top of one of the metal strips.)

Lesson #8: Magnetic Boats
1. What shape do three magnets give? Why is this different from the shape that four magnets make? (Equilateral triangle. Four makes a square, because this is the minimum energy pattern.)
2. Why do the magnets flip over when you first place them in the water? (Because they are heavier on the bottom and lighter on top, unless your foam is large enough to prevent them from flipping over.)
3. How many magnets make a hexagon? (Six and seven – the seventh one is in the middle of the hexagon.)
4. How is this experiment like the compass experiments we've done so far? (The magnetized needle is like a tiny magnet floating in the cup of water, just like these are. When you bring a large magnet close, the floating magnets align themselves with the large magnet.)
5. Why do the boats repel each other, yet still hold in a pattern? (The floating magnets repel each other because they have the same pole oriented up. Yet the hold each other in a pattern because of their interacting magnetic fields.)

Lesson #9: Curie Heat Engine
1. Why does the tiny magnet lose its attraction to the large magnet? (Curie temperature is the temperature at which a ferromagnetic material becomes paramagnetic on heating and the effect is reversible. A magnet will lose its magnetism if heated above the Curie temperature.)
2. How long does it take for the attraction-repulsion cycle to repeat? (It depends on the size of your bead magnet and the temperature of your flame. Larger magnets take longer to heat up.)
3. Draw out your experiment, explaining how it works and labeling each part:

Lesson #10: Linear Accelerator

1. Does it really matter where you start the first ball bearing? If so, does it matter *much*? (Refer to your data table.)
2. Why does only the last ball go flying away? Why don't the others break away as well? (Have you ever shot a billiard ball toward another on a pool table and watched the first one stop while the second goes flying? This has to do with a concept known as momentum. The ball furthest from the magnet breaks free because it has enough momentum (which is directly related to speed) to escape the magnetic field of the strong magnet.)
3. What happens if you try this experiment without the magnets? Can you get one ball bearing to transfer all its momentum to a second one? (It works, but the ball doesn't travel as far. The magnets provide extra energy (speed) to the incoming ball, which is transferred to the breakaway ball on impact.)
4. How many inches did the first initial ball (the one you let go of) travel? (Refer to data table.)
5. How many inches did the last ball (the one that detached from the magnet) travel? (Refer to data table.)
6. Why did we use four magnets in the second lab? What did that do? (With each impact, there's an increase in speed. The advanced model is like lining up four of the simple models all in a row.)

Lesson #11: Earth Pulse

1. Does the instrument work without the magnet array? (Yes, but only as a compass.)
2. Why did we use the stronger magnets inside the instrument? (Small lightweight magnets are needed to be used to move the mirrors and detect the fluctuations.)
3. Which planet would this instrument probably not work on? (Venus and Mars)

Lesson #12: Ferrofluid

1. Is the ferrofluid a solid or a liquid? (Both, depending on the conditions it's placed in.)
2. Does the strength of a magnet matter? (Yes. The stronger the magnet, the more the ferrofluid interacts with the magnet.)
3. What would happen if the magnet went over the rim of the cup? (Don't get the magnet above the rim of the cup, or the ferrofluid will stick to the magnet and you'll never get it off again.)
4. Does the ferrofluid have a north and south pole? (Ferrofluid is made up of very tiny particles mixed with water. These particles don't "settle out" but rather remain suspended in the fluid. Each tiny particle has a north and south pole.)
5. What happens if you bring a compass near the ferrofluid? (Nothing, until you bring a magnet close by. But ferrofluid can conceivably be used as a compass.)

Lesson #13: Braking Magnets

1. What is the average speed of your fastest magnet? (Find the shortest time in your data table. Divide the length of the ramp by the time in seconds to get your answer in inches per second.)
2. What makes the magnet slow down the most? Is it the size of the magnet, the strength of magnet, number of magnets, or something else? (The stronger the magnetic field, the more eddy currents it will produce and the more braking the magnet will experience.)
3. What if you stack two aluminum plates on top of each other and use this for a ramp? How would this affect your data? (This is going to depend on the thickness of each plate to begin with, but in general you'll get a slower-moving magnet down the ramp.)
4. Does the angle of the ramp matter? (Yes, but it's not obvious to the naked eye without taking actual measurements because the difference is so small.)

Lesson #14: Galvanometers

1. Why didn't the coil of wire work when it wasn't hooked up to a battery? What does the battery do to the coil of wire? (The wire is just wire until you have electricity passing through it. The electricity causes a small magnetic field around the wire. When you bundle and coil the wire up, you multiply this effect to create an electromagnet.)
2. How does a moving magnet make electricity? (If you moved that magnet back and forth along a coil of wire fast enough you could power a light bulb. However, by fast enough, I mean like 1,000 times a second or more!)
3. What makes the compass needle deflect in the second coil? (When a magnet is moved in and out of the first coil quickly, it creates a current in the wire which travels to the second coil of wire, turning the second one into an electromagnet. An electromagnet is a magnet that you can turn on and off with electricity. Since the compass is affected by magnets, this tells us that the compass is near a magnetic field when it deflects, which means that the wire is creating a magnetic field.)
4. Does a stronger or weaker magnet make the compass move more? (Stronger)
5. Does it matter how fast you move the magnet in and out of the coil? (Yes – the faster you move it, the more the needle deflects.)

Lesson #15: Electromagnets

1. How does the number of wraps affect the electromagnet? (The more times you wrap the wire, the stronger the electromagnet will be.)
2. Does it matter if you wrap neat and tight, or loose and messy? (Neat and tight creates a stronger magnetic field.)

Lesson #16: Motors and Generators

1. How and why does the LED change colors? (Spin the shaft in opposite directions to cause electricity to flow in a different direction. The LED is bi-polar, which means there are actually two LEDs inside, lined up opposite each other. When electricity flows one way, the red LED lights up but not the green. When it flows the other way, the green LED lights up but not the red.)
2. Why does it matter which way the air flows over the propeller (at the front or the back)?
3. Which set of conditions gave you the most energy from your generator? (Refer to your data table).

Lesson #17: Quick 'n' Easy DC Motor

1. How does this work? (When you touch the paintbrush wire to the magnet, electricity starts to flow, which creates a magnetic field. That magnetic field interacts with the magnetic field in the metal magnet, and the result is that it starts to rotate. Two magnetic fields are interacting and causing stuff to rotate.)
2. What happens if you reverse the polarity and attach the screw to the negative side of the battery? (The magnet spins in the opposite direction.)
3. How do you get your motor to spin the fastest? (Make sure the screw is centered on both the battery and the magnet, and that the wire barely touches the magnet.)

Lesson #18: Homemade Relay Shockers

1. Is there a permanent magnet and/or an electromagnet inside a relay? (Electromagnet.)
2. What makes the relay a switch? (When the electromagnet inside is energized, the relay switches things on or off, depending on how the circuit is connected.)
3. What makes the relay turn on and off (*click*)? (When power is added to the tabs that connect to the electromagnet, the electromagnet attracts the metal contact, which makes the click.)
4. Is the same power source that activates the relay also used for the circuit it's switching? (No, they are two different circuits, so you can use a low-power signal to activate the relay but run high-power through the switch contacts.)

Lesson #19: Relays and Telegraphs

1. Why does the soup can clicker move? (When the switch is on, the nail becomes a magnet. When it's off, it's not a magnet. Magnets attract steel, and that's why the strip bends and clicks.)
2. Does this circuit use a permanent or electromagnet? (Electromagnet)
3. Why do we need multiple turns around a nail? Why not just a couple wraps? (Anytime you run electricity through a wire, a magnetic field shows up. We're multiplying this effect when we coil the wire around a nail. A nail with wire wrapped around it is called an electromagnet.)
4. What is the paper-clip switch used for? (Using a paper-clip switch, we can turn the electricity on and send it through the electromagnet, turning the ordinary nail and wire into a magnet. When we release the paperclip switch, the current stops flowing and our electromagnet turns back into ordinary nail and wire.)
5. How can a relay be used in real life? Give three examples. (As part of the circuitry to keep the fridge cold, to repeat signals over long distances, and as a position indicator using a mercury switch.)

Lesson #20: DC Motor

1. Will the DC motor work without the magnet? (No. The electromagnet needs to interact with a magnet in order to move.)
2. Where is the electromagnet? (The coil of wire is the O-shaped ring. When the sanded parts of the "ears" are connected to the paper clip, current flows through the circuit and energizes the rotor into an electromagnet.)

Lesson #21: Hearing Magnetism

1. Why does the electromagnet make sound when you bring the permanent magnet close to it? (When the magnet comes close to the electromagnet, it gets magnetized in increments, which is what the sounds are in the amp as the atoms are lining up.)
2. How is this like a microphone? (The magnet moves in and out at the frequency of your voice next to a coil, which transmits your sound vibrations to an electrical signal. In our experiment, we are physically moving the magnet next to a coil of wire, which is transforming that signal to an electrical signal.)
3. What did the aluminum do to the electromagnet? (The aluminum sheet worked against the moving magnet by creating eddy currents that canceled out the magnet's effect on the electromagnet, so you don't hear very much.)

Lesson #22: Rail Accelerator

1. Do the magnets need to be opposite in order for this to work? (Yes, they must be perpendicular to the track and to the direction of the current flow.)
2. Why do the wheels move? (When electricity flows through the aluminum rail, the magnetic field in the rail creates a force perpendicular to the tiny magnet's magnetic field. These two magnetic fields interact, causing the little wheels to roll.)
3. Which track works the best? (Refer to your data table.)

Lesson #23: Homemade Speakers

1. Does it matter how strong the magnets are? (Yes, the stronger they are, the better the signal you hear from the speaker.)
2. What else can you use besides a foam plate? (Plastic cups, paper plates…)
3. Which works better: a larger or smaller magnet wire coil? (Larger)
4. How can you detect magnetic fields? (With a compass)
5. How does an electromagnet work? (When you put electricity through the wire, it turns it into a magnet.)
6. How does your speaker work? (Refer to the Background Reading Section.)
7. Is a speaker the same as a microphone? (No – they are opposite. Refer to the Background Reading Section.)
8. Does the shape and size of the plate matter? What if you use a plastic cup? (Yes – shape and size do matter!)

Vocabulary for the Unit

If an **atom** has more electrons spinning in one direction than in the other, that atom has a magnetic field. Atoms are made of a core group of neutrons and protons, with an electron cloud circling the nucleus.

The proton has a positive **charge**, the neutron has no charge (neutron, neutral get it?) and the electron has a negative charge. These charges repel and attract one another kind of like magnets repel or attract. Like charges repel (push away) one another and unlike charges attract one another. Generally things are neutrally charged. They aren't very positive or negative; rather have a balance of both.

When electric current passes through a material, it does it by electrical **conduction**. There are different kinds of conduction, such as metallic conduction, where electrons flow through a conductor (like metal) and electrolysis, where charged atoms (called ions) flow through liquids. Metals are **conductors** not because electricity passes through them, but because they contain electrons that can move.

LED stands for "Light Emitting Diode". A **diode** is like a one-way valve for electricity. It lets current go through it one way, but not the other. They have two leads, called the **anode** and the **cathode**.

The **Earth** has a huge magnetic field. The Earth has a weak magnetic force. The magnetic field probably comes from the moving electrons in the currents of the Earth's molten core. The Earth has a north and a south magnetic pole which is different from the geographic North and South Pole.

Electricity is a flow of electrons. A flow of electrons creates a magnetic field. Magnetic fields can cause a flow of electrons. Magnetic fields can cause electricity.

Electrons can have a "left" or "right" spin in addition to 'going around' the nucleus. Electrons technically don't orbit the core of an atom. They pop in and pop out of existence. Electrons do tend to stay at a certain distance from a nucleus. This area that the electron tends to stay in is called a shell. The electrons move so fast around the shell that the shell forms a balloon like ball around the nucleus.

A **field** is an area around an electrical, magnetic or gravitational source that will create a force on another electrical, magnetic or gravitational source that comes within the reach of the field. In fields, the closer something gets to the source of the field, the stronger the force of the field gets. This is called the inverse square law.

Magnetic fields are created by electrons moving in the same direction. A magnetic field must come from a north pole of a magnet and go to a south pole of a magnet (or atoms that have turned to the magnetic field.) Iron and a few other types of atoms will turn to align themselves with the magnetic field. Compasses turn with the force of the magnetic field.

If an object is filled with atoms that have an abundance of electrons spinning in the same direction, and if those atoms are lined up in the same direction, that object will have a **magnetic force**.

Magnetism is caused by moving electrons. Electricity is moving electrons. Electricity causes magnetism. Moving magnetic fields can cause electrons to move. Electricity can be caused by a moving magnetic fields.

All magnets have two **poles**. Magnets are called dipolar which means they have two poles. The two poles of a magnet are called north and south poles. The magnetic field comes from a north pole and goes to a south pole. Opposite poles will attract one another. Like poles will repel one another.