Electromagnetism

Inventory:

1 Insulated wire

1 D battery

1 D battery holder

1 Compass

Directions:

1) Take the coated wire by itself and move it over the compass. Observe what happens.
2) Place the battery in the battery holder.
3) Clip one end of the wire onto each end of the battery holder so current is running through it.
4) Move the connected wire over the compass. Observe what happens.
5) Be CAREFUL not to leave the wire connected too long as it will get HOT!

What do you notice?

What do you wonder?

Short Science Story (S^3)

Just as moving magnets through coils of wire causes electrons to move, producing an electric current, when electrons move through a wire in an electric current, they produce a magnetic field. We can see evidence of that magnetic field in this demonstration. When the current is running through the wire, the magnetic field created causes the magnetized needle on the compass to move. The compass needle would normally be lined up with the magnetic field of the Earth but the magnetic field produced by the electric current in the wire is strong enough to affect it.

What the heck?

Using a battery, a piece of copper wire, and a compass, you were able to convert electrical energy into motion. When you clipped the ends of the wire to the ends of the battery holder there was an electric current produced, creating a magnetic field. When you placed the wire and battery over the compass, the magnetic field caused the needle to move.

You should have seen the needle of the compass start moving. What do you think caused this to happen? The electric current flowed through the wire and turned the wire into an electromagnet. The needle in the compass is also a magnet, pointing to north. What happens when two magnets are placed together? Either they attract or repel each other, right? That is what was happening here.

When you picked up the compass and moved it over the wire, what was the result? The needle moved in the opposite direction. This is because the magnetic field around the wire is like a circle magnet—one side is the north pole of the magnet and the other side is the south pole.

In this investigation we have used electrical energy from a battery to move the needle of a compass. We have changed chemical energy to electrical energy to motion energy. The chemical energy in the battery is converted to electric current that flows in one direction through the wire forming an electromagnet with a north and south pole. This type of current is called "direct current" or DC because it flows in one direction.

Source: The NEED Project (www.need.org) - Science of Energy Curriculum

Electromagnetism

Safety and Pedagogical Hints and Tips

- WARNING – the wire, battery, and battery holder can get HOT if left connected for too long. Let students experiment but then disconnect the wire between demonstrations.
- NOTE: the battery itself becomes magnetized and acts like a weak magnet. You can show this by bringing it near the compass and seeing that it will cause the needle to move from its normal position. This is why the wire included in this demo is so long. It will allow for the battery to be kept further away and not impact the compass needle.
- The best way to see the needle move is to connect one side of the wire to the battery holder, lay the wire over the compass, and then simply touch the other end of the wire to the battery holder for a short time and then release. This should cause the needle to move and then move back when the circuit is disconnected. If the needle is not moving, rotate the wire 90 degrees on top of the compass.
- You can teach the students the vocabulary associated with circuits. An open circuit is not connected. A closed circuit is complete, connected, and electricity is flowing. They are acting like a switch when they open and close the circuit manually by either touching or not touching the second end of the wire to the battery holder.

World’s Simplest Electric Motor

Inventory:

1 copper wire with insulation

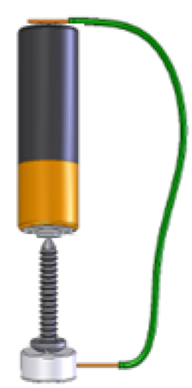
1 neodymium (rare earth) magnet

1 screw or nail with a tape tag

1 D Cell Battery

Directions:

1) Center the magnet on the head of the screw as shown to the right.
2) Hold the sides of the cylinder of the battery between your fingers and thumb with the positive (nib) side facing down.
3) Gently hang the screw, with the magnet centered on its head, from the nib of the battery, as shown in the diagram below. It should be dangling vertically.
4) Using the index finger of the hand holding the battery, hold one end of the wire firmly again the negative (top) side of the battery.
5) With your free hand, take the other end of the wire and touch the side of the magnet on the head of the screw. This works best if you let the magnet rest against the wire just a bit.



What do you notice?

What do you wonder?

Short Science Story (S^3)

When the circuit is complete and electrons run through the wire, moving electrons create a magnetic field around the wire. This magnetic field pushes or repels the magnetic field of the magnet causing the screw (with very little friction) to spin. Moving electrons create a magnetic field!

What the heck?

Magnets affect materials in one of three ways, attraction, non-attraction (neutral) and repulsion. In the world's simplest electric motor (also known as a homopolar motor, the flow of electrons through a wire creates a magnetic field that is in opposition to that of the disc magnet and thus is repulsed by it. This repulsion creates a tangential force called the Lorentz force that is responsible for creating the spinning motion. Dependent on which item is fixed the opposite item will spin. So in this example, the magnet on the head of the screw, the copper wire is fixed (not moving) and the magnet/screw spin. In another case, you can eliminate the screw, fix the magnet to the bottom of the battery, stand it on a table, and the copper wire will spin. This case is shown in the diagram below. The wire must be shaped just right so it balances on top of the battery and gently touches the magnet to complete the circuit.

Adapted from: http://www.imagesco.com/magnetism/homopolar-wire-motor.html

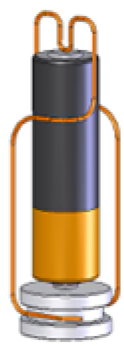


Image source: https://www.kjmagnetics.com/blog.asp?p=homopolar-motors

World’s Simplest Electric Motor

Safety and Pedagogical Hints and Tips

- **WARNING:** Short circuiting a battery like this means the battery, wire, screw, and magnet could get quite HOT! Please do not leave the device short circuited for long periods of time. If the screw stops spinning, reset it to the middle of the nib and then resume the activity.
- **WARNING:** Rare-earth neodymium magnets are strong enough to erase the magnetic strip on credit cards and damage the electronics of a cell phone. **DO NOT PLACE THEM NEAR YOUR WALLET OR ELECTRONIC DEVICES OF ANY KIND!**
- DO NOT DEMONSTRATE THIS! Let the students hold the battery and connect the circuit to make it spin. You showing this to them is much less dramatic and ruins the ah-ha moment for them.
- You can challenge them to flip the battery over and set up the motor again. If they observe carefully, they should notice the motor spins in the opposite direction. Flipping the battery over causes the electrons to move the other directions which changes the direction of the magnetic field created. This means the screw/magnet are pushed in the opposite direction.
- Students who seem particularly fascinated by this demonstration should be encouraged to search for “homopolar motor” on YouTube to find a variety of arrangements for setting these motors up. All the parts needed can be found at your local hardware store. (Home Depot carries “super” magnets otherwise known as rare-earth neodymium magnets.)

Eddy Current Tube

Inventory:

1 copper pipe ½" Type M (red stripe)

1 copper pipe ½" Type L (blue stripe)

1 PVC pipe ½"

2 neodymium (rare-earth) magnets

1 small pebble

Directions:

1) One by one, hold the copper and pvc pipes vertically and off the table or ground a few inches.
2) Drop the small pebble through each and observe what happens.
3) Drop a magnet down each and observe what happens.
4) Drop two magnets stuck together down each and make observations about similarities and differences between this experiment and the previous one. (BE CAREFUL – two strong magnets are attracted by a lot of force and can easily pinch you!)
5) Play with different variables and continue to make observations about what is happening.

What do you notice?

What do you wonder?

Short Science Story (S^3) – the electromagnetism side

As the magnet falls through the copper pipe, it pushes electrons around the pipe creating an electric current. The moving electrons (electric current) create their own magnetic field which repels the falling magnet, slowing it down.

Short Science Story (S^3) – the energy side

The magnet starts with a particular amount of potential energy. Without the copper pipe, this energy would be converted into kinetic energy (energy of motion), causing it to speed up as it falls. When the magnet is dropped through the pipe, some of the initial potential energy is converted into electrical energy (energy given to the moving electrons). Because some of the magnet's original energy has been given to the moving electrons, it doesn't gain as much kinetic energy and therefore moves slower.

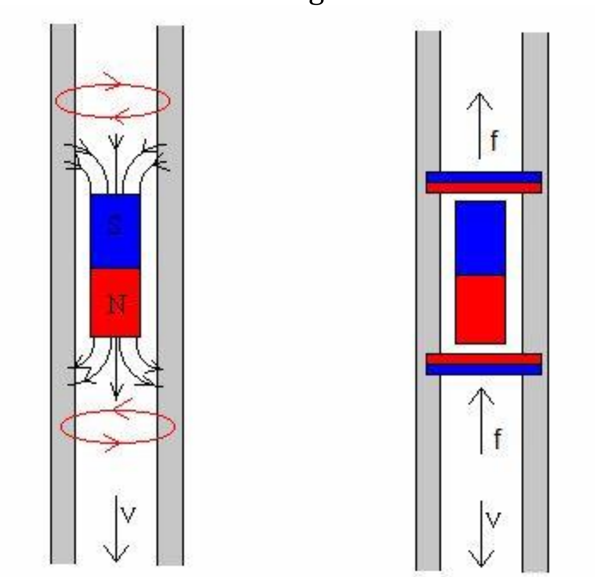
What the heck?

Eddy currents are an electric phenomenon that is produced when a conductor (metal) passes through a variable magnetic field. The relative movement causes a circulation of electrons, or induced current within the conductor. These circular Eddy currents create electromagnets with magnetic fields that oppose the effect of the applied magnetic field.

The **Eddy currents** and the generated contrary fields will be stronger

- when the applied magnetic field is stronger, or
- with higher conductivity of the conductor, or
- with higher relative speed of movement.

For a practical demonstration of the **Eddy Currents**, cylindrical magnets are used that fall vertically in a copper or aluminum pipe. It can be experimentally proven that the force that opposes the weight is proportional to the speed of the magnet. The experience is illustrated in the attached drawing:



Let's suppose that the cylindrical magnet descends with its North pole (color red) in front and its South pole (color blue) behind. On a magnet, the magnetic field lines are outgoing at the North pole and incoming at the South pole.

During the descent of the magnet, the flow from the magnetic field increases in the region near the magnet's North pole. An induced current originates in the pipe, **Eddy Current**, which opposes the increased flow, in the direction that is indicated in the first figure.

In the following figure, the equivalency between currents (spirals or solenoids) and magnets is shown, in such a way that the induced current ahead of the North pole equals a magnet of opposing polarity, by which they repel each other. However, the induced current behind the magnet has the same polarity by which they attract each other. Both currents generate a force (f) that stops the falling movement of the magnet.

Source: http://www.regulator-cetrisa.com/eng/magnetism.php?section=foucault

Conservation of Energy Story

The magnet has gravitational potential energy when at the top of the pipe. When you drop it outside the pipe, the potential energy is converted almost completely into kinetic energy. When you drop it inside the pipe, some of the potential energy is converted into electrical energy (the energy required to move the electrons in the conducting pipe). Because some of the original energy is converted to the electrical energy while the magnet is falling, it won't have as much kinetic energy when it reaches the bottom of the eddy current tube.

Eddy Current Tube

Safety and Pedagogical Hints and Tips

- **WARNING:** Rare-earth neodymium magnets are strong enough to erase the magnetic strip on credit cards and damage the electronics of a cell phone. **DO NOT PLACE THEM NEAR YOUR WALLET OR ELECTRONIC DEVICES OF ANY KIND!**
- Students love to watch the magnet as it falls through the copper pipe. They can hold the pipe below eye level and peer down through the pipe as the magnet falls.
- Neodymium magnets are brittle. Carefully let them come together without slamming into each other. Be wise about letting students take the magnets apart and put them together based on age. It is very easy to pinch a finger and even draw blood from the pinch.
- To get two magnets apart, slide them horizontally and then pull them apart.
- If you lose one of the magnets, check the metal chair and table legs near the demonstration area. The magnet has generally attracted toward and attached to one of them.
- Students should note that the PVC pipe, an insulator, has no impact on the pebble or the magnet.
- Students should note that there is a difference in the PVC pipe. The Type L (blue stripe) pipe has a thicker wall. This means less electrical resistance and more electricity produced as the magnet falls. That means a stronger magnetic field is produced and slows the magnet more than when if falls through the Type M copper pipe (red stripe).

Simple Generator

Inventory:

1 PVC spool simple generator

2 physics wands (a dowel with neodymium magnets on the end, one with three magnets and one with five magnets)

Directions:

1) Push the magnets on the ends of the physics wands back and forth through to spooled magnet wire.
2) Make observations about what you observe going faster or slower.
3) Make observations about similarities and differences when using the different physics wands.

This is how we create 99.4% of our electricity!

(Source: www.eia.gov for 2015)

What do you notice?

What do you wonder?

Short Science Story (S³)

As the magnets move through the coils of wire, they push on electrons inside the wire causing them to move first one way and then pull on them to move them back the other way. Moving magnets through coils of wire converts some of the kinetic energy of the magnets into electrical energy – lighting up the LEDs! This principle, called Faraday's Law, is how we create 99.4% of our electricity – moving coils of wire through strong magnetic fields.

What the heck?

An LED (light-emitting diode) is an electric device that converts electric energy into radiant energy. LEDs are directional which means electricity must move through it in a specific direction in order for it to work. The LED used in the simple generator is a bi-directional LED which is basically two LED's in one. When electricity moves through the LED in one direction, it will light up with a specific color of light. When the electricity moves through in the other direction, it will light up with a different color of light because it is using the other LED.

In this station, you were generating electricity using the electromagnetic effect. When you were moving the magnets through the coils of wire, the changing magnetic field induced a force on the loose electrons in the coils of wire pushing them in one direction. You should have noticed that the color of the LED switch when the magnets where halfway through the spool of coils. This occurred because the force on the electrons was reversed, changing their direction through the LED, which produced a different color of light. (If you did not observe this, go back and experiment a bit more while making careful observations.)

The electromagnetic effect used in this experiment is the same physics used to produce more than 99.4% of our electricity, just on a much larger scale. Whether the primary source of energy is coal or natural gas or wind or uranium or water, energy conversions take place which cause magnets to move through coils of wire or coils of wire to move through magnetic fields to produce electricity.

Technical Note: On a large scale, permanent magnets like the neodymium magnets used in this experiment, are replaced with electromagnets – magnetic fields produced when current moves through coils of wire. This seems counter intuitive to use electricity to produce magnetic fields that are then used to produce electricity. However, the net output based on the conversion of input kinetic energy from the primary energy source into electrical energy is significantly more than the electrical energy required to power the electromagnets. Also, no permanent magnets exist that would be large enough and strong enough to use in large-scale power plants.

Simple Generator

Safety and Pedagogical Hints and Tips

- **WARNING:** Rare-earth neodymium magnets like those on the end of the physics wand are strong enough to erase the magnetic strip on credit cards and damage the electronics of a cell phone. **DO NOT PLACE THEM NEAR YOUR WALLET OR ELECTRONIC DEVICES OF ANY KIND!**
- DO NOT DEMONSTRATE THIS! Simply give students directions and let them be the ones to create electricity and light up the LEDs.
- Be careful about holding this demo at or below waist level as it can be mistaken for something inappropriate.
- Be sure to connect the motion of the magnet to the creation of the electricity. You might even have them put the physics wand in backward to show it doesn't work when the magnets don't pass through the coils of wire.
- You can also demonstrate that either the magnets can be moved (physics wand moved back and forth) or the coils of wire can be moved (spool moved while physics wand held still). Either way, electricity is still produced.
- Students should notice that the physics wand with more magnets doesn't need to be moved as quickly to get the LEDs to light up due to the stronger magnetic field which pushes on the electrons harder when moved through the coils of wire.
- For an advanced demonstration, you can have students either push or pull the physics wand in just one direction. When they do this, ask them to observe if just one or if both the LEDs light up. They should see both light up even though the magnets were either pushed in or pulled out in one direction. This means the magnet first pushes electrons in one direction and then about half way through the coils it pulls on them changing their direction. The LEDs are set up in opposing directions and only work when electricity passes through them in a very specific direction. Seeing both of them light up means the electricity first went one direction and then the other.

Electromagnetism Energy Stations

These demonstrations focus on electromagnetism – the science behind how we produce 99.4% of our electricity. (The other 0.6% is created using photovoltaics – solar panels.) The main ideas we would like students to understand after experiencing these demos include:

- The science of energy is super interesting and lots of fun!
- The law of conservation of energy – energy cannot be created or destroyed, only transformed from one form into another.
- Magnets and coils of wire can be used to produce electricity.
- The movement of a magnet through coils of wire will produce a current (moving electrons). Some of the magnets kinetic energy is transformed into electrical energy.
- The movement of charged particles, like electrons in an electric current, produce magnetic fields.

Read the Safety and Pedagogical Hints and Tips before you get started. These are for your eyes only.

Whenever possible, let the students actually get their hands on the demonstrations. If you don't have time to let them rotate through all of the stations, then try to let a few students help with the demonstrations.

MAKE THEM READ AND FOLLOW DIRECTIONS! There are two sets of directions and equipment for each of the demonstrations. Make the students read and follow the directions. Offer tips and assistance only after they have attempted it first.