**VANDERBILT STUDENT VOLUNTEERS FOR SCIENCE**

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**Lenz’s Law**

**Inducing Magnetic Fields**

**Spring 2013**

**Goal:** To explain how Lenz’s law works and the application of it in commonplace items.

**Outline**

1. Introduction
2. Students will briefly discuss about magnetism
3. Students will learn about Lenz’s law
4. Activity 1: Seeing Lenz’s Law
5. Students will swing a neodymium magnetic plug and a steel plug over the copper tube to see Lenz’s law in action
6. Activity 2: Free Fall and Floating Magnets
7. Students will determine the amount of time it takes for a non-magnetic plug to fall through a tube
8. Students will determine the amount of time it takes for a neodymium magnet and ceramic magnets to fall through a tube
9. Activity 3: Determining Magnetic Strength
10. Students will examine which magnet is strong by finding out how many paperclips it can hold
11. Demonstration: Galvanometer
12. Students will see how a galvanometer can detect the presence of an electric current
13. Review

**Materials Needed Per Student**

 1 Neodymium magnetic plug

 1 Steel plug

 2 Ceramic disk magnets ½”

 1 Copper tube

 1 Aluminum tube

 1 Plastic tube

 1 Large Nail

 8 Paperclips

1 Galvanometer

2 Pieces of String

**I. Introduction**

Ask the students in the class if anyone can describe what a magnet is. Some things students may say are:

1. Magnets have attractive and repulsive properties based on their north and south poles. (Same poles repel each other, opposite poles attract each other).
2. Natural magnets are called lodestones and are made of magnetite which is composed of iron and oxygen
3. A magnet generates a magnetic field which is a field of attractive and repulsive forces

Next, ask the students if they know anything about Lenz’s law.

* Lenz’s law was defined by a Russian physicist named Heinrich Lenz who lived from 1804-1865 in 1833
* Lenz’s law says that an electric current induced by a changing magnetic field will move in the direction such that its own magnetic field opposes the magnetic field that creates it
* Lenz’s law is used in many everyday applications such as electric generators, roller coaster breaks, and electric motors

**II. Activity 1: See Lenz’s Law**

* Hand out to students a steel plug, a neodymium magnet plug, a copper tube, a plastic tube, and two pieces of string.
* Tell the students to tie some string around a steel plug and use the other piece of string to tie around the neodymium plug.
* Next, the students should hold the copper tube leveled horizontally in one hand and using their other hand swing the steel plug magnet over the copper tube. Students may need to pair up (with one holding the tube and the other swinging the magnet). Tell students to note any observations.
* Then, have students swing the neodymium magnet plug in the same manner over the copper tube.
* Next, tell students to swing the both plugs over the plastic tube.
* Ask students did they notice any differences? Some differences they might notice are:
	+ The steel plug swung over the tube as any normal object. In other words its trajectory motion does not look like it was affected.
	+ The neodymium magnet plug slowed down whenever it approached closer to the tube or when it neared the lowest point of its trajectory.
	+ For both plugs, the trajectory is not affected at all.
* Ask students can they explain why this occurs? Students should use Lenz’s law to explain this phenomena. As the magnet gets closer to the tube, the magnetic field the tube experiences becomes stronger. Since the copper tube is conductive, a current is induced in the copper tube. This current moves in a direction such that its own magnetic field opposes the magnetic field that was created by the magnet (in other words in the opposite direction the magnet is swinging from). This is the reason why the magnet slows down when approaching the copper tube. However, a steel plug does not generate a magnetic field, and therefore, it does not produce an opposing magnetic field in the copper tube to slow it down. The plastic tube is not a conductive material, and as such no current can be induced in it. Therefore, Lenz’s law does not apply to it.

**III. Activity 2: Free Fall and Floating Magnets**

* We will now demonstrate Lenz’s laws in a quantitative manner. The students should have the copper and plastic tubes with the both plugs. In this experiment, please make sure that the rubber bumper is attached to one of the sides of the plugs or magnets to prevent damage.
* Hand out the aluminum tube and the two ceramic disk magnets stacked together (with one side of the stack attached to a rubber bumper).
* Have students now drop the steel plug down the plastic tube (which should be completely vertical), while measuring the time it takes to travel through it. Make sure that the students catch the plug/magnet when it falls out from the bottom of the tube to prevent damage; the plugs/magnet should never hit a hard surface.
* The students should run 2-3 more trials with the steel plug.
* Repeat this experiment for both the copper and aluminum tubes (with five trials per tube).
* Now repeat this experiment using the neodymium plug for all three types of tubes.
* Then, repeat this experiment using the two ceramic disk magnets.
* Tell students to average the values for the three trials per subset (in other words, average the three trials of the steel plug falling through the plastic tube and so on)
* Ask students now if any observations in these values can be made. Some things can be:
	+ For the plastic tube
		- The experimental values for the steel plug are all about the same among the three tubes
	+ For the neodymium magnets
		- The amount of time it takes for the neodymium plug to fall through the plastic tube is almost the same as for the steel plug
		- The amount of time it takes for the neodymium plug to fall through the copper tube though is a lot longer compared to the steel plug; likewise it takes a longer time to travel the aluminum tube compared to the steel plug
		- It took slightly a little longer for it to fall through the copper tube compared to the aluminum tube
	+ For the ceramic disk magnets
		- The ceramic magnet fell through the plastic tube quickly, but took longer to fall in the copper and aluminum tube
		- Likewise similar to neodymium magnets, the time it took to fall through the copper tube was a little longer compared to the aluminum tube
		- The time it took for ceramic disk magnets to fall through the copper/aluminum tubes were a little shorter compared to the neodymium magnets
* Ask students can they apply Lenz’s law to explain what happened during the experiment:
	+ For the plastic tube:
		- Since, the steel plug generates no magnetic field, the rate at which it falls is dependent on gravity only; therefore, since all three tubes are the same length, it takes approximately the same time for the steel plug to fall through all three types of tubes
	+ For the neodymium magnets
		- A plastic tube cannot have a current induced in it, so Lenz’s law does not apply; therefore, the time it takes for the steel plug to fall through the plastic tube is about the same time it takes for the neodymium plug to fall through the plastic tube
		- A copper and aluminum tube can both have currents induced in them as they are conductive. As a result, when the plug falls through the tube, the changing magnetic field creates a current which induces a magnetic field in the opposite direction which puts a force on the neodymium plug slowing its descent in the tube
		- Also when falling down the copper and aluminum tube, the neodymium magnet seems to stick to the sides of the tube, which also slows down its descent
		- Since, copper is a stronger conductor, the current which is induced is stronger than the one in the aluminum tube, as such the magnetic field which is created is stronger which slows the descent of the plug even more in the copper tube
	+ For the ceramic disk magnets:
		- The first four bullet points mentioned above for the neodymium magnets can be applied to the ceramic disk magnets
		- Furthermore, the magnetic field of the ceramic disk magnet is weaker than the magnetic field of the neodymium magnet. Therefore, the induced current is weaker in the ceramic disk magnet than the neodymium magnet. In effect, the magnetic field induced is weaker in the ceramic disk magnet, which means its descent is not slowed as much as the neodymium magnet. (Please mention this last point if students do not as it will be a point that will be tested in the next activity).

**IV. Activity 3: Determining Magnetic Strength**

Students should have been able to conclude that the magnetic field of the neodymium plug is stronger than that of the ceramic disk magnets from the last experiment since it took a longer time for it to fall. (Therefore, the effect from Lenz’s law is stronger in the neodymium plugs compared to the ceramic disk magnets). Tell students they well now test to make sure the magnetic field of the neodymium magnet is stronger than that of the ceramic disk magnets.

* Hand out to students 8 paperclips and a large nail
* Tell students to first attach the stack of ceramic disk magnets to the flat head of a large nail (using the side with no bumper attached)
* Now have students using the tip of the nail try to pick up as many paperclips as possible
* Have the students repeat the experiment using the neodymium magnet plug
* Students should conclude that the amount of paper clips the neodymium plug picks up is greater than that of the ceramic disk magnets. Therefore, the magnetic field strength of the neodymium magnet is stronger than that of the ceramic disk magnet. (Indeed, neodymium magnets can have a magnetic field of ~0.2T compared to normal lab magnets which only have a magnetic field of 0.01T).

**V. Demonstration: Galvanometer**

Take out the galvanometer; it should be a plastic tube with wire coiled around it attached to a spool of wire wrapped around a compass on a piece of cardboard. Ask the students if they know what a galvanometer is. A galvanometer is simply a device which can show if an electric current is present. In this galvanometer, the presence of an electric current is determined by the movement of the compass needle.

* One may have to visit individual groups of tables with this demonstration in order for students to really see what is happening. In this case, have one volunteer go around with the galvanometer. After, the demonstration has been done, another volunteer should ask the students in that group if they can explain what happen.
* Take the neodymium magnet plug and insert it inside one of the ends of the tube,
* Block both ends of the tube, and then move the tube back and forth such that the magnet slides back and forth.
* The compass needle should move back and forth as this occurs.
* Ask students if they can explain what happened
	+ As the magnet moves back in forth and the tube, it passes the coils of wire. When this happens, a current is induced in the loops of wire due to the change in magnetic field strength as stated in Lenz’s law. The current which is induced travels to the spool of wire wrapped around the compass and creates a magnetic field. This magnetic field affects the compass needle. Since, the magnet is sliding back and forth, the direction of the current induced changes. As such the magnetic field induced at the compass changes direction. When this occurs, the needle of the compass swivels back and forth due to the change in magnetic field direction.

**VI. Review**

* Ask students what they learned from today’s experiments
* Students should be able to restate Lenz’s law back to you.
* Ask students does the current induced by magnetic field depend on the magnetic field strength of the magnet?
	+ Students should say yes. In the experiment with the tubes, the neodymium magnet creates a stronger induced current and therefore a stronger magnetic field which opposes the direction of the original magnetic field. Therefore, the neodymium magnet fell slower compared to the ceramic disk magnet which had a weaker magnetic field.
* Now ask students is the current induced by the magnetic field dependent on the material which the magnet passes by?
	+ Students should conclude that it does. In the case of the plastic tube, the current induced was zero, since plastic is not conductive. On the other hand, the neodymium plug fell through the copper tube with the highest measured time since the current induced was the strongest as it is a more conductive material than plastic and aluminum.
* Students should understand the function of a galvanometer. Modern-day uses for galvanometers are in laser TVs, laser engraving (which is to mark something with laser), beam positioning in laser scanning systems, printing machines, and space systems.

Observation Sheet

**I. Free Fall and Floating Magnets**

- Steel Plug

|  |  |
| --- | --- |
|  | Time of Drop |
| Plastic Tube | Aluminum Tube | Copper Tube |
| Trial 1 |  |  |  |
| Trial 2 |  |  |  |
| Trial 3 |  |  |  |
| Average |  |  |  |

- Neodymium Magnet Plug

|  |  |
| --- | --- |
|  | Time of Drop |
| Plastic Tube | Aluminum Tube | Copper Tube |
| Trial 1 |  |  |  |
| Trial 2 |  |  |  |
| Trial 3 |  |  |  |
| Average |  |  |  |

- Ceramic Disk Magnets

|  |  |
| --- | --- |
|  | Time of Drop |
| Plastic Tube | Aluminum Tube | Copper Tube |
| Trial 1 |  |  |  |
| Trial 2 |  |  |  |
| Trial 3 |  |  |  |
| Average |  |  |  |

**II. Determining Magnetic Strength**

1. # of paperclips picked up for the neodymium plug: .
2. # of paperclips picked up with ceramic disk magnet: .

**III. Lenz’s Law**

What is Lenz’s law?