Project: Electromagnetism Demonstration

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Abstract

Certain materials can produce permanent magnetic fields because of how they are atomically structured. Voltages can create an electric potential, which can be used to induce current through a conducting material such as copper wire. Magnetism and electricity, two seemingly different concepts, are together governed by the same electromagnetic force [2]. The interaction of the electromagnetic field permits current within wires to induce magnetic fields surrounding the current. In contrast, external magnetic fields can even cause current-carrying wires to experience force. This force can be utilized to create basic motors that can convert electric energy into kinetic energy. The series of experiments in this demonstration seek to convey the fundamentally invisible nature of the electromagnetic realm through a series of interactive exhibits that anyone can play with. Ultimately, these demonstrations will invoke enthusiasm within the viewing audience and will educate the public about the hidden world of physics.

Background

Magnetism exists as a field. The magnetic field flows from the north pole to the south pole of a permanent magnet [3]. Magnetism, as a field, can be traced to the material property of magnetic domains. Within a permanent magnet, the small interior microscopic magnets called magnetic domains exist, of which help form create the overall permanent magnet. There is a magnetic field associated with each of these domains, and these domains can point in a single direction. If enough of these domains line up in the same direction, then there exists an overall permanent magnet, like with horseshoe magnets. For any magnetized objects, similar poles repel and opposite poles attract.

Magnetic objects can also temporarily induce magnetic fields in ferromagnetic (or easily magnetizable) objects [3]. When a permanent magnet is placed near a ferromagnetic material, the magnet will cause the magnetic domains in the ferromagnetic material to line up with the field of the permanent magnet, permitting an induced attraction. Therefore, bar magnets can pick up unmagnetized paper clips along with other permanent magnets.

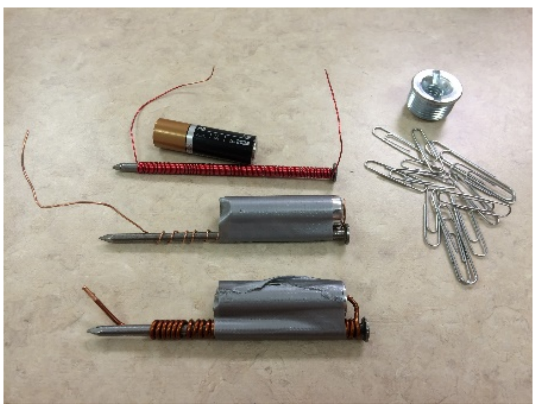
Magnetic fields can also be created by moving charges. When electrons move through a wire, a magnetic field is created that flows perpendicularly to the direction of current. This current flows in a circle around the circumference of the wire [2]. Fundamentally, electricity and magnetism are interconnected by this principle. Using this principle, electromagnets and electric motors can be made which exploit this effect between electricity and magnetism [1].

Materials and Methods

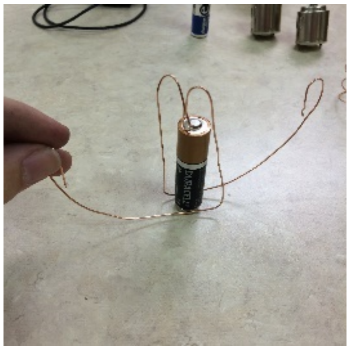
1. A Small Compass
2. 8 Large (Magnetizable) Nails
3. 10 Metal Paper Clips
4. Duct Tape
5. 0.8 mm Diameter Magnet Wire
6. 0.8 mm Diameter Magnet Wire
7. 6 AA-size Batteries

8. 2 D-size Batteries
9. An Alligator Clip
10. Assorted Nuts and Bolts
11. 1 Brushed Motor
12. 6 Small Neodymium Magnets
13. 4 Ferrite Fridge Magnets (with center holes)

For section one of this lab, four ferrite fridge magnets were gathered along with a single four-inch iron nail. We inserted the nail through the hole of each magnet and alternated the poles of the fridge magnets. After this, we set the nail on a table, head down, to illustrate the principle of magnetic repulsion by observing how the fridge magnets repel one-another. We also took individual fridge magnets and picked up paper clips to illustrate how magnets can induce magnetic fields in other materials. After this, we took the neodymium magnets and brought them near the various nuts and bolts to show the strength of the magnets. Lastly, for this section, we took a single refrigerator magnet and placed it near a compass placed on a flat surface. We then moved the magnet slowly in circles at varying distances to visualize the principle of magnetic fields.



For the second section of the lab, we handmade electromagnetic nails using copper wiring, a nail, duct tape, AA batteries, and magnet wire. First, a piece of copper wire was connected to the ends of a AA battery, and the compass was placed on top of the wire to show how a current can impact the magnetic field. Next, an electromagnetic nail was made by first taking 0.8 mm diameter copper wiring and placing a single wind at the base of the nail, near the head. Next, we wound the wire repeatedly around the nail as many times as possible without letting the wires cross over or touch. It is important to prevent contact between adjacent windings of wire so that the current does not short and travel past the windings. However, it is also important to make as many windings as possible around the nail so that the electromagnet can be as strong as possible since more windings can permit greater magnetic strength [3]. A battery was then taped parallel to the nail shaft and the ends of the wound wire were connected to the ends of the battery. After this was done, we picked up paper clips off a table after completing the circuit to illustrate the electromagnetic properties of the nail magnet. This was contrasted with the opposite scenario, where there was no completed circuit. In this situation, the same nail was used to pick up nails, which should experience significantly decreased magnetic strength. Lastly, we made an electromagnet by tightly winding magnet wire around another nail and performing the same experiment as with the copper-wire electromagnet. This was used to pick up heavy bolts, illustrating how more windings leads to a stronger electromagnet.



In the last section of the experiment, we took 0.8 mm diameter copper wire and wound a section of it so that it could balance on top of a AA battery (as seen on the left) and could rest lightly against a single neodymium magnet centered at the base of the AA battery. If balanced and made properly, a homopolar motor should have been made which rotates the wire. Next, magnet wire was wound into a loop one inch in diameter, as seen in the second picture on the left. The loop was fitted into the rungs of the taped paperclips as constructed in the second picture on the left. The ends of the magnet wire were stripped to complete the circuit, and the neodymium magnets were placed below the magnet wire on the battery to induce rotation. This makes a basic motor. Lastly, we used alligator clips along with a brushed motor connected to a AA battery to induce rotation. A square piece of tape was placed on the protruding prong of the motor to help visualize the motor's rotation, as seen on the right. Also, we flipped the orientation of the battery in the circuit to display the polar nature of the electromagnetic force.

Results and Discussion

All the lab exhibits functioned as expected and gave the desired results. In the second section of the lab, we noted that the batteries used to convey electromagnetism in the nail electromagnets became scalding hot at the anode/cathode. The batteries used quickly lost their energy to heat since the current produced experienced little resistance in the wire, and permitted the battery's internal chemical reaction to progress at a very rapid pace. Also, after exposing the nail to permanent magnets, they became permanently magnetized themselves. The exposure of iron nails to strong permanent magnets induced permanent magnetic fields in the nails that remained even after the electromagnetic field was removed.

As mentioned in the second lab, the nails used became relatively strong permanent magnets. The permanent magnetization of these nails was so strong that they could still hold several paperclips after the current was shut off from the wiring. In comparison, when the current was turned on, the electromagnetic nail could hold several large and small paperclips at the tip.

In the third experiment, the D battery became extremely hot after leaving the wound coil on the circuit for a period longer than a couple of seconds. Also, the coil of wire would accelerate up to a certain limit, which was determined by how close the coil's center of mass was to the axis of rotation. Another impact that limited the coil's rotation included air resistance. In addition, the brushed motor's direction of rotation inverted when the current direction was changed. This was because the direction of the electromagnetic field inverts when current direction is inverted, causing the torque in the motor to change orientation. This effect was consistent with our predictions, along with the results of every other experiment implemented.

Conclusions

Several metallic materials can become permanently magnetized after exposure to strong magnetic fields, where the internal magnetic domains become permanently altered. The other experiments behaved in ways consistent with modern theories of electricity and magnetism, where electric currents can produce magnetic fields perpendicular to the flow of current. Furthermore, these experiments were consistent with the principles of magnetic domains since the many of the provided metal objects became magnetized as predicted. Lastly, the various results observed from the electromagnets and motors were consistent with modern theories of electricity and magnetism.

References

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