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Pre-Lab 8: Magnetic Force and Induction

Pre-Lab Due 6/8

The pre-lab questions are to be answered using the provided template. Only the pre-lab work needs to be digitized into PDF format and uploaded to gradescope.com by the due date.

1. A wire segment of length 4.75 cm carries a 3.46 A current. This wire is placed within a uniform magnetic field. At some initial orientation of the wire in the field, the wire experiences a magnetic force of magnitude 0.375 N. By changing the wire's orientation in the field, the maximum force on the wire is found to be three times greater than the initial force.
a) Find the strength of the B field:

b) Find the angle between the two orientations of the wire:

2. A particle accelerator fires protons to a speed of 3.65×10^6 m/s perpendicularly to a magnetic field. The protons go into a circular orbit of radius 0.68 m in a horizontal plane.

a) What potential difference is needed to accelerate the protons to this speed?

b) What is the magnitude and direction of the magnetic field necessary for this motion?

3. Explain how a bolt of lightning can cause excessive (even damaging) currents in your household appliances even when the bolt does not strike your house directly (nor any utility lines connected to your house).

4. A bar magnet falls freely, with its north pole pointing straight down. It approaches and passes through a fixed, horizontally orientated, metal ring.

a) How, if in any way, is the magnet's motion affected as it approaches the ring?

b) How, if in any way, is the magnet's motion affected as it leaves the ring?
Explain briefly with appropriate diagrams showing induced currents and their magnetic effects.

Lab 8: Magnetic Force and Induction

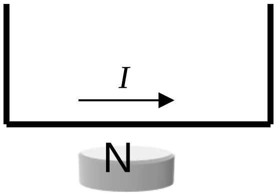
This lab consists of a variety of activities or stations. At each one, you'll have the chance to observe and think about magnetic forces and induction, to do some simple experiments and make and evaluated some observations.

I. Magnetic Force on a Current-Carrying Straight Wire

In this activity, you will use a U-shaped wire that hangs from support wires on a wooden dowel. The hanging wire is designed to swing freely. Do not yet connect the leads to the battery. You will predict the outcome of a situation before you connect the battery, and then you will perform the experiment to check your predictions. **Connect the battery only for a moment to make your observations; do not leave the battery connected once you have made your observations.** Be sure you understand the relationship between the connections to the battery terminals and the direction of current flow in the wire.

A magnet sits just below the horizontal part of the U-shaped wire with its magnetic field directed vertically, enclosing the wire. For each case, predict the direction that the wire will swing when the current is turned on in the direction shown. Then, connect the battery and check your prediction.

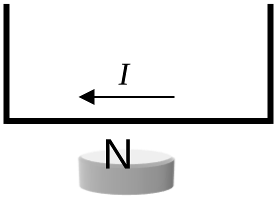
(1)



Predict:

Observe:

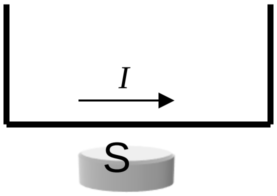
(2)



Predict:

Observe

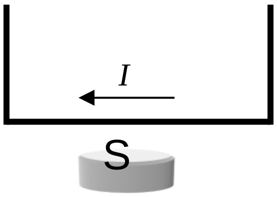
(3)



Predict:

Observe:

(4)



Predict:

Observe

Do your predictions agree with your observations? If not, you need to practice your right hand rule for the direction of force on a current-carrying wire within a magnetic field!

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II. A Simple Motor - Magnetic Force on a Current Carrying Loop

This simple motor consists of a coil of current-carrying wire suspended in such a way that it makes electrical contact with a battery but can still rotate freely. A magnet held below the coil provides the magnetic field needed to provide the magnetic force (torque) on the coil. In order to get your motor started, you may need to adjust the coil so that it balances nicely. You may need to give it a gentle nudge to get it moving.

a. Determine what position(s) of the coil with respect to the magnetic field is (are) important for creating the rotation. Explain briefly.

b. Apply the right hand rule to find the direction of the force on the coil. Is that force the same everywhere around the coil?

c. *Very important* to the operation of this motor is exactly when and where the coil makes contact with the supports that provide the current. The wire is insulated, *except for* a couple of very specific places on the wire ends. Explain why this is absolutely necessary if the coil is going to rotate. If the insulation were removed from all sides of the wire ends, what would happen?

d. What are a couple of different things you can do to speed up the rotation of the coil? How might a second magnet held in your hand speed up the rotation? Try it!

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III. Eddy Currents - Give Me a (Magnetic) Brake

Horseshoe magnets create a very uniform, constant magnetic field between the poles of the magnet. At this station, you will pass a conductor through the uniform field of a horseshoe magnet and observe the effects. You will not see the induced current in the conductor directly, but you will be able to feel the magnetic force on the moving charges in the conductor. Such induced currents that occur in extended metal objects (i.e. not thin wires) are called eddy currents, and, like all electric currents, they create new magnetic fields of their own.

Experiment 1a: Holding the rod at the top by your fingers, swing the square loop (the one with the hole) of aluminum metal back and forth like a pendulum so that you get the feel of it swinging freely. Next, swing it so that the aluminum loop passes through the gap between the poles of the large horseshoe magnet on the floor. Describe what you feel as it swings between the poles of the magnet. Be as specific as possible. Is this effect because the aluminum is naturally magnetic? You may already know the answer to this, but test it anyway: Dangle the metal motionless between the poles of the magnet. Does it attract or repel from either pole?

Draw two diagrams to explain the effect that you observed when swinging the ring through the magnetic field. First, draw a diagram of the square loop as it is entering the B-field—so that part of it is in the field and part of it has yet to enter. Then diagram it as it is leaving the field—so that part of it is still inside and part has already emerged. Label the induced currents in the loop and magnetic forces in each of your diagrams. What is the direction of that force (relative to the motion of the metal loop)? Is the force towards either pole of the magnet?

Experiment 1b: Now do the same with the solid square (no hole) of aluminum through the same magnetic field. Is the effect (force on the aluminum) more or less than in Experiment 1a? Why?

Experiment 2a: Orientate the solid aluminum disk vertically and give it a good spin. As it is spinning, insert it into the gap of the smaller (tabletop) horseshoe magnet. What happens? Explain this behavior, using your observations and analysis of Experiment 1, above.

Experiment 2b: Spin the slotted aluminum disk. As it is spinning, insert it into the gap in the horseshoe magnet. Does it behave the same as the solid rotating wheel did? What is different? Why is it different?

Experiment 3a: Stand the metal tube on end with the lower end just a couple inches over a piece of foam and drop the non-magnetic (or only slightly magnetic) cylinder through it. Does it seem to fall freely through the tube? Note, particularly, how long it takes to fall through.

Experiment 3b: Now drop the magnetic (or more magnetic) cylinder through the metal tube. Does this behave differently than the non-magnetic cylinder? Explain this behavior—use diagrams as necessary (probably very necessary). Is the difference in fall time because the magnet is somehow adhering to the metal (like a magnet adhering to a refrigerator)? How do you know?

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IV. Lenz's Law, or Hey! Look at Me! I'm Making Electricity!

For this station, you have two coils of wire - each with different numbers of loops, a magnet, some connecting wires, and a galvanometer. A galvanometer is an ammeter that measures very small currents (micro-amperes) and can also indicate the direction of that current. Understanding how the meter behaves is important here, because you're going to use the meter to determine when there is current and its direction. For this galvanometer, when (conventional) current enters the terminal on the right (as viewed when reading the dial), the needle will swing to the right. If the current flows into the terminal on the left, then the needle will swing to the left. (So the positive and negative signs on the dial simply distinguish between two directions, not the sign of the charge flowing into or out of the respective terminals.)

Experiment 1a: Using the alligator clip wires, attach the coil with more loops to the galvanometer. Look carefully at the direction that the wires are turned. You will be moving the pole of a magnet closer to the coil, increasing the magnetic field strength in the vicinity of the coil, which is one way to increase magnetic flux.

Thinking about the orientation of your loops of wire, and using the appropriate right-hand rule(s), decide which direction the current will be created in the wire as you move the north pole of your magnet towards, and into the center of, the coil, and therefore, which direction the needle of the galvanometer will move. Sketch a diagram below and the show the direction of the induced current in the wire coil as the magnet is moved towards and into the coil.

Now, do it. Watch the meter as you move the magnet into the coil, N-pole first. Did your created current behave as you expected? What happens when you stop the motion of the magnet within the loop? Why?

Experiment 2 through More:
Repeat but with variations on the theme. Send in the south pole. Vary the speed of the magnet's motion. Hold the magnet still and move the coil instead. Pass the magnet all the way through and out the other side. Send the side of the magnet up to the coil instead of one of the poles. Repeat with the coil with fewer turns/loops.

Report briefly below on all the options you can think of and try and your observations. Are all your observations consistent with your expectations?

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V. Induced Current and Force. Leaping Lizards! I mean Metal Rings!

Exercise some caution with the equipment for this station. Carefully note and obey all instructions at this station. The device consists of a a coil of many turns of wire, and a metal core down the center of the coil that extends above the wire coil, a connection (plug) to a conventional 120 V outlet, and a *momentary* switch that allows a short but large current surge to pass through the coil.

Most of the time, the switch should be OFF. When the switch is turned on, it sends a very brief but quite large current “spike” through the coil. This transient current creates a strong magnetic field in the coil, magnified in strength by the metal core. Since the current is changing very rapidly (rising up and decaying quickly), the magnetic field is changing equally rapidly. A changing magnetic field near a loop means changing flux, which means induced voltage. We will see some possible effects in the following experiments/demos.

Experiment 1: With the switch OFF, place one of the large, flat, aluminum rings over the core, so that it sits atop the coil. Now turn the switch on briefly (for just a second) and turn off again.
What happened to the aluminum ring when you sent current through the coil (i.e., turned it on)?
Remember, aluminum is non-magnetic, but it is very conductive (of electricity.)
Why does it behave as it does when a short pulse of current goes through the coil? Draw a diagram of the current induced in the ring and the resulting force on the ring.

Experiment 2: Put the slotted (cut) aluminum ring on the core. Predict what will happen in this case.
Now do the experiment. What happens? Why is this different than the solid ring?

VI. Creating Potential, or Hey! I'm a Battery!

Okay, this doesn't exactly fit in with the theme (induction, force) but do it anyway! You've got a (digital) voltmeter, and two dissimilar metals, one connected to each probe of the meter. With the meter on, (and still connected to the metal cylinders), grab a metal cylinder, one in each hand. How much voltage can you generate? What conditions increase the potential? Are females more electric than males? Damp hands different than dry? More contact? Less?

You'll probably find you're somewhere around a 0.6 or 0.7 V battery. (The types of metals being a really big factor in this.) If you are just a 0.6 V battery, but you need or want 1.2 V, how can you get there? (Think, batteries in series...) So, have your partner also pick up two dissimilar metals (one in each hand.) How can you connect each other to get 1.2 V? 1.8 V? (May need more people!) 2.4 V? How high can you go?! How many people can you connect together? Can a string of you and your labmates light a light bulb? (Why not?!)

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