Encounters with Electricity and Magnetism

Prelab Exercise

The questions below should help you to be prepared for a productive experience in lab. Please provide a brief response to each question and bring it to lab with you.

1. Matter is made up of charged particles. A mole of hydrogen, for example, contains nearly $4 \times 10^5$ C of charge! Why is matter usually electrically neutral (or nearly so)?

2. What is the difference between an electric conductor and an electric insulator (also called a dielectric)?

3. Where does the excess electric charge reside on a charged conducting body? Why?

4. What is the electric field inside a charged conducting body? Why?

5. How does an electric dipole behave when placed in an electric field? (The word “torque” should appear in your answer to this question.)

6. How are torque, angular speed, and power related?

Objectives

This lab will give you hands on experience with a variety of phenomena in electricity and magnetism. Rather than go in depth into any single topic, my aim here is to challenge your intuition and spark your curiosity in a range of areas we will be studying throughout the term. Many of these phenomena we will see again in more depth either in the classroom or in a later lab.

The lab will be set up with six stations, each equipped for you to perform a simple experiment. For each station, the procedure will include a short write-up intended to guide you through the experience and to help you observe it and reflect on it. You are not expected to understand each experiment in any depth. If you don’t understand why a particular experiment responds the way it does, that’s okay; the ultimate goal is to understand them by the end of the term. Take the time to ponder some about each observation. Are the results intuitive or counter-intuitive?

Station 1: Van de Graaff Generator
Station 2: Charged Cats, Balls, and Coffee Cans
Station 3: Electric Currents and Magnetic Forces
Station 4: Electromagnetic Induction
Station 5: Microwave Electromagnetic Radiation
Station 6: Magnetic Eddy Currents
Procedures

1 Van de Graaff Generator

**Equipment**

- Van de Graaff Generator
- 2 Orbs on insulated wand
- String wigs (nylon and cotton) Comb (for wigs)
- Fluorescent light tube Ringstand to hold fluorescent tube
- 2 Grounding wires Pin and adhesive wax
- Incense sticks and matches Flashlight

**CAUTION:** Although the Van de Graaff generator can produce only small currents that aren’t dangerous, it *can* give you an unpleasant shock. Stay at least two feet away from the dome while the machine is in operation. Before touching the dome, always discharge it first by touching it with the grounded orb. Handle the orb by its insulating wand. *Don’t touch the Van de Graaff generator dome while it is charged!*

1. Comb out a string wig, place it on the Van de Graaff generator dome, and turn the generator on. What happens? Explain if you can.

2. Now hold the grounded orb (by its insulating wand) near the generator and draw sparks from various points around the generator dome. Turn the Van de Graaff generator off and discharge it by touching the grounded orb to it momentarily. Use a bit of wax to stick a pin to the side of the generator dome, making sure the metal of the end of the pin touches the metal of the dome. Turn the generator back on. Again, draw sparks at various points around the dome. Remove the pin when you finish. (Discharge the generator first!)

How do these results differ?
Why do lightning rods have pointed ends?

3. Mount the fluorescent tube on the insulated ringstand, and ground the fixed end.
   (a) Move the tube so the free end is close to the generator dome and observe.
   (b) Now put the ungrounded end of the fluorescent tube in contact with the ungrounded orb. Move the combination close to the generator and observe.

![Diagram of experiments](image)

How does the peak light intensity compare between the two trials?

The average intensity?

4. Stick a pin to the side of the generator sphere using wax. Observe what happens to a column of rising smoke when it approaches the pin. Use the flashlight to make the smoke more visible. Try this experiment on the side away from the pin also. Where do you think the smoke ends up? (Remember the wig!) Electrostatic precipitators use this effect.
2 Charged Cats, Balls, and Coffee Cans

**Equipment**
- Cat’s fur and rubber rod
- Electroscope
- Coffee Can (“Faraday’s Ice Pail”)
- Capacitor
- Silk and glass rod
- Electrophorus (for inducing charge)
- Foil ball on string

NOTE: This station will take more time than any other.

1. Touch the foil ball lightly with your finger to discharge it. Rub the rubber rod in the cat fur and then bring the rod toward the foil ball. What is the sense (attractive or repulsive) of the electrostatic interaction between the rod and the ball...

   *Before* they touch?

   *After* they touch?

   Explain this observation.

2. Use your hand to discharge the electroscope (touch the top and the base at the same time. The two leaves should fall together). Now charge the rubber rod (rub with the cat fur) and draw it across top of the electroscope to transfer some charge. What happens?

   Recharge the rubber rod and bring it near the electroscope. As you bring it closer without touching, what happens first? Later?
3. Rub the electrophorus base with the cat’s fur. Place the metal electrophorus disk on it and momentarily ground the plate with your hand twice (you’ll get a little shock the first time).

Now pull the disk away then touch it twice. Return it to the base and touch it twice again. What happens? Where is the energy coming from? Do you think the disk is positively or negatively charged?

4. Faraday’s Ice Pail. Place the coffee can on the electroscope. Discharge the electroscope by touching across it with your hand. Charge the electrophorus disk as above by placing it on the base, grounding it momentarily with a touch of your hand, and then removing it from the base. Transfer a charge to the aluminum foil sphere by touching it with the electrophorus disk. You should verify that the ball is charged by noting that it is now repelled by the disk, and also by lowering it into the can (without touching the sides or bottom) and observing deflection in the electroscope. Raise the ball out of the can, lower it in again, and note that the charge has not changed (it changes only when it touches something or sparks).

a) Raise the ball out of the can. Now touch the ball to the outside of the can momentarily. Discharge the electroscope and lower the ball into the can (without touching the sides or bottom). Does the ball still have charge?

b) Discharge the electroscope and recharge the ball. Lower the ball into the can without touching the sides or bottom to demonstrate that it is charged. Now touch the ball to the inside (bottom) of the can, and then remove it from the can. Discharge the electroscope. Test the sphere (how?) to see if any charge remains. Describe your observations and explain why the two results from part a and part b differ.
3 Electric Currents and Magnetic Forces

**Equipment**
- Car battery
- Momentary contact switch
- U-Magnet
- Compass
- High power resistor
- Banana plug connecting wires
- Copper conductor on wood mount

**CAUTION:** The magnet is quite strong. Keep the compass a foot or more away from the magnet.

1. Connect the battery and switch as shown in the diagram below. Have one wire long enough to be able to place it in the gap of the magnet. Press the switch key to complete the electric circuit and allow current to flow through the wire. (Don’t hold the key down for more than a few seconds at a time, or the wires may burn!) What happens when the current flows? Try reversing the magnet.

![Diagram of battery, switch, and magnet](image1)

2. Connect the car battery, resistor, and switch in series with the copper tube mounted on a wooden stand as shown in the figure below. Orient the tube roughly north-south and take note of which ends of the tube are connected to the positive and negative terminals of the battery. Move the magnet more than five feet away from the copper tube. Press the switch key to complete the electric circuit and allow current to flow through the copper of the tube. (Again, don’t hold the key down for more than a few seconds at a time.) While the current is flowing (key down) hold a compass near the copper tube and note the direction of the compass needle.

![Diagram of battery, resistor, switch, and copper tube](image2)

A compass is a magnetic dipole analogous to the electric dipole. Just as an electric dipole aligns itself to an electric field, a magnetic dipole aligns itself to a magnetic field, so you can use a compass to map out a magnetic field. Place the compass in at least the six positions indicated by ovals in the diagram below and note the direction of the needle using the notation shown.

![Diagram of compass positions](image3)
4 Electromagnetic Induction

**Equipment**
- Coil and galvanometer assembly
- Bar magnet
- Hand generator and bulb assembly

1. A galvanometer is a device that measures the rate of transport of charge in an electric current. Move the bar magnet around in the vicinity of the coil of wire and observe the galvanometer deflection. Try moving the magnet into the coil and even passing it all the way through. How do the direction and speed of the magnet’s motion affect what you see? Does it matter which end of the magnet you insert into the coil?

2. Turn the crank of the small generator and get a feeling for how hard you have to turn (that is, how much torque you must exert) to overcome friction in the mechanism. Now push the button switch while turning the crank. How does the brightness of the bulb depend on the speed with which you crank? Explain why the torque you exert should differ when the button switch is open and when it is closed.
5 Microwave Electromagnetic Radiation

**Equipment**
- Klystron and horn microwave transmitter
- Microwave mirror (aluminum plate)
- Foamcore sheet
- Microwave receiver
- 2 Microwave polarizers (slotted plates)

If you are the first to arrive at this station, your TA will turn on and adjust the klystron transmitter.

Microwaves are a form of electromagnetic radiation just like visible light except with a lower frequency and therefore longer wavelength. The frequency of our microwave transmitter is \( f = 9 \) GHz, so the waves have a wavelength of \( \lambda = \frac{c}{f} = 3.3 \text{ cm} \). They are *transverse* (or vector) waves, more like mechanical waves on a string than like the *longitudinal* (or scalar) waves of sound.

1) Aim the transmitter horn at the receiver horn and note the power transfer. Does the aluminum plate block the beam? How about the foamcore (dielectric) plate? What is the difference between these two materials?

2) Try reflecting the microwaves off the aluminum plate. Move the source and receiver to try different reflection angles. Does the aluminum act like a mirror? Does the dielectric plate act like a mirror?

3) Try placing the polarizer between the source and receiver. How does the received power depend on the orientation of the polarizer? The transmitter transmits vertically polarized waves, and the receiver will only receive vertically polarized waves. What orientation of the polarizer passes waves best?
6 Magnetic Eddy Currents

**Equipment**
- Electromagnet
- Aluminum “saw”
- Aluminum ring
- Split aluminum ring

**Warning:** The magnet is very powerful near the gap. It can magnetize watches and destroy electronics. *Keep watches and electronic equipment away from the magnet.*

1) Take off your watch first. With the magnet on, try sawing between the pole pieces. How does the effort you must expend depend on the speed with which you saw? On the magnetic field strength? Where might the energy go?

2) Now try dropping the continuous aluminum ring through the magnet. What happens? Does this result change for a split ring?

3) Move the coil of wire in the field and observe the connected bulb. What experimental variables does the bulb brightness depend on?

**Homework**

The writeup will constitute the homework for this lab. Turn it in at the end of your lab session.