Physics 4 Laboratory

The Electric Motor

Prelab Exercise

Please read the Procedure section and try to understand the physics involved and how the experimental procedure works. You will be provided with a kit of parts and equipment from which you will be challenged to build a working electric motor. This lab is intended to be fairly simple and enjoyable, but still challenge you to build on your understanding magnetic fields and their interactions with matter. The questions below should help you to be prepared for a productive experience in lab. Complete this exercise and bring your written responses to lab with you.

1. How do you compute the magnetic moment of a flat, circular coil of wire carrying a current?
2. What is the effect of adding turns to the coil? Think about mass, moment of inertia, electrical resistance, and anything else that might be relevant.
3. When you immerse a current-carrying coil in a magnetic field, is there a net force on the coil? (Warning: trick question!)
4. When you immerse a current-carrying coil in a magnetic field, the field applies a torque to the coil. What orientation of the coil in the field minimizes the torque? What orientation maximizes the torque? (Use this question to help you think about how the torque arises in the first place, and how the equation $\boldsymbol{\tau} = \boldsymbol{\mu} \times \mathbf{B}$ expresses the result.
5. Which direction is the torque? (Warning: trick question!)
6. How does the direction of the torque correspond to the direction of the current in the wire?

Equipment

You will be provided with a kit of the materials listed below.

- Power Supply.
- Wood block baseboard with magnet pedestal and bearing posts.
- Neodymium disk magnets.
- Enameled wire, 22 or 24 AWG.
- Clip leads.
- Cutter-strippers.
- Long-nose pliers.
- Sandpaper.
- Razor knife.

Power Supply

The power supply for your work will provide up to 30 V of emf and 1 A of current. It is shown in Figure 1. The power supply functions very nearly as an ideal voltage source up to the current limit set by the "Output Current" knob. The two meters simultaneously read output voltage and current.

Operation is pretty simple. You turn it on with the green rocker switch. The "Output Voltage" knob sets the source emf value; the "Output Current" knob sets the current limit value. Since you will be operating into essentially a short circuit, the voltage can be set at some low value, and output current adjusted to the desired value.

Figure 1: Power Supply

Enameled Wire

The wire provided is is specifically intended for winding into coils in magnets and motors, and is therefore called *magnet wire*. In order to keep the insulation as thin as possible, and thereby allow more turns in the same space, the wire is insulated with a thin coating of clear plastic enamel. Consequently this wire is also called *enameled wire*. Your wire strippers will not effectively remove enamel from this type of wire. You can either scrape it off with a knife, or sand it off with sandpaper. Using either tool you will find it most effective to scrape or sand in one direction—towards the free end of the wire.

The diameter of the wire is given by the "American Wire Gauge," or AWG. The larger the gauge number, the smaller the wire diameter. Smaller diameter wire allows more turns per unit length in a coil, but has more resistance per unit length of wire. The table below gives weight and resistance for the two gauges of enameled copper wire that you might be using.

Copper Wire Characteristics

Gauge AWG	Diameter mm	Resistance Ω/kft	Density lb/kft
22	0.644	16.5	1.94
24	0.511	26.2	1.2

Magnets

The magnets provided are neodymium permanent magnets constructed such that the flat surfaces are the poles. The poles are unmarked.

Objective and Background

The objective of this exercise is to construct a working electric motor using only the rather crude materials you have been provided.

A motor has two main mechanical components: the turning part, called the *rotor* and the stationary part, called the *stator*. In any motor one of these components produces the motive power and is called the *armature*. In your motor, the armature is the rotor. In order to produce power, the armature must interact with a magnetic field produced by the other component, called the *field*. In your motor the stator is a permanent magnet which provides the field.

Your rotor (armature) will take the form of a coil of magnet wire. Your stator (field) will be a permanent magnet. The main challenge will be to get the torque on the rotor to always be in the same direction. It will also be important to get the rotor to balance so that it turns freely, and to optimize the design for the greatest speed.

Procedures

Be sure to keep records of what you do so that you can prepare a coherent description of your findings.

1. Rotor

Start by constructing the rotating coil of wire (the armature) such as the one depicted in Figure 2.

Here are a few of the practical things you will need to keep in mind along with all the physical theory as you think about an armature design:

1. The more wire you use in a coil the more turns of wire you can have enclosing a given area (and hence the more torque), but the more resistance your coil will have (hence the smaller the current and the smaller the torque).
2. The more wire you use in a coil, the more mass your coil will have (and hence the greater the moment of inertia about its rotation axis).
3. The larger you make the area enclosed by your coil the greater the torque, but also the greater the moment of inertia.

To make the windings of the loop stay together, you can clip off a few pieces of the wire and twist them around the loop at a few places (you will not cause any "shorts"; the copper wire is insulated). These loops of wire can also be strategically placed or pruned to balance the rotor. Some students avoid this approach and simply wrap the axle leads around the coil at appropriate spots.

The wire leads from the coil also serve as the bearings for the rotor, so take care to make them collinear and to make their common line pass through the center of mass of the coil.

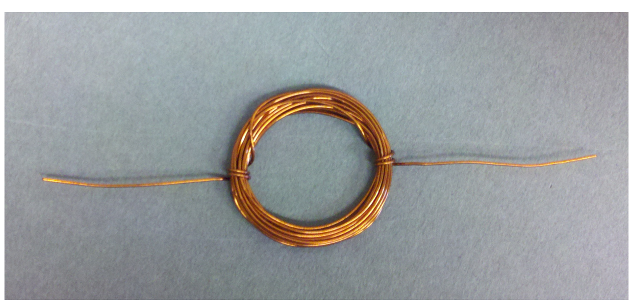

Figure 2: Armature made as a circular coil with axial leads.

2. Mounting

Next you need to think about suspending your armature so that it can rotate freely. The supplied motor base includes two metal posts with holes suitable for accepting the wires of your armature. The holes in these posts provide the rotary bearing for your armature. One side is cut to facilitate assembly. The magnet attaches by its own magnetism to a mounting pedestal made from a screw.

When the armature is mounted above the magnet as shown in Figure 3, you can connect the posts to the power supply using clip leads.

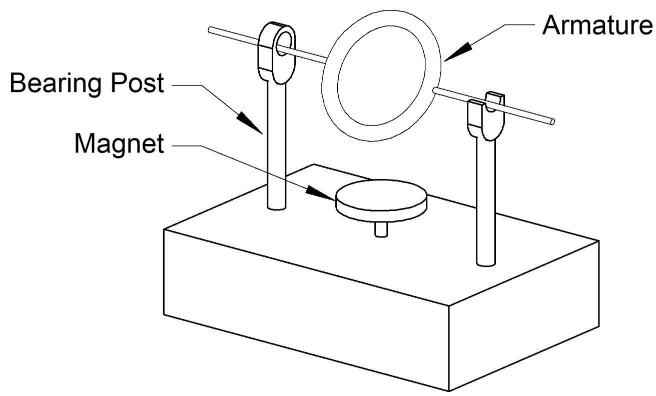

Figure 3: Arrangement of complete motor showing bearing posts and magnet mount. The rotor is somewhat stylized in this figure; your design may vary. Power is supplied through clip leads clipped to the bearing posts

3. Commutator

Now comes the hardest part: getting the current to flow in the armature in such a way that the rotor will spin. The wire supplied is coated with plastic enamel as shown in the left panel of Figure 4. The insulation on the two ends of the copper wire must be removed so that the current can flow. This can be done with the supplied sandpaper or the blade of the razor knife.

You will not want current to flow in the coil all the time, however, because the torque will be in the correct direction only half the time. If you remove the enamel insulation all around the wire, the rotor will not rotate continuously! You will need to make what is called a *commutator*—a mechanism to make the current flow only when the torque is in the correct direction. One simple solution is to remove the enamel on only one side of the wire as shown in the right panel of Figure 4. Think carefully about how to treat each end of the wire relative to the plane of the coil and the configuration of the field.

4. The Field

Place a magnet on the pedestal under the loop—or choose another magnetic field configuration.

5. Energize and Test

Connect your power supply to the bearing posts using clip leads. Does your motor run? You may need to give at a little push to get it started, but it should turn continuously. Make an estimate of the speed and measure the power it consumes. Don't be discouraged if it runs poorly or not at all on your first try.

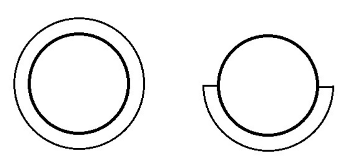

Figure 4: Cross section of magnet wire. The left panel shows the original insulation. The right panel shows half the insulation removed to make a commutator.

6. Improve

Once you get your motor working, and have characterized its performance by speed and power consumption, try to make an improvement.

You might consider improving the design or fabrication of your rotor by improving its balance or by designing it to have a larger magnetic moment.

To get a truly fast motor, you will need to be more clever in your commutator design. Can you think of a design that will force the current to flow through the coil nearly all the time (rather than just half the time), giving you a higher average torque on the rotor? To build a commutator in such a way that there is a net gain is not so easy; friction is the killer. Manufactured motors use components called *brushes* to accomplish this feat. Perhaps the terminology will be suggestive to you.

Whatever improvement you attempt, characterize the performance of the new motor and see what effect your design changes had.

Writeup

Be sure to show your TA your working motor and your speed and power data.

Final Report

For the homework portion of this lab exercise, prepare a brief report indicating how you configured your motor and how well it worked. If you succeeded in any improvements to your first working model, describe what you did and quantify the improvement.

This report is not intended to be a complex or extensive document, but it should give you an opportunity to organize your thoughts about your experiments and to present a coherent account of your results. A formal report is not necessary. Rather the report should be in the form of a very neat and complete lab notebook entry.

Please type your report. Hand drawings are acceptable. Don't be concerned about hitting a particular length target; include what you need in order to explain what you did—no more, no less.

Collaborate with your lab partners in understanding what you accomplished but please prepare your own report to hand in. Don't forget to include the names of your lab partners, and don't fail to ***cite your sources.*** (See the syllabus.)