Chapter 7

Lab 1: Magnetic DC motor

7.1 Pre-Lab

The materials provided for this lab are:

- Enamelled copper wire (About 3 meters)
- One neodymium magnet or one disc magnet
- One 1.5V AA battery
- Two metal paper clips or two safety pins
- Tape
- Scissor

You may wish to bring objects with round, square, and rectangular cross-sections to help with the winding. For the circular shape, something about the size of a white-board marker can work well. For the rectangular shape, a rubber eraser is roughly the right size. Many other objects can work and you can also coil them by hand.

There will be a number of stations set up so you will need to rotate through each station to determine the difference between each kind of coil.

7.2 Purpose

- To build a DC motor and explain how it works

- To understand the torque on a current-carrying loop in the magnetic field
- To explain the speed of a DC motor by changing the magnetic field strength and the number of loops
- To locate magnetometer in phone
- To graph magnetic fields

7.3 Introduction

This lab aims to make a DC motor and discover how it works. Generally speaking, a DC motor converts electrical energy into mechanical energy by applying electromagnetic induction. DC motors have various applications in our everyday life. Some of its utilization is in blenders, laptops, electric toothbrushes, toys, radio-controlled cars, and many other electrical devices [1, 2, 3].

A DC motor is built based on the interplay between two magnetic fields called the temporary and permanent magnetic fields. When the battery powers the circuit, current flows through the wire creating a temporary magnetic field around the wire. With careful placement of another magnet, a torque can be created to make the coil rotate [3].

This temporary magnetic field has the north and south poles similar to a permanent magnet. To make a real DC motor, we place the permanent magnet right in the middle of the coil when we power the battery's circuit. The interaction between the permanent and temporary magnetic fields generates attractive and repelling forces, making the armature move [3].

We can obtain the coil's rotational direction with the right-hand rule, shown in Fig. 7.1. In the right-hand rule, the middle finger indicates the direction of the rotation of the coil. The pointer finger characterizes the direction of the magnetic field, and the thumb gives the direction of the current.

To understand the DC motor and how it operates even better, we can use a magnetometer to map out the magnetic field magnitude around our DC motor. Since most cell phones have magnetometers inside them, you will be using your phones to map out the magnetic field.

7.4 Analysis

Here we study the current-carrying rectangular loop of height, h, and width, w in a magnetic field, as is shown in Fig. 7.2 [4]. The magnetic force $\vec{F}$ is zero on the two horizontal parts of the wire because the current I is parallel with the magnetic field $\vec{B}$. The magnetic force is given as

$$\vec{F} = Ih\vec{B}\hat{z} \tag{7.1}$$

Here, $\vec{F}$ is in the z direction. In the left vertical section, the magnetic force comes out of the page. However, the magnetic force on the right vertical part has the opposite direction with the same

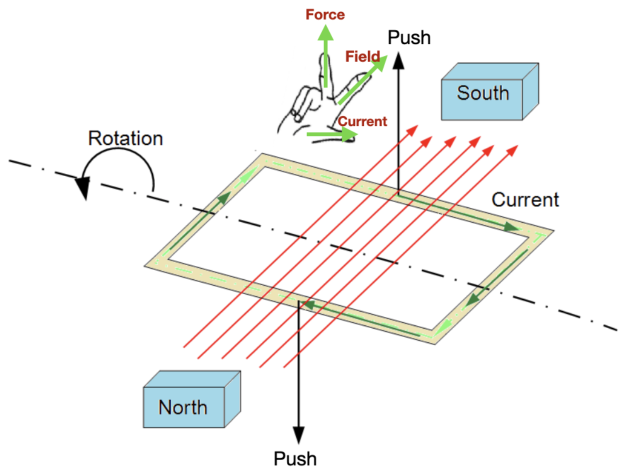

Figure 7.1: This diagram depicts the direction of rotation of the current-carrying wire loop when it is placed in a permanent magnetic field based on the right-hand rule.

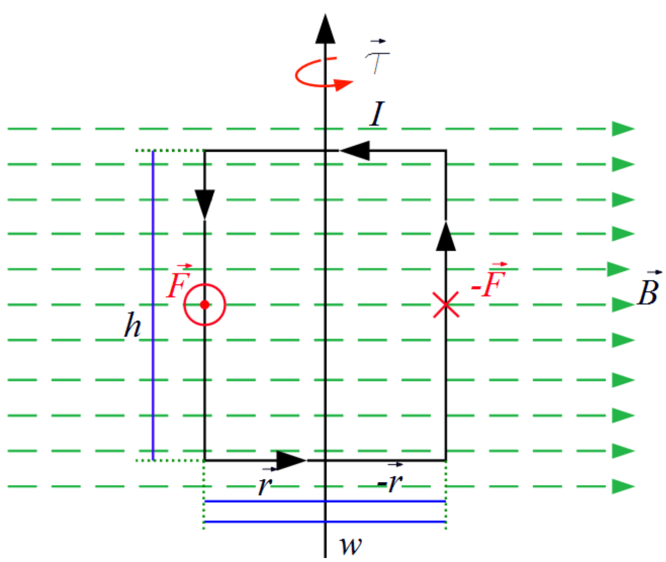

Figure 7.2: This diagram illustrates the rectangular loop carrying current which is counter-clock wise in a magnetic field

magnitude. Therefore, the net force on the vertical axis of the loop is zero. We can also explain the net torque $\vec{\tau}$ on the rectangular loop on its vertical axis. The torque is defined as

$$\vec{\tau} = \vec{r} \times \vec{F} \tag{7.2}$$

where $\vec{r}$ is the distance between the axis of rotation and where the force is applied. The total torque is calculated from the following equation:

$$\vec{\tau} = \vec{r} \times \vec{F} + (-\vec{r} \times -\vec{F}) = 2(\vec{r} \times \vec{F}) \tag{7.3}$$

So, one can write

$$\begin{aligned}\vec{\tau} =& 2(\vec{r} \times \vec{F}) = 2\left(\frac{-w}{2}\hat{x}\right) \times Ih\vec{B}\hat{z} = Ih\vec{B}w(-\hat{x} \times \hat{z}) \\ =& I\vec{B}hw\hat{y}\end{aligned} \tag{7.4}$$

7.5 Procedure and Setup

Required material: 1.5V AA battery, a disc magnet (preferably neodymium), enameled copper wire (about 3 meters), two metal paper clips or two safety pins, scissors, and tape. In Fig. 7.3, we depict the material needed for this experiment. **Note:** For this experiment, we need magnet wire or copper wire coated with a thin layer of insulating enamel.

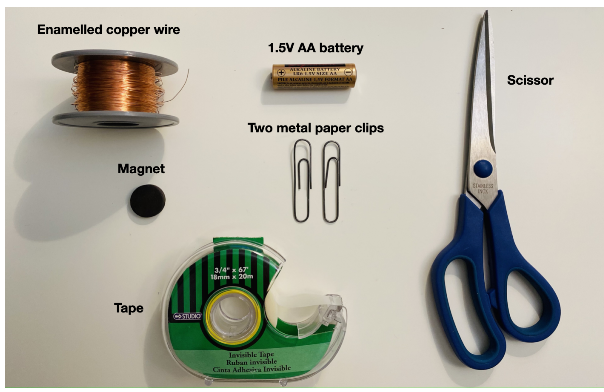

Figure 7.3: A diagram of the required materials for building a DC motor.

To make a homemade DC motor, you should follow these steps:

1. In the first step, wrap the metal wire around a cylinder (such as a dry erase marker) ten times to make a coil. Cut the wire with the scissor. Leave about four centimeters free from both ends of the magnet wire, shown in Fig. 7.4.

Figure 7.4: Wrap the enameled copper wire around a marker to make loops.

2. In the second step, bundle the loops tight such that they stay parallel and touch each other. Then, knot both ends of the loop to keep its shape as is shown in Fig. 7.5. You can make circular, square, rectangular, or oval-shaped coils with the magnet wire and try making a DC motor with each of them.

Figure 7.5: Image of the finished wire loop.

3. In the next step, remove the insulating coating entirely from one end of the magnet wire. You will see shining copper after scraping the insulation. We only need to remove the insulation cover from the top half of the wire for the other end of the wire. So, the bottom of the wire will be insulated (facing away from us in Fig. 7.5. The electric current can flow through the coil and generate a temporary magnetic field for a while. The temporary magnetic field will be stopped when the electric current terminates flowing through the wire as the enameled half of the wire rotates into position and breaks the circuit.

4. In this step, try to bend two metal paper clips from the inner side to make axle supports for the magnet wire, as is depicted in Fig. 7.6. You can use two safety pins instead of two metal paper clips to make your axle supports.

Figure 7.6: A diagram of how to bend a paperclip to make the axle support

5. Attach the metal paper clips to the battery using the tape shown in Fig. 7.7. Make sure that the two ends of the paper clips are secured with tape.

6. Place the magnet wire in the metal paper clips axle. Ensure that the wire moves and rotates freely in the axles.

Figure 7.7: A diagram of how to attach the paper clips to the battery.

7. In the last step, place the permanent magnet on top of the battery right in the middle of the coil between the two-axle supports, as illustrated in Fig. 7.8. Make sure that the coil does not rub against the magnet and move freely in the axle support. Then, give a push and let it spin. You might need to push the coil for a while to see it rotating
   Warning! The coil will get hot if run the battery for more than one minute, so do not touch the coil.

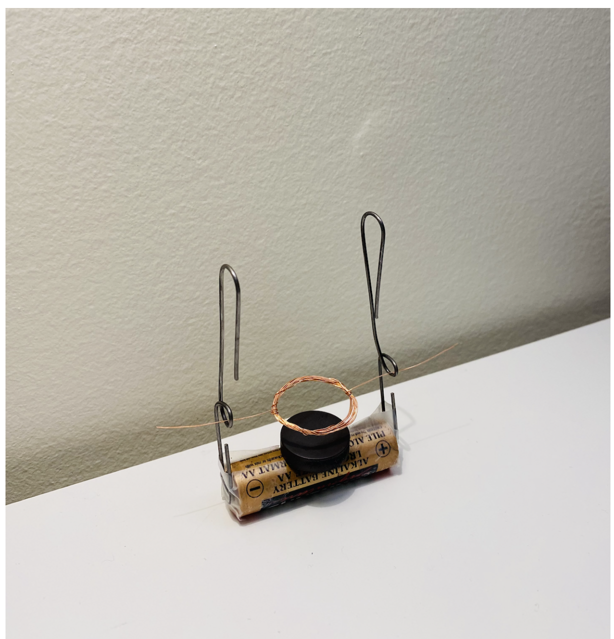

Figure 7.8: A diagram of the DC motor

You can use the magnetometer in your phone to measure the magnetic fields around the DC motor. First you must locate the position of the magnetometer in your phone. The easiest way to do this is to bring a magnet close to your phone in both the y and x directions while measuring the magnetic field. You have some freedom on how you want to do this but we will give the basic idea.

Download the Phyphox (see https://phyphox.org for a link to your relevant app store) app onto your phone and open the “Magnetometer” experiment in the “Raw Sensors” group. You can either use the “Graph” tab or the “Absolute” tab for the experiment. Click the play button and it will begin to collect data. You can export the data by selecting the “three dots” menu in the top-right, and clicking on “Export Data”. You can either upload the data to your Google Drive, email it to yourself, or use any other method that is convenient.

Use a magnet to ”probe” the sides of your phone until you find the location of your sensor. The easiest way is to move your magnetic up and down your phone in the y direction until you reach maximum magnetic field. Repeat this in the y direction (z direction/ flat part of phone is not necessary since so small). Record the position of the sensor with respect to the top left location of your phone.

Use this information to ”probe” the magnetic fields around your DC motor and record the values. We would you to create a small graph with at least 25 points showing the magnetic field in your motor. This graph should be in the same plane as the magnetic and coil. It will be a 2D graph showing the magnatude of the magnetic field coming in or out of the page.

Bibliography

[1] https://www.sciencebuddies.org/science-fair-projects/project-ideas/Elec_p051/electricity-electronics/build-a-simple-electric-motor

[2] http://www.phy.ntnu.edu.tw/demolab/html.php?html=Others/motor/motor

[3] https://nationalmaglab.org/education/magnet-academy/watch-play/interactive/dc-motor

[4] https://phys.libretexts.org/Bookshelves/University_Physics/Book%3A_Introductory_Physics_-_Building_Models_to_Describe_Our_World_(Martin_Neary_Rinaldo_and_Woodman)/21%3A_The_Magnetic_Force/21.04%3A_The_Torque_on_a_Current-Carrying_Loop

7.6 Assignment

In a single PDF answer the following questions and upload it to eClass. Handwritten work or images of handwritten work will not be marked. There is a limit of 4 pages. Please make sure each question is visibly separated:

1. Image - Provide a captioned image of your setup. Label all components.
2. Summary - Summarize your experiment in a short paragraph and describe what you saw.
3. Sensor - What is the position of your magnetometer sensor in your phone with respect to the top left corner of your phone? Give a quick diagram of the location and which axis is the x,y,z directions.
4. Graph - Report your 2D location graph of the magnitude of magnetic field in the same axis as your magnet and coil (x direction should be left to right and z direction will be down to up). Make sure you label things like battery, magnets, coil and field direction. You only need to show the field direction. These should just be arrows showing the direction of the magnetic field based on your phone's report of the magnetic field strength and direction. You should show somewhere between 9 and 25 arrows in the x/z plane.
5. Shape - Try with squared, rectangular, and oval-shaped coils. How does changing the shape of the coils affect the motor? Which one do you think would run the best if the shape makes a difference?
6. Coil - Modify the number of loops in the coil. Do you think having an even or odd number of loops in the coil matters? Will changing the number of coils affect the speed of your DC motor? Describe your results.
7. RPM - Can you think of any approach for measuring the DC motor's speed in RPM? Can you make the electric motor do any work?
8. Improve - How can we improve our DC motor?
9. Magnet - What will happen if we make the permanent magnet stronger or weaker? Use equations to support your claim.
10. Current - Explain what will happen if you change the direction of the current. What will happen if you increase the current? Use equations to support your claim.
11. Field - How efficient is the fields through your coils? Are the perfectly perpendicular to your coil?
12. Error - What are some of the main sources of error in this experiment?
13. References and Acknowledgements - Include the references and acknowledgements you used in preparing this submission. Make sure that you clearly state "Acknowledgements: None" if you do not need to give additional credit to other people or resources.