

## EXPERIMENT V

### 1. MAKE AND TEST A MOTOR

### 2. DEMONSTRATIONS OF MAGNETIC FIELD WITH THE CYCLOTRON MAGNET

**Introduction.** In this lab you will build a little electric motor using a small “refrigerator” magnet, and a coil of wire. You will measure the amount of torque your motor can deliver and from the torque calculate the motor's magnetic field.

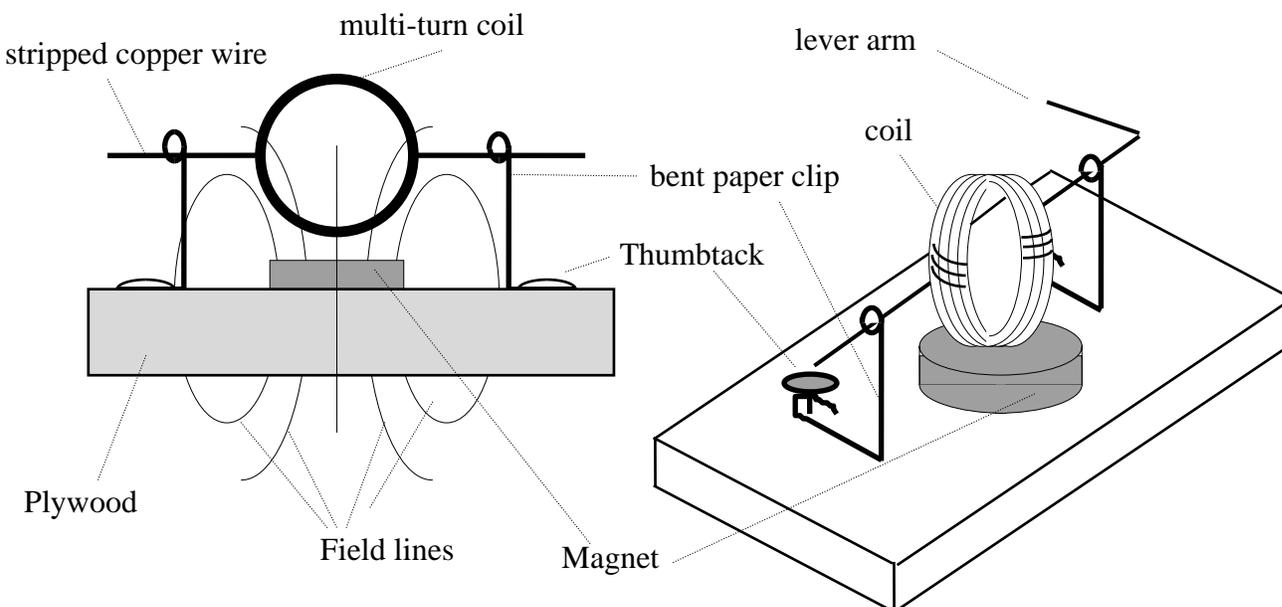
Everyone builds his or her own motor, which you can take home, if you wish.

The lab also includes a visit to the old Princeton cyclotron magnet (which no longer has a cyclotron in the magnet gap), which is an excellent opportunity for hands-on experience of the effects of a large magnetic field.

#### 1. Build and Test a Motor

A sketch of the motor is shown below, and your lab instructor has a model that you can examine for details. The needed material, a soldering iron, and pliers are provided.

- Wind a coil of  $n = 15$  turns (strictly speaking,  $n = 15\frac{1}{2}$  turns) around the form, bundle the turns with wraps at diametrically opposite points on your coil, and leave straight ends at least two inches long sticking out as axles.
- Using sandpaper, completely strip the insulation off the axles.
- Tape your magnet to the center of the plywood block.
- Use the pliers to bend the paperclips into bearings for the axles, and thumb tack the paper clips to the block. The spacing and height of the paper clips are important. The coil should just clear the magnet when spinning in the paper-clip bearings.
- Solder wire leads for the power supply to the paper clips. **If you have never soldered before ask your lab instructor to show you how. Be careful with the soldering iron. The tip is very hot and can cause a bad burn if touched. It can also start a fire.**
- Take your motor over to the sample and compare.



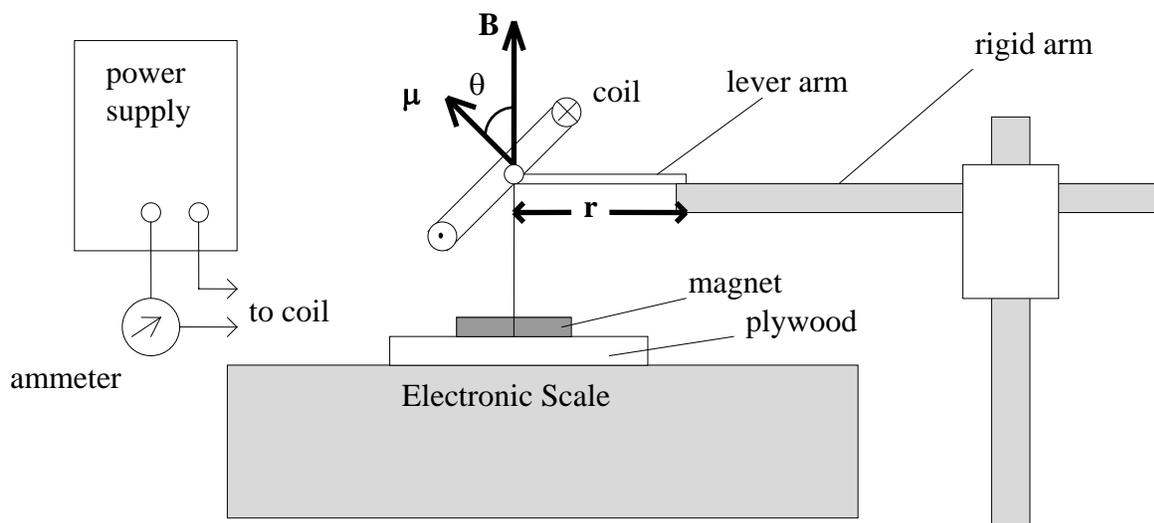
Once the motor is assembled, power it by connecting its leads to a DC power supply of about 2 volts. Always keep the voltage low enough that the current is less than 5 amps. If the coil doesn't turn, give it a little twist to get it started. If it still doesn't turn, you need to make some adjustments. Carefully bend the axles until the coil is balanced. It should rotate without too much wobbling when spun with no current applied. Check that all insulation is cleaned off the axle wire.

This Lab is a bit subtle in that a well made motor of the present design would never work. Your motor will work only if it is constructed in a somewhat “sloppy” manner. Your coil (when powered) has a (vector) magnetic moment  $\mu$ , so that when it is placed in a (vector) magnetic field  $B$  it experiences a (vector) torque  $\tau = \mu \times B$ . When the coil makes a half rotation about the axle, the magnetic moment  $\mu$  reverses direction, and so the torque reverses direction also. This should, in principle, reverse the rotation of the coil, so that it would oscillate rather than spin about its axle.

For an electric motor to work, the current in the coil should reverse direction every half turn, which requires more sophisticated contacts between the axle and the support. Or, if the current were shut off every half turn of the coil, the motor could also work. This is what happens “accidentally” for working motors in this Lab. The relatively poor quality of the contact between somewhat bent axles and the paper clips may be such that the contact is “good” only for some angular positions of the coil, which provides intermittent power to your coil such that the magnetic torque is (almost) always in one direction, and the coil spins! If you look closely at the point of contact between the paper clips and the spinning axle, you can see a sequence of sparks corresponding to the desirable intermittent contact.

### Measuring the Motor's Torque.

Bend one axle of your coil by  $90^\circ$  to form a lever arm, as shown in the sketch below. This lever arm is to be held fixed by a rigid arm via a point of contact, *below the lever arm*, at distance  $r$  from the axle of the coil. To hold the (powered) coil from moving, the rigid arm must exert a force  $F$ , that will be perpendicular to the lever arm if the rigid arm points towards the axle of the coil. Then the magnitude of the torque exerted by the motor would be  $\tau = r F$ .



If the coil rotates away from the rigid arm when powered, reverse the leads of the motor to the power supply.

Since the torque on the coil due to the magnet is  $\tau = \mu \times B$ , whose magnitude is  $\tau = \mu B \sin\theta$ , you will want to arrange the lever arm so that  $\theta = 90^\circ$ , *i.e.*, so that the coil is vertical.

To measure the (upward) force  $F$  exerted by the rigid arm on your motor, note that this force tends to lift the motor up off the table. So by placing the motor on an electronic balance (scale), and noting the apparent loss of weight of the motor when it is powered, you can determine  $F$ . (Use the “tare” feature, if you wish. It zeroes the balance reading each time you push it.)

If you prefer, arrange the rigid arm to press down on the lever arm of the motor, reversing the current in the motor if necessary. Then, the motor will appear to be heavier on the balance when powered.

Increase the current  $I$  from 0 to 3 amps (never more than 5 amps!) in 0.5 or 1 amp increments and measure the decrease in the scale reading per ampere of current. After you measure the length  $r$  of the lever arm you will have the data needed to calculate the torque  $\tau$  (in N-m) per amp of current in your motor.

Also deduce the average magnitude of the magnetic field  $B$  (in tesla) over the face of the coil, via the relation  $\tau = \mu B \sin\theta$ . Recall that the magnetic moment of a loop of  $n$  turns is given by  $\mu = nI\text{Area}$  (in ampere-meters<sup>2</sup>).

One tesla =  $10^4$  gauss. The vertical component of the Earth’s magnetic field is about 0.5 gauss. What percentage error did you make by ignoring the Earth’s field?

## **2. Palmer Cyclotron Magnet Tour**

During the lab session, small groups will be taken to the B level of Jadwin Hall to see the venerable Palmer Cyclotron magnet.

You will get to play with several “toys” in the magnetic field. Do not put anything into the field other than the objects indicated by your tour guide. In particular, there are plenty of metal pieces lying around large enough that they would be attracted very strongly to the pole pieces — and your hand would not fare well if it got in the way of this attraction. In general, do not put anything larger than, say, 0.25 inches in diameter by a few inches long into the field.

A 1-tesla field is very strong. Please observe the following rules:

1) Remove all magnetic objects (iron or common steel) from above the waist. At some points you will be leaning into the field and they could be pulled from you. Precious metals are okay, as is surgical steel (*e.g.*, bone pins). If you wear wire frame glasses, pay attention to them if you start to feel any tugging.

2) Remove all magnetically encoded cards: credit cards, meal cards, bank cards, *etc.*, before entering the magnet area. They could be erased by the magnetic field. It is also a good idea to remove watches, as they could be damaged. There will be a box outside the magnet area for this purpose.

The Palmer Cyclotron was originally located in the basement of Palmer Hall. As part of one of the first cyclotrons ever built, this magnet was used for physics research from 1935 until the late 1960's. Since then it has served as a valuable tool for instruction, giving our students the rare opportunity to experience a large area magnetic field of approximately 1 tesla. The magnet was moved from Palmer to Jadwin in the fall of 1998 (when the physics department gave up Palmer Hall for newly built McDonnell Hall, and Palmer Hall was transformed into the Frist Campus Center.)

PRINCETON UNIVERSITY

Physics Department

Name: \_\_\_\_\_

PHYSICS 104 LAB

Week #5

Date/Time of Lab: \_\_\_\_\_

## EXPERIMENT V

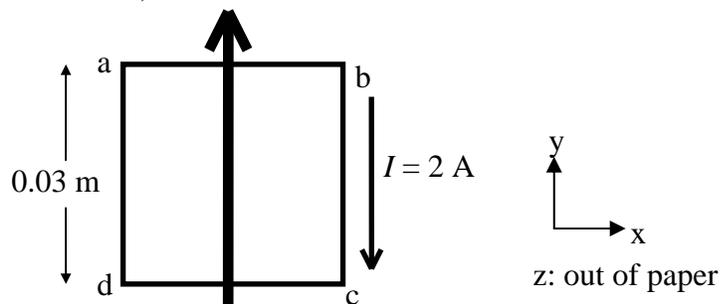
## PRELAB PROBLEM SET

1. A square 5-turn coil with sides 0.03 m long and carrying 2 A of current is placed in a uniform magnetic field of 0.07 T, as shown.

What is the magnitude and direction of the force on each of the four sides?

ab \_\_\_\_\_  
 bc \_\_\_\_\_  
 cd \_\_\_\_\_  
 da \_\_\_\_\_

$n = 5$  turns,  $B = 0.07$  T



What is the magnitude and direction of the torque  $\tau$  on the coil about its center, if any? Use the fact from mechanics that  $\tau = \mathbf{r} \times \mathbf{F}$  due to a force  $\mathbf{F}$  applied with lever arm  $\mathbf{r}$ .

What is the magnetic moment  $\mu$  of this coil? What is the torque on the coil evaluated using the relation  $\tau = \mu \times B$ ?