

Lab 7: Magnetic fields and forces

Lab Worksheet

Name _____

This sheet is the lab document your TA will use to score your lab. It is to be turned in at the end of lab. To receive full credit you must use complete sentences and explain your reasoning clearly.

What's this lab about?

In this lab you investigate magnetic fields and magnetic forces.

There are two parts to the lab:

PART A

Map out magnetic fields using a magnetic dipole as a probe.

PART B

Observe and measure the force a magnetic field exerts on a moving charged particle.

Why are we doing this?

Magnetic fields are a bit more complicated than electric fields, but we usually have more experience with magnetic forces than electric forces. In this lab you can start to get a feel for the shape of magnetic fields, and how they exert forces on other magnets and on moving charged particles.

What should I be thinking about before I start this lab?

As discussed in class, the fundamental 'charge' in magnetism is the magnetic dipole.

Permanent magnets are approximations to magnetic dipoles. Compass needles also are. You'll use these in the first part of the lab to look at magnetic field lines, the forces between permanent magnets, and torques on magnetic dipoles. A uniform magnetic field will exert a torque on a magnetic dipole. The torque will rotate the dipole toward a direction where it aligns with the local magnetic field.

Magnetic fields also exert forces on moving charged particles. The faster the particle goes, the bigger the force. The direction of the force is perpendicular to both the particle velocity and the magnetic field.

This is the first of two labs on magnetism. This lab looks at magnetic fields that are not varying in time (static magnetic fields). In next week's lab you discover some of the surprising behaviors of magnetic fields that change in time (for instance when you move a permanent magnet around with your hand).

A. Mapping a Magnetic Field:

Need to first establish that magnetic dipole will align with a magnetic field? Usually do this by thinking about current loops as magnetic dipole. So maybe should start my mapping current loop

The plastic board has two strong magnets mounted in rotating holders. These produce the magnetic fields that you will map.

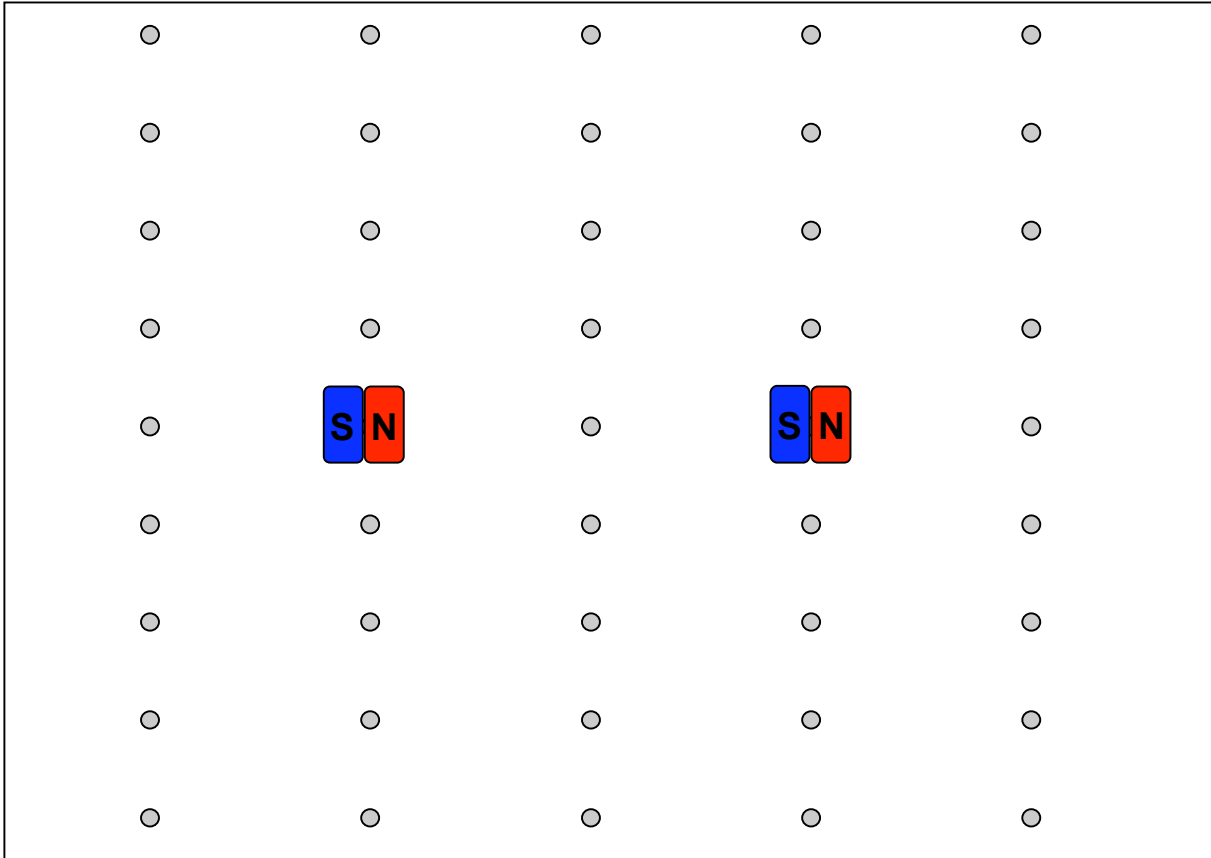
You map the fields by looking at the direction of a test dipole as it aligns with the local field.

You will use:

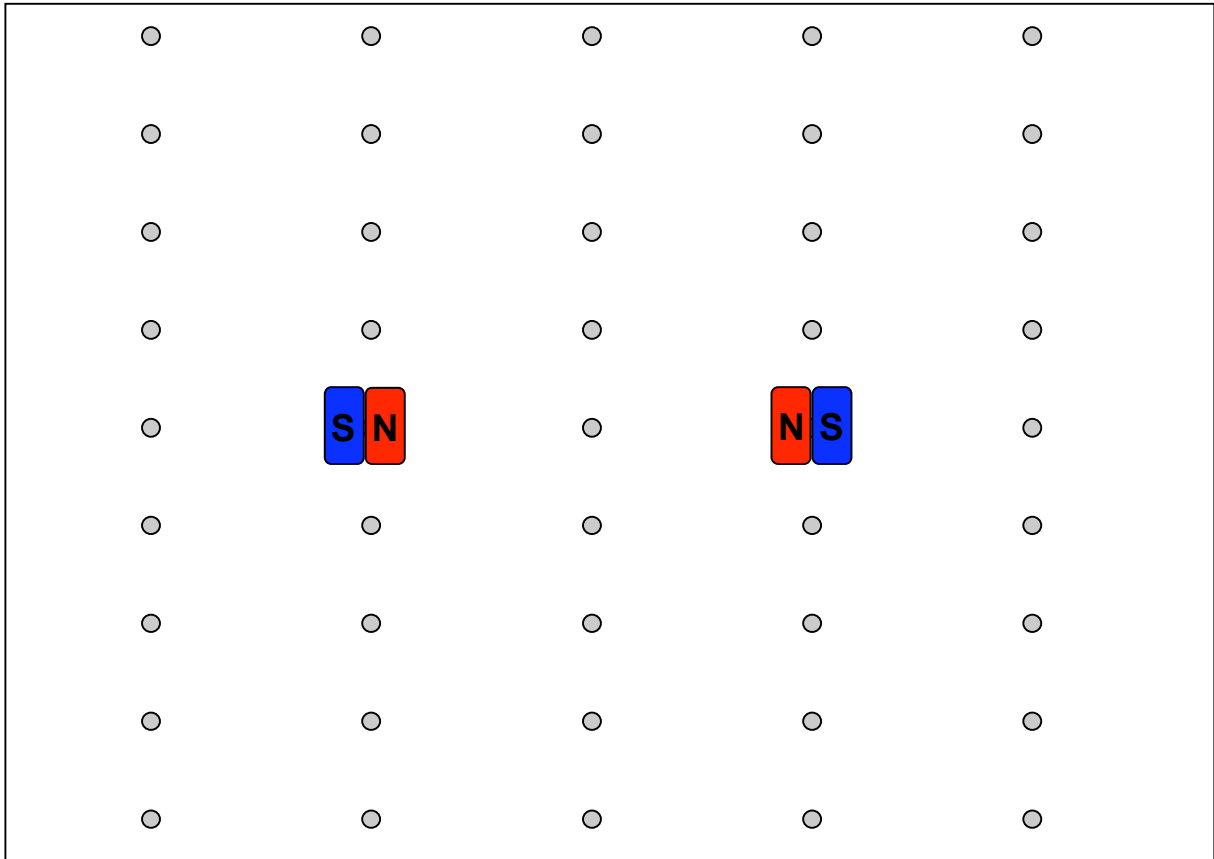
- A compass

- A grid of small magnets enclosed in a plastic case.

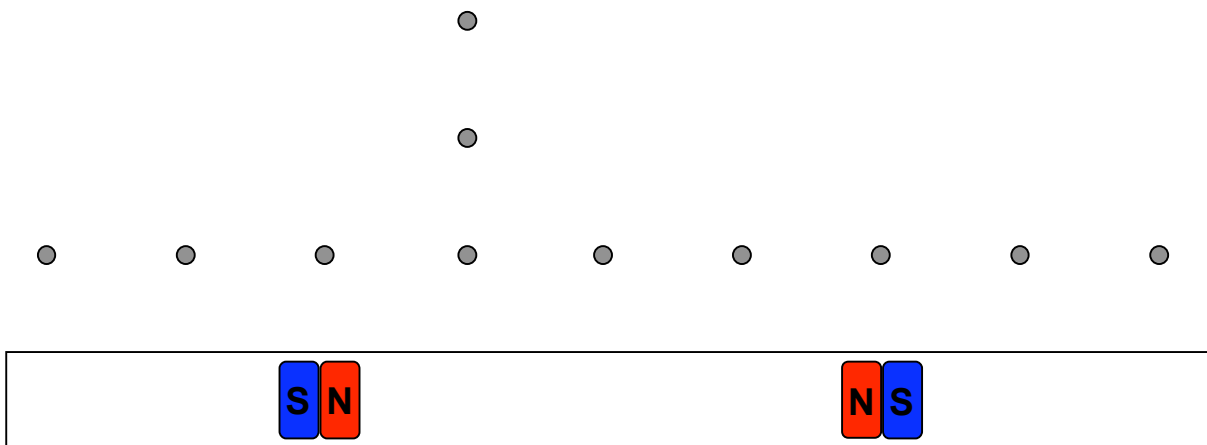
I. Orient the magnets in the plastic so that red (North) of one magnet faces blue (South) of the other. Use the compass to map the direction of the magnetic field at the points indicated, and any others necessary to sketch the magnetic field lines below.



2. Now orient the magnets red to red, and sketch the magnetic field lines using the compass as a test dipole.



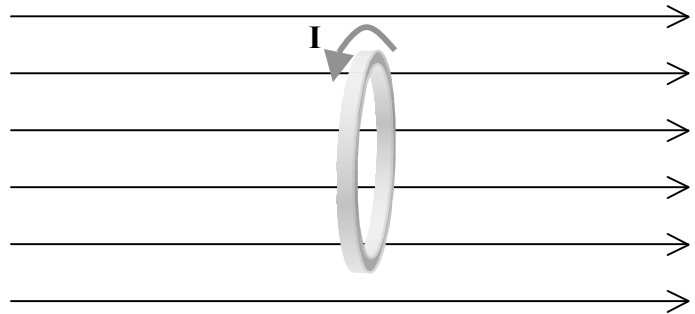
Here is a side view of this setup. Find field direction at points indicated and sketch field lines.



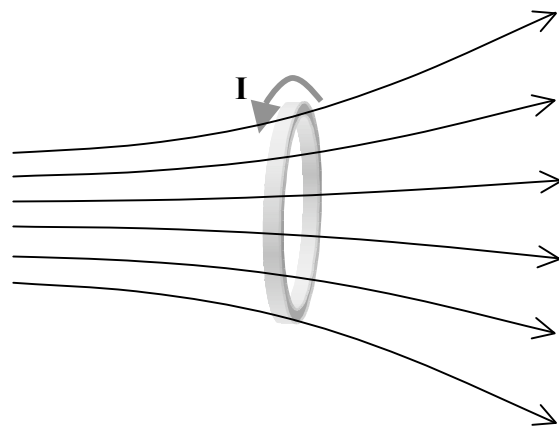
3. Force on a magnetic dipole from these fields.

As discussed in class, a model for a magnetic dipole is a circular loop of current. Suppose a magnetic dipole is oriented as shown below in a uniform magnetic field (generated by some external means – the dipole's field lines are not shown).

Use the right-hand rule for the Lorentz force to determine the net force on the dipole (magnitude and direction).



Now suppose the magnetic field is not spatially uniform, but is as below (magnetic field lines use the same convention as electric: higher density of field lines means larger magnetic field). Now what is the direction of the net force?



4. Based part 3, you can use one of the small cylindrical magnets to test the magnetic field uniformity in the region between the large magnets.

Hold one of the small magnets loosely between your fingers. Move it around while resting it flat on the plastic board in a small region between the two large magnets for both of the configurations and feel the forces and torques. The torques will try to twist the magnet, and any net force will try to pull the magnet from your fingers.

Let the small magnet twist in your fingers to align with the local field, then move it slightly up, down, left, right, and feel the net force. Determine where the forces are small and where they are large based on feeling the pull on the small dipole magnet.

Based on this, which configuration generates more uniform fields in a small region midway between the two magnets? Write down what you did.

Is this consistent with your field mapping in parts 1 and 2? Explain.

B. Lorentz force on moving charged particles.

In this section of the lab you use the huge apparatus that has been taking up most of your lab table. It is a system in which you can launch an electron beam and measure the effect of an applied magnetic field on the path of the electron beam.

This effect is the Lorentz force, $\vec{F}_B = q\vec{v} \times \vec{B}$

A magnetic field can be created by the large rings of current (Helmholtz coils) above and below the glass globe. In each of these coils the current is in the same direction.

The two rings of current are similar to the two permanent magnets in sections 1 & 2. Which magnet orientation (aligned magnetic dipole moments or anti-aligned magnetic dipole moments) is similar to the Helmholtz coils? Explain

What does this suggest about the uniformity of the field between the coils? Explain.

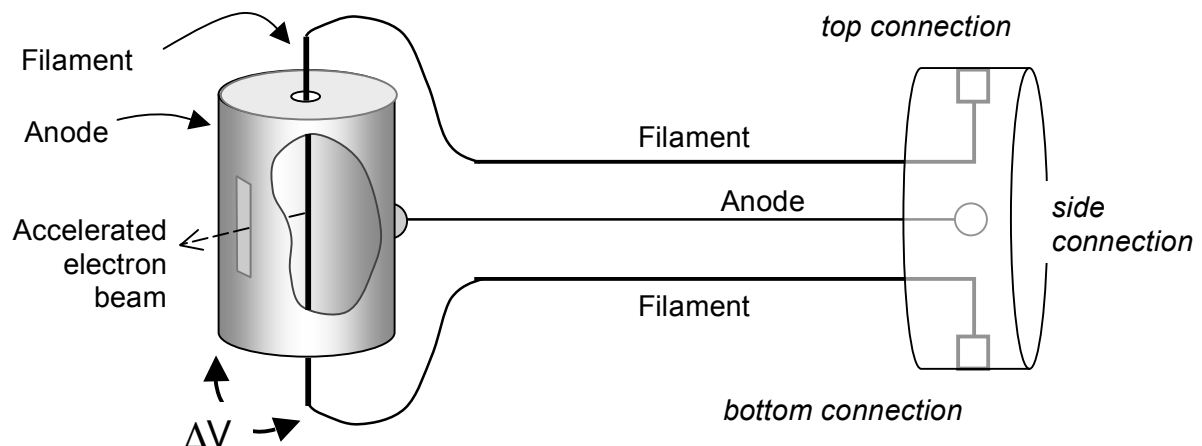
Connecting the experiment

The first step in creating the electron beam is to eject them from a metal filament. To do this, the filament is heated by passing a current of about 10 mA through it.

Connect the Anode (filament) outputs to the top and bottom connections on the Teflon plastic connector block on the end of the glass globe.

The second step in creating the beam is to give the electrons some speed by accelerating them through a potential difference. This is done by applying an 'accelerating' voltage between the filament and the cylindrical anode. Do this by connecting a banana plug cable between the Anode output and the 'side' connection on the Teflon plastic connector block.

The accelerated electron beam escapes through a rectangular slit in the anode. They are moving at a speed v determined by the accelerating potential ΔV .



Shown above is the piece inside the glass globe that generates the electron beam. This diagram helps you connect to the power supply

1. What is the velocity of an electron accelerated from rest through a 22 V potential?
2. If the accelerating potential doubles, by what factor does the electron's velocity change? Explain.

Now turn on the power supply. At this point you should have in place the connections to produce the electron beam, but not yet connected to the Helmholtz coils.

The ANODE Volts should be in its lower voltage position (21-22 V).

Supply some filament current by turning up the knob below the "ANODE milliamps" display. The reading will stay zero for a while, then start to increase at some position after the "Filament On" lamp lights. Set the filament current to about 10 mA. You should see the ionization path from the electron beam (dimming the lights helps).

3. Use one of the cylindrical magnets to steer the electron beam (hold up to the glass globe and move it around). What is happening? Imagine the pattern of field lines from the magnet to determine the sign of the magnetic field at the electron beam. Turn the cylindrical magnet upside down to check your reasoning.

4. Now connect the "Field" outputs to the banana-plug connections on the Helmholtz coils, and increase the current to the coils until "FIELD Amps" reads about 2 Amps. What are the electrons doing? Vary the field and observe the results. Reverse the field direction by changing the current leads and observe the results. Explain.

5. Set the accelerating potential to 44V by flipping the switch under the “ANODE Volts” display. What happens to the orbit? Explain.

6. Adjust the magnetic field so that the beam of electrons hits one of the “cross-bars”.

Crossbar No.	Distance to Filament	Radius of Beam Path
1	0.065 meter	0.0325 m
2	0.078 meter	0.039 m
3	0.090 meter	0.045 m
4	0.103 meter	0.0515 m
5	0.115 meter	0.0575 m

Calculate the magnetic field at the center of the glass globe for the current you are using in the coils. (Each coil has 72 turns of wire, and a radius of 0.33m: see your lab manual). How does this compare in magnitude and direction to the Earth’s field?

7. Calculate the magnitude and direction of the force on a single electron in the beam from this magnetic field.

8. A particle moving at constant speed in a circular orbit is accelerating, since its velocity is continually changing direction. This ‘centripetal’ acceleration is directed toward the center of the orbit, and has magnitude v^2/r , where r is the radius of the circular orbit. (Your lab manual has a table that will let you determine the orbit radius from the crossbar number)

i) What force is producing this acceleration?

ii) Calculate the required magnitude of the force. Compare to the result in part G.