

**Topics:** Magnetic Dipoles

**Related Reading:**

Course Notes (Liao et al.): Sections 8.4, 9.1 – 9.2, 9.5

Serway & Jewett: Sections 30.1 – 30.2

Giancoli: Sections 28.1 – 28.3, 28.6

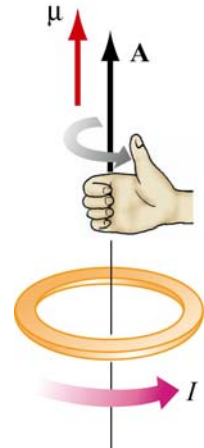
**Experiments:** (7) Forces and Torques on Magnetic Dipoles

## Topic Introduction

This class continues a topic that was introduced on Friday – magnetic dipoles.

### Magnetic Dipole Moment

In the Friday problem solving session we saw that the torque on a loop of current in a magnetic field could be written in the same form as the torque on an electric dipole in an electric field,  $\vec{\tau} = \vec{\mu} \times \vec{B}$ , where the dipole moment is written  $\vec{\mu} = I\vec{A}$ , with the direction of  $\vec{A}$ , the area vector, determined by a right hand rule:



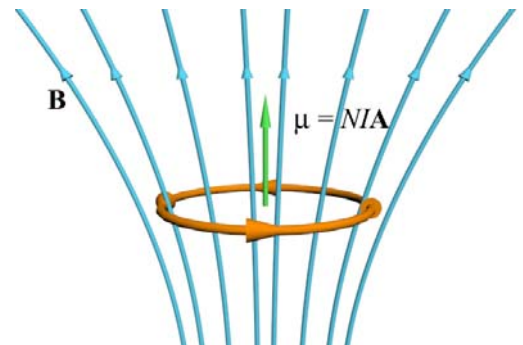
### Right Hand Rule for Direction of Dipole Moment

To determine the direction of the dipole moment of a coil of wire: wrap your fingers in the direction of current. Your thumb points in the direction of the North pole of the dipole (in the direction of the dipole moment  $\vec{\mu}$  of the coil).

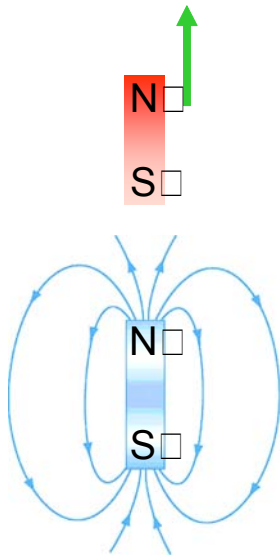
### Forces on Magnetic Dipole Moments

So we have looked at the fields *created* by dipoles and the *torques they feel* when placed in magnetic fields. Today we will look at the *forces they feel* in fields. Just as with electric dipoles, magnetic dipoles only feel a force when in a non-uniform field. Although it is possible to calculate forces on dipole moments using an equation ( $\vec{F}_{Dipole} = (\vec{\mu} \cdot \nabla) \vec{B}$ ) it's actually much more

instructive to think about what forces will result by thinking of the dipole as one bar magnet, and imagining what arrangement of bar magnets would be required to create the non-uniform magnetic field in which it is sitting. Once this has been done, determining the force is straight forward (opposite poles of magnets attract).



As an example of this, consider a current loop sitting in a diverging magnetic field (pictured above). In what direction is the force on the loop?



In order to answer this question one could use the right hand rule and find that the force on every current element is outward and downward, so the net force is down. An often easier way is to realize that the current loop looks like a bar magnet with its North pole facing up and that the way to create a field as pictured is to put another bar magnet with North pole up below it (as pictured at left). Once redrawn in this fashion it is clear the dipole will be attracted downwards, towards the source of the magnetic field.

A third way to think about the forces on dipoles in fields is by looking at their energy in a field:  $U = -\vec{\mu} \cdot \vec{B}$ . That is, dipoles can reduce their energy by rotating to align with an external field (hence the torque). Once aligned they will move to high  $B$  regions in order to further reduce their energy (make it more negative).

### Important Equations

Magnetic Moment of Current Carrying Wire:

$$\vec{\mu} = I\vec{A} \text{ (direction from RHR above)}$$

Torque on Magnetic Moment:

$$\vec{\tau} = \vec{\mu} \times \vec{B}$$

Energy of Moment in External Field:

$$U = -\vec{\mu} \cdot \vec{B}$$

### Experiment 7: Forces and Torques on Magnetic Dipoles

**Preparation:** Read lab write-up.

This lab will be performed through a combination of lecture demonstrations and table top measurements. The goal is to understand the forces and torques on magnetic dipoles in uniform and non-uniform magnetic fields. To investigate this we use the “TeachSpin apparatus,” which consists of a Helmholtz coil (two wire coils that can produce either uniform or non-uniform magnetic fields depending on the direction of current flow in the coils) and a small bar magnet which is free both to move and rotate.