

Topics: Magnetic Levitation; Magnetic Forces on Dipoles

Related Reading:

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

Experiments: (4) Forces and Torques on Magnetic Dipoles

Topic Introduction

In this class we will begin by looking at some examples of using magnetic forces to levitate various objects – frogs, sumo wrestlers, etc. The bulk of the class will be spent doing an experiment to see the forces and torques on magnetic dipoles that we discussed in theory in Monday's class.

Magnetic Levitation

Last time we saw that when magnetic dipoles are in non-uniform fields that they feel a force. If they are aligned with the field they tend to seek the strongest field (just as electric dipoles in a non-uniform electric field do). If they are anti-aligned with the field they tend to seek the weakest field. These facts can be easily seen by considering the energy of a dipole in a magnetic field: $U = -\vec{\mu} \cdot \vec{B}$. Unfortunately these forces can't be used to stably levitate simple bar magnets (try it – repulsive levitation modes are unstable to flipping, and attractive levitation modes are unstable to “snapping” to contact). However, they can be used to levitate diamagnets – materials who have a magnetic moment which always points opposite the direction of field in which they are sitting. We begin briefly discussing magnetic materials, for now just know that most materials are diamagnetic (water is, and hence so are frogs), and that hence they don't like magnetic fields. Using this, we can levitate them.

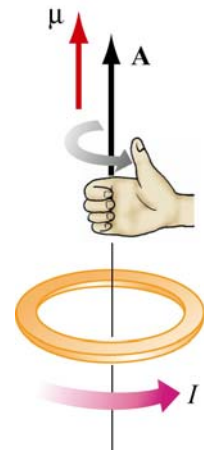
Neat, but is it useful? Possibly yes. Magnetic levitation allows the creation of frictionless bearings, Maglev (magnetically levitated) trains, and, of course, floating frogs.

Magnetic Dipole Moment

The rest of the class will be spent doing an experiment where you get to observe the motion of a magnetic dipole in an external field created by a Helmholtz coil (the same one you measured the field profile of last week). In thinking about the field profile of the Helmholtz coil, remember that coils are magnetic dipoles with the dipole moment $\vec{\mu} = I\vec{A}$, where I is the current in the loop and the direction of \vec{A} , the area vector, is 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).



Magnetic Dipole Moments in External Fields

You will observe both the torque and force that a dipole can feel in an external field. Recall that the magnet will only feel a torque if not aligned with the external field – $\vec{\tau} = \vec{\mu} \times \vec{B}$ – and that the direction of the torque tends to align the dipole with the external field.

There will only be a force on the dipole if it is in a non-uniform field. If aligned with the external field, the dipole will seek higher field (it will climb the gradient) in order to minimize its energy $U = -\vec{\mu} \cdot \vec{B}$.

Important Equations

Magnetic Moment of Current Carrying Wire: $\vec{\mu} = I\vec{A}$ (direction from RHR above)

Torque on Magnetic Moment: $\vec{\tau} = \vec{\mu} \times \vec{B}$

Force on Magnetic Moment: $\vec{F}_{Dipole} = (\vec{\mu} \cdot \vec{\nabla}) \vec{B}$

Energy of Moment in External Field: $U = -\vec{\mu} \cdot \vec{B}$

Experiment 4: Forces and Torques on Magnetic Dipoles

Preparation: Read pre-lab and answer pre-lab questions

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 magnet which is free both to move and rotate.