

**Topics:** Magnetic Fields

**Related Reading:**

Course Notes (Liao et al.): Chapter 8  
Serway and Jewett: Chapter 26  
Giancoli: Chapter 29

**Experiments:** (5) Magnetic Fields of a Bar Magnet and of the Earth

## Topic Introduction

Today we begin a major new topic in the course – magnetism. In some ways magnetic fields are very similar to electric fields: they are generated by and exert forces on electric charges. There are a number of differences though. First of all, magnetic fields only interact with (are created by and exert forces on) charges that are moving. Secondly, the simplest magnetic objects are not monopoles (like a point charge) but are instead dipoles.

### Dipole Fields

We will begin the class by studying the magnetic field generated by bar magnets and by the Earth. It turns out that both bar magnets and the Earth act like magnetic dipoles. Magnetic dipoles create magnetic fields identical in shape to the electric fields generated by electric dipoles. We even describe them in the same way, saying that they consist of a North pole (+) and a South pole (-) some distance apart, and that magnetic field lines flow from the North pole to the South pole. Magnetic dipoles even behave in magnetic fields the same way that electric dipoles behave in electric fields (namely they feel a torque trying to align them with the field, and if the field is non-uniform they will feel a force). This is how a compass works. A compass is a little bar magnet (a magnetic dipole) which is free to rotate in the Earth's magnetic field, and hence it rotates to align with the Earth's field (North pole pointing to Earth's magnetic South – which happens to be at Earth's geographic North now). If you want to walk to the geographic North (Earth's magnetic South) you just go the direction the N pole of the magnet (typically painted to distinguish it) is pointing.

Despite these similarities, magnetic dipoles are different from electric dipoles, in that if you cut an electric dipole in half you will find a positive charge and a negative charge, while if you cut a magnetic dipole in half you will be left with two new magnetic dipoles. There is no such thing as an isolated “North magnetic charge” (a magnetic monopole).

### Lorenz Force

In addition to being created by and interacting with magnetic dipoles, magnetic fields are also created by and interact with electric charges – but only when those charges are in motion. We will discuss their creation by charges in the next several classes and in this class will focus on the force that a moving charge feels in a magnetic field. This force is called the Lorenz Force and is given by  $\vec{F} = q\vec{v} \times \vec{B}$  (where  $q$  is the charge of the particle,  $\vec{v}$  its velocity and  $\vec{B}$  the magnetic field). The fact that the force depends on a cross product of the charge velocity and the field can make forces from magnetic fields very non-intuitive.

If you haven't worked with cross products in a while, I strongly encourage you to read the vector analysis review module. Rapid calculation of at least the direction of cross-products will dominate the class for the rest of the course and it is vital that you understand what they mean and how to compute them.

Recall that the cross product of two vectors is perpendicular to both of the vectors. This means that the force  $\vec{F} = q\vec{v} \times \vec{B}$  is perpendicular to both the velocity of the charge and the magnetic field. Thus charges will follow curved trajectories while moving in a magnetic field, and can even move in circles (in a plane perpendicular to the magnetic field). The ability to make charges curve by applying a magnetic field is used in a wide variety of scientific instruments, from mass spectrometers to particle accelerators, and we will discuss some of these applications in class.

### Important Equations

Force on Moving Charges in Magnetic Field:

$$\vec{F} = q\vec{v} \times \vec{B}$$

### Experiment 5: Magnetic Fields of a Bar Magnet and of the Earth

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

In this lab you will measure the magnetic field generated by a bar magnet and by the Earth, thus getting a feeling for magnetic field lines generated by magnetic dipoles. Recall that as opposed to electric fields generated by charges, where the field lines begin and end at those charges, fields generated by dipoles have field lines that are closed loops (where part of the loop must pass through the dipole).