General Physics - E&M (PHY 1308) Lecture Notes

Lecture 017: Magnetic Force between Currents

YourName, 1 April 2011 (created 1 April 2011)

no tags

Goals of these lectures:

- Discuss the implications of moving charge creating magnetic fields
    - Exercise: calculate the scale (order of magnitude) of terrestrial magnetism using the Bohr model of the atom
    - Loops of current exposed to magnetic field: dipoles and motors
- Introduce and Discuss Ampere's Law

Review from last time

We discussed two application of the *Biot-Savart* Law, a law which allows you to determine the magnetic field created by a moving electric charge (or charges). We obtained two results from that effort:

- The magnetic field around a current-carrying wire:

$$|\vec{B}| = \frac{\mu_0 I}{2\pi y}$$

  where y is your distance from the wire. The magnetic field CIRCULATES around the wire, perpendicular both to the current AND the line from the current to where you measure the field.

- The magnetic field along the central axis of a current-carrying loop: this is the simplest circuit, and the magnetic field along the central axis of such a loop is

\oint ds = 2 \pi

$$|\vec{B}| = \frac{\mu}{2(x^2+a^2)^{3/2}}$$

> where a is the radius of the loop and x is the distance from then center of the loop along the axis. This is just like the dipole electric field along the bisecting axis of an electric dipole; in fact, a current loop, the simplest circuit, is just a magnetic dipole with a dipole field.

When you are VERY FAR from the center of the current loop, so that the loop appears tiny compared to the distance from the loop ($x >> a$), the above equation simplifies to:

$$|\vec{B}| = \frac{\mu_0 I a^2}{2x^3}$$

Magnetic attraction of two wires

What if you place two parallel lines of current next to one another, separated by a distance d? Since each wire emits a magnetic field, and we know that moving charge RESPONDS to magnetic field by feeling a force, something must happen. Force causes motion.

We know from the last lecture that the magnetic field emitted by current 1 at the location of current 2, a distance d away, will be:

$$B_1 = \frac{\mu_0 I_1}{2\pi d}$$

We determined this from the *Biot-Savart* Law (BSL).

Let us define the currents to flow along the x-axis in the direction $\hat{\imath}$. The magnetic field from current 1 will point UP at the location of current 2; thus it points in the $+\hat{\jmath}$ direction. Current 2 also flows in the positive $\hat{\imath}$ direction (x-direction) so by construction current 2 and the magnetic field from current 1 are perpendicular and

$$I_2\vec{L}_2 \times \vec{B}_1 = I_2 L_2 B_1 (\hat{\imath} \times \hat{\jmath}) = I_2 L_2 B_1 \hat{k}$$

and we immediately know the direction of the force on current 2 due to current 1: it pulls current 2 in the positive z direction, TOWARD current 1. The magnitude of the force is just:

$$F_{12} = I_2 L_2 B_1 = I_2 L_2 \frac{\mu_0 I_1}{2\pi d} = \frac{\mu_0 I_1 I_2 L_2}{2\pi d}$$

If you then ask what force the magnetic field from current 2 exerts on current 1 we have only to recognize that at current 1's location, the magnetic field from current 2 points DOWN and thus:

$$\vec{F}_{21} = I_1 \vec{L}_1 \times \vec{B}_2 = I_1 L_1 B_2 (\hat{\imath} \times -\hat{\jmath}) = I_1 L_1 B_2 (-\hat{k})$$

and substituting with the equation for B_2 from the *Biot-Savart* Law:

$$\vec{F}_{21} = \frac{\mu_0 I_2 I_1 L_1}{2\pi d} (-\hat{k})$$

and current 2 also pulls current 1 toward it.

If the currents point in the same direction, the force between them is attractive. If they point in opposite directions, it's repulsive.

This force can be QUITE LARGE for large currents. Engineers have to worry about this force when designing electricity transport systems, like power lines or transformers (which contain many close coils of wire with high current in them). The hum or buzzing you often hear near high-current devices is due to the vibration from this magnetic force, as the current in such devices alternates (changes direction and magnitude) and thus the force changes in strength at about 120 times per second (120Hz).

SHOW THE MIT VIDEO OF TWO WIRES WITH CURRENT FLOWING IN THE SAME OR OPPOSITE DIRECTIONS.