Week 8 - Magnetism

> Magnetism, as you recall from physics class, is a powerful force that causes certain items to be attracted to refrigerators.
>
> Dave Barry

Exercise 8.1: Magnetic field from power lines

You're traveling in the forest while using a compass. Suddenly the compass needle jumps and points in a completely different direction. While looking around, you realize that there is a building nearby with a huge power wire attached to it that continues along the ground. Since this affects your compass, you realize this must be a wire carrying DC current and you become curious about how large the current actually is.

Before getting started with the exercise, try to think out for yourself how you could measure the current using your compass.

a) In what direction would the current have to go not to affect the compass?

b) Assume that the direction of the current is so that the field is exactly oppositely directed relative to the magnetic field from the Earth's core. The magnetic field from the Earth's core is $B = 0.5 \cdot 10^{-4}\,\mathrm{T}$. If your compass is $1\,\mathrm{m}$ above the wire, how large must the current be to produce a magnetic field greater than that of the Earth? You can assume that the wire is quite long, so that the magnetic field from the wire is to a good approximation

$$B = \frac{I\mu_0}{2\pi r}$$

Answer: $B = 250\,\mathrm{A}$

c) Do regular power lines cause such problems for compass users? Should one consider the direction power lines are built because of this?

Answer: They are carrying AC-current at $f = 50\,\mathrm{Hz}$ and will therefore quickly vary the magnetic field produced with 180 degrees. With 50 switches a second, this will probably be too fast for the compass needle to be able to turn.

Exercise 8.2: The Lorentz' Force

Now that we've studied the magnetic equivalent of Coloumb's law, it's time to study the equivalent of the electric $\mathbf{F} = q\mathbf{E}$. We therefore ask the question, what effect does a magnetic field produce on a body? The answer is

$$\mathbf{F}_B = q\mathbf{v} \times \mathbf{B}$$

where v is the velocity of the body in motion and q is the charge of the body. In other words, magnetic fields produce a force only on moving charges. So in magnetism everything is moving. It is produced by moving charges, and it is also felt by moving charges. By using the Lorentz force law one can show that the force on a current carrying wire is $F = \int I d\mathbf{l} \times \mathbf{B}$.

Let us now place a square loop of sides a in the xy-plane a distance r in y direction from an infinite wire carrying the current I in the x direction. The current in the loop goes clockwise and is also I. The loop has a mass m.

(a) Find the magnetic force on the current loop.

(b) Gravity is acting down the negative y direction. How large a current is needed to make the loop levitate a above the wire?

(c) If you now increase the current, the magnetic force exceeds the gravitational force. The loop will lift up which clearly means an increase in potential energy. What is providing the required work?

Exercise 8.3: Exercise 2 from the 2009 exam

Do exercise 2 from the 2009 exam. Earlier exams are published here:

http://www.uio.no/studier/emner/matnat/fys/FYS1120/h11/undervisningsmateriale/eksamensoppgaver/

Exercise 8.4: Biot-Sawart Law

Earlier we became familiar with Coloumb's law which was one of the first laws we studied in electromagnetism. It is only valid for *stationary* charges and tells us that stationary charges are sources of stationary electric fields.

We will now study the magnetic equivalent of Coloumb's law, namely *Biot-Savart's law*. It tells us that for a *steady* line current

$$\mathbf{B}(\mathbf{r}) = \frac{\mu_0}{4\pi} \int \frac{I d\mathbf{l}' \times \hat{\mathbf{r}}}{r^2}$$

where μ_0 is called the *permeability of free space* and the integration is taken along the wire carrying the current. A steady current means that the current is not varying at any point along the wire so that we produce a constant magnetic field. For currents that are varying this law is not exact[1], but is still a good approximation as long as the current is not variying to rapidly.

(a) Use Biot-Savarts law to find the field a distance a perpendicular to the center of a wire of length l carrying a steady current I.

(b) Let the length of the wire l go to infinity and compare this to the expression for the electric field from an infinite wire.

[1] We will see later what happens when we have varying electric and magnetic fields.