Institutt for fysikk, NTNU
TFY4155/FY1303: Elektrisitet og magnetisme
Vår 2004

Øving 14

Guidance: Monday April 26
To be delivered by: Thursday April 29

Exercise 1

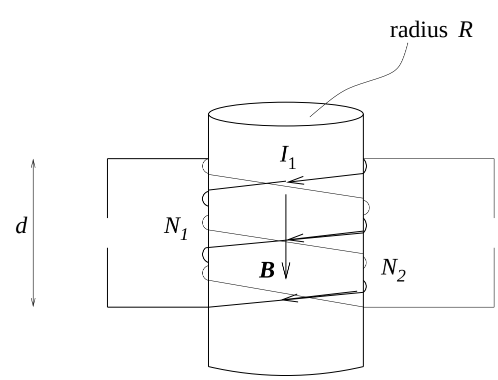
a) A bar magnet har its magnetization vector $\boldsymbol{M}$ in the direction from the south pole (S) towards the north pole (N). Draw a bar magnet and sketch field lines for $\boldsymbol{B}$ inside and around the bar magnet. Also include the bound surface current I_m (including its direction) associated with the magnetization $\boldsymbol{M}$.

b) Explain, on the basis of *a*), why two bar magnets placed after each other with S agaist N attract each other and why they repel each other when they are placed with S against S (or N against N). (Hint: Use for example what you know about magnetic force on an electric current in your argumentation.)

c) Explain next why a sphere (or a needle or an object with any shape) of unmagnetic iron is attracted both by the S-pole and the N-pole of the bar magnet.

Hint: These things is for certain discussed in some detail in your book, whether it is Fishbane or Young.

Exercise 2



The figure shows two solenoids 1 and 2 that are both wound onto the same cylinder of radius R. We assume that the cylinder has magnetic properties as vacuum, i.e., we assume there is no magnetization of the cylinder. Solenoid 1 har N_1 windings, solenoid 2 has N_2 windings. Both solenoids are wound onto a length d of the cylinder, which is (appoximately infinitely) long compared to the radius of the cylinder. (So the figure is only qualitatively correct...!) You may assume that both solenoids are tightly wound, and that each winding of both solenoids enclose the same amount of magnetic flux. (The wire of the solenoids is covered with some kind of electrically insulating material, e.g. a layer of plastic, so that an electric current is forced to follow the solenoid wire. This assumption is by the way implicit in all such exercises with solenoids.)

a) Assume that solenoid 1 carries a current I_1. What is then the strength of the magnetic field B inside the solenoid? Next, what is the *total* magnetic flux ϕ_1 enclosed by the wire of solenoid 1 (i.e., all the N_1 windings)? What is the total magnetic flux ϕ_2 enclosed by the wire of solenoid 2 (again: all the N_2 windings)? (Note: There is no current in solenoid 2. The current in solenoid 1 can be made e.g. by coupling it to a battery and a resistance.)

b) The ratio between the total enclosed magnetic flux ϕ_1 and the current I_1 in the current loop it*self* is, by definition, a quantity which is called the *self inductance* L of the loop:

$$L = \frac{\phi_1}{I_1}$$

Then, what is the self inductance L of such a long cylindrical solenoid with radius R, length d and N_1 windings?

c) The ratio between the total enclosed magnetic flux ϕ_2 that is enclosed by solenoid 2 and the current I_1 in solenoid 1 is, by definition, a quantity which is called the *mutual inductance* M between the two current loops:

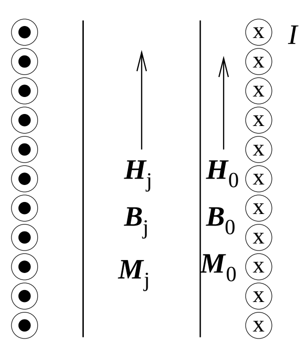
$$M = \frac{\phi_2}{I_1}$$

Then, what is the mutual inductance M between two such long cylindrical solenoids, both being wound onto a cylinder of radius R over a length d, and with N_1 and N_2 windings, respectively?

d) Determine numerical values for L and M (in SI units) when R = 2 cm, d = 30 cm and $N_1 = N_2 = 300$. (Answer: $L = 4.7 \cdot 10^{-4}$)

Comment: We will come back to mutual inductance and selfinductance in the final lectures, and see why these are "useful" quantities in many connections.

Exercise 3



A cylindrical iron rod with relative permeability μ_r = 2000 is placed coaxially inside a solenoid, but fills only partially the volume inside the solenoid. The solenoid has a winding density (i.e.,

windings pr unit length) $n = 2000\ \mathrm{m}^{-1}$ and the current in the solenoid wire is $I = 3$ A. We assume that both the solenoid and the iron rod are sufficiently long that we may neglect edge effects.
Assume first that we have linear response in the iron rod, i.e. $\boldsymbol{M} = \chi_m \boldsymbol{H}$, and determine $\boldsymbol{H}$, $\boldsymbol{B}$ and $\boldsymbol{M}$ inside the solenoid, both inside (index j) and outside (index 0) the iron rod. (Remember that the H-field is determined by the "free" current, whereas B is determined by the total current.)
Discuss the calculated value of M_j inside the iron rod, taking into account the *saturation magnetization* in iron, i.e., the maximum possible magnetization, which you calculated in exercise 1d in øving 13. Calculate next a corrected (maximum) value of B_j.

Given information

$$\boldsymbol{B} = \mu_0 (\boldsymbol{H} + \boldsymbol{M}) = \mu_r \mu_0 \boldsymbol{H} = \mu \boldsymbol{H}$$

$$\boldsymbol{M} = \chi_m \boldsymbol{H} = (\mu_r - 1) \boldsymbol{H}$$

(The last line is only valid when we have linear response.)

A couple of answers: $B_j = 15$ T ("uncorrected"), $B_j = 2$ T ("corrected").