4. Magnetic Materials

4.1 Definitions and General Relations

4.1.1 Fields, Fluxes and Permeability

- There are many analogies between dielectric and magnetic phenomena; the big difference being that (so far) there are *no magnetic "point charges"*, so-called magnetic monopoles, but only *magnetic dipoles*.
  - The first basic relation that we need is the relation between the magnetic flux density ***B*** and the magnetic field strength ***H*** *in vacuum*. It comes straight from the Maxwell equations:

$$B = \mu_o \cdot H$$

  - The symbols are:
    - B = **magnetic flux density** or **magnetic induction**,
    - μ_o = **magnetic permeability of the vacuum = 4π · 10^{-7} Vs/Am = 1,26 · 10^{-6} Vs/Am**
    - H = **magnetic field strength**

    .
  - The units of the magnetic field ***H*** and so on are
    - **[H] = A/m**
    - **[B]** = **Vs/m^2**, with **1Vs/m^2 = 1 Tesla**.

    B and ***H*** are vectors, of course.
  - **$10^3/4\pi$ A/m** used to be called **1 Oersted**, and **1 Tesla** equales **10^4 Gauss** in the old system.
  - Why the eminent mathematician and scientist *Gauss* was dropped in favor of the somewhat shady figure *Tesla* remains a mystery.
- If a material is present, the relation between magnetic field strength and magnetic flux density becomes

$$B = \mu_o \cdot \mu_r \cdot H$$

  - with μ_r = **relative permeability of the material** in complete analogy to the *electrical flux density* and the *dielectric constant*.
  - The relative permeability of the material μ_r is a material parameter without a dimension and thus a *pure number* (or several pure numbers if we consider it to be a *tensor* as before). It is the material property we are after.
- Again , it is useful and conventional to split ***B*** into the *flux density in the vacuum* plus the *part of the material* according to

$$B = \mu_o \cdot H + J$$

  - With J = **magnetic polarization** in analogy to the dielectric case.
- As a new thing, we now we define the **magnetization *M*** of the material as

$$M = \frac{J}{\mu_o}$$

  - That is only to avoid some labor with writing. This gives us

$$B = \mu_o \cdot (H + M)$$

- Using the independent definition of ***B*** finally yields

$$M = (\mu_r - 1) \cdot H$$

$$M := \chi_{mag} \cdot H$$

- With χ_{mag} **= (μ_r – 1) = magnetic susceptibility**.
- It is really straight along the way we looked at dielectric behavior; for a direct comparison use the link

The magnetic susceptibility χ_{mag} is the *prime material parameter* we are after; it describes the response of a material to a magnetic field in exactly the same way as the dielectric susceptibility $\chi_{dielectr}$. We even chose the same abbreviation and will drop the suffix most of the time, believing in your intellectual power to keep the two apart.

- Of course, the four *vectors* ***H***, ***B***, ***J***, ***M*** are all parallel in isotropic homogeneous media (i.e. in amorphous materials and poly-crystals).
- In anisotropic materials the situation is more complicated; χ and μ_r then must be seen as tensors.

We are left with the question of the *origin of the magnetic susceptibility*. There are no **magnetic monopoles** that could be separated into magnetic dipoles as in the case of the dielectric susceptibility, there are only *magnetic dipoles* to start from.

- Why there are no magnetic monopoles (at least none have been discovered so far despite extensive search) is one of the tougher questions that you can ask a physicist; the ultimate answer seems not yet to be in. So just take it as a fact of life.
- In the next paragraph we will give some thought to the the origin of magnetic dipoles.