

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 \mathbf{B} and the magnetic field strength \mathbf{H} *in vacuum*. It comes straight from the [Maxwell equations](#):

$$\mathbf{B} = \mu_0 \cdot \mathbf{H}$$

- The symbols are:

- \mathbf{B} = magnetic flux density or magnetic induction,
- μ_0 = magnetic permeability of the vacuum = $4\pi \cdot 10^{-7} \text{ Vs/Am} = 1,26 \cdot 10^{-6} \text{ Vs/Am}$
- \mathbf{H} = magnetic field strength

- The [units of the magnetic field](#) \mathbf{H} and so on are

- $[\mathbf{H}] = \text{A/m}$
- $[\mathbf{B}] = \text{Vs/m}^2$, with $1 \text{ Vs/m}^2 = 1 \text{ Tesla}$.

\mathbf{B} and \mathbf{H} are vectors, of course.

- $10^3/4\pi \text{ A/m}$ used to be called 1 **Oersted**, and 1 **Tesla** equals 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

$$\mathbf{B} = \mu_0 \cdot \mu_r \cdot \mathbf{H}$$

- 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 \mathbf{B} into the *flux density in the vacuum* plus the *part of the material* according to

$$\mathbf{B} = \mu_0 \cdot \mathbf{H} + \mathbf{J}$$

- With \mathbf{J} = **magnetic polarization** in analogy to the dielectric case.

As a new thing, we now we define the **magnetization** \mathbf{M} of the material as

$$\mathbf{M} = \frac{\mathbf{J}}{\mu_0}$$

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

$$\mathbf{B} = \mu_0 \cdot (\mathbf{H} + \mathbf{M})$$

Using the [independent definition](#) of \mathbf{B} finally yields

$$\mathbf{M} = (\mu_r - 1) \cdot \mathbf{H}$$

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

- With $\chi_{\text{mag}} = (\mu_r - 1)$ = **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](#) χ_{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* \mathbf{H} , \mathbf{B} , \mathbf{J} , \mathbf{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.