

## 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](#):

$$B = \mu_0 \cdot H$$

- The symbols are:

- $B$  = magnetic flux density or magnetic induction,
- $\mu_0$  = magnetic permeability of the vacuum =  $4\pi \cdot 10^{-7} \text{ Vs/Am} = 1,26 \cdot 10^{-6} \text{ Vs/Am}$
- $H$  = magnetic field strength

- The [units of the magnetic field](#)  $H$  and so on are

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

$B$  and  $H$  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

$$B = \mu_0 \cdot \mu_r \cdot H$$

- with  $\mu_r$  = **relative permeability of the material** in [complete analogy](#) to the *electrical flux density* and the *dielectric constant*.

- The relative permeability of the material  $\mu_r$  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

$$B = \mu_0 \cdot H + J$$

- 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

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

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

$$B = \mu_0 \cdot (H + M)$$

Using the [independent definition](#) of  $B$  finally yields

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

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

- 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  $\chi_{\text{mag}}$  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](#)  $\chi_{\text{dielectr}}$ . 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*  $\underline{H}$ ,  $\underline{B}$ ,  $\underline{J}$ ,  $\underline{M}$  are all parallel in isotropic homogeneous media (i.e. in amorphous materials and poly-crystals).

- In anisotropic materials the situation is more complicated;  $\chi$  and  $\mu_r$  then must be seen as **tensors**. That should be no surprise anymore.

▶ 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.