Magnetism in Matter

The elementary magnets in an object align with an external magnetic field and produce an additional magnetic field inside the object. The resultant field is the superposition of the external and the internal field.

For most substances, the internal magnetic field is very small compared to the external field. Depending on the magnitude of the internal field, we distinguish *paramagnetic* substances (internal field parallel to the external field) and *diamagnetic* substances (internal field opposite to the external field). For *ferromagnetic* substances, the magnitude of the internal field is much greater than the external field.

The influence of matter on the magnetic field can be described quantitatively by the ratio of the magnetic field B (measured in the object) to the external magnetic field B_0, which is called *(relative) magnetic permeability* μ_r:

$$\mu_r = \frac{B}{B_0}$$

Alternatively, the *magnetic susceptibility* χ can be used to describe the relative deviation of the magnetic field in the object from the external field:

$$\chi = \frac{\Delta B}{B_0} = \frac{B - B_0}{B_0} = \mu_r - 1$$

Some typical examples and properties of the three classes of magnetic substances are given in the table below.

- Ferromagnetic ($\mu_r >> 1$)

  Examples: Iron, nickel, cobalt, certain compounds (e.g. CrO_2, MnAs, Mu-Metal, Permalloy), certain ceramics

  Typical values for μ_r: Iron: up to 5'000
  Alloys: up to 200'000

  The permeability of ferromagnetic substances also depends on the shape of the object and the magnitude of the external field.

- Paramagnetic ($\mu_r > 1$, $\chi > 0$)

  Typical values for χ: Aluminium: $+16.5 \cdot 10^{-6}$
  Air: $+0.4 \cdot 10^{-6}$

- Diamagnetic ($\mu_r < 1$, $\chi < 0$)

  Typical values for χ: Copper: $-5.5 \cdot 10^{-6}$
  Water: $-13.1 \cdot 10^{-6}$

  In diamagnetic substances, the external magnetic field is reduced. This corresponds to the behaviour of electric fields in a dielectric.

The difference between para- and diamagnetic substances can be demonstrated very well in an inhomogeneous magnetic field: An oblong object made of a paramagnetic material aligns parallel to the field lines, one made of a diamagnetic material perpendicular to the field lines.