

### 4.2.3 Summary to: Dia- and Paramagnetism

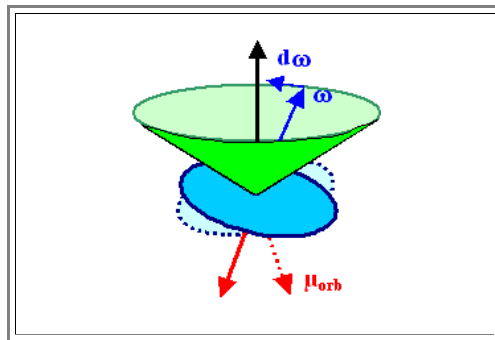
Dia- and Paramagnetic properties of materials are of no consequence whatsoever for products of electrical engineering (or anything else!)

- Only their common denominator of being essentially "non-magnetic" is of interest (for a submarine, e.g., you want a non-magnetic steel)
- For research tools, however, these forms of magnetic behaviour can be highly interesting ("paramagnetic resonance")

Normal diamagnetic materials:  $\chi_{\text{dia}} \approx - (10^{-5} - 10^{-7})$   
 Superconductors (= ideal diamagnets):  $\chi_{\text{SC}} = -1$   
 Paramagnetic materials:  $\chi_{\text{para}} \approx +10^{-3}$

Diamagnetism can be understood in a semiclassical (Bohr) model of the atoms as the response of the current ascribed to "circling" electrons to a changing magnetic field via classical induction ( $\propto dH/dt$ ).

- The net effect is a precession of the circling electron, i.e. the normal vector of its orbit plane circles around on the green cone.  $\Rightarrow$
- The "Lenz rule" ascertains that inductive effects oppose their source; diamagnetism thus weakens the magnetic field,  $\chi_{\text{dia}} < 0$  must apply.



Running through the equations gives a result that predicts a very small effect.  $\Rightarrow$  A proper quantum mechanical treatment does not change this very much.

$$\chi_{\text{dia}} = - \frac{e^2 \cdot Z \cdot \langle r \rangle^2}{6 m^* e} \cdot \rho_{\text{atom}} \approx - (10^{-5} - 10^{-7})$$

The formal treatment of paramagnetic materials is mathematically completely identical to the case of orientation polarization

- The range of realistic  $\beta$  values (given by largest  $H$  technically possible) is even smaller than in the case of orientation polarization. This allows to approximate  $L(\beta)$  by  $\beta/3$ ; we obtain:

$$\chi_{\text{para}} = \frac{N \cdot m^2 \cdot \mu_0}{3kT}$$

- Inserting numbers we find that  $\chi_{\text{para}}$  is indeed a number just slightly larger than 0.

$$W(\varphi) = - \mu_0 \cdot \underline{m} \cdot \underline{H} = - \mu_0 \cdot m \cdot H \cdot \cos \varphi$$

Energy of magnetic dipole in magnetic field

$$M[W(\varphi)] = c \cdot \exp(-W/kT) = c \cdot \exp \left( \frac{m \cdot \mu_0 \cdot H \cdot \cos \varphi}{kT} \right) = N(\varphi)$$

(Boltzmann) Distribution of dipoles on energy states

$$M = N \cdot m \cdot L(\beta)$$

$$\beta = \frac{\mu_0 \cdot m \cdot H}{kT}$$

Resulting Magnetization with Langevin function  $L(\beta)$  and argument  $\beta$