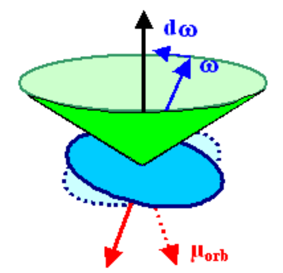
4.2.3 Summary to: Dia- and Paramagnetism

- Dia- and Paramagentic propertis 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 magnitc behavious can be highly interesting ("paramagentic resonance")

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

- 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. ⇒
  - The "Lenz rule" ascertains that inductive effects oppose their source; diamagnetism thus weakens the magnetic field, $\chi_{dia} < 0$ must apply.



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

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

- The formal treatment of paramagnetic materuials is mathematically completely identical to the case of orientation polarization
  - The range of realistc β values (given by largest H technically possible) is even smaller than in the case of orientation polarization. This allows tp approximate **L(β)** by **β/3**; we obtain:

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

  - Insertig numbers we find that χ_{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 magetic dipole in magnetic field

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

(Boltzmann) Distribution of dipoles on energy states

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

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

Resulitn Magnetization with Langevin function **L(β)** and argument **β**