2.5 Magnetodielektrika

$$\frac{1}{v^2} = \varepsilon\mu = \varepsilon_r\mu_r\varepsilon_0\mu_0 = \frac{\varepsilon_r\mu_r}{c^2}$$

Telegraphengl. $n^2 = \frac{c^2}{v^2} = \varepsilon_r\mu_r \Rightarrow n = \pm\sqrt{\varepsilon_r\mu_r}$

$\mu_r = 1+\chi$, $\vec{M} = \chi\vec{H}$, $|\chi| = 10^{-4} - 10^{-6}$

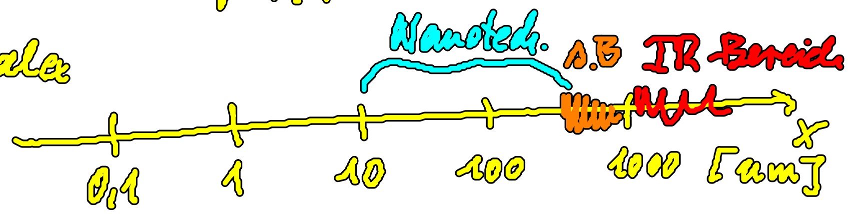
Wenn $\varepsilon_r < 0$, $\mu_r < 0 \Rightarrow n < 0$, $\varepsilon_r < 0$ bei Metallen $\varepsilon_r = 1 - \frac{\omega_p^2}{\omega^2}$

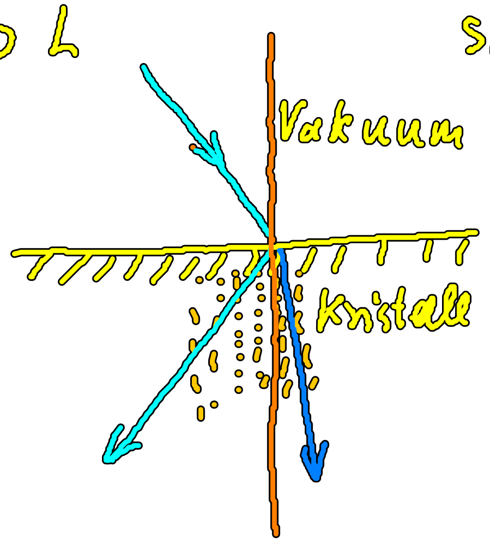
a) negativer Brechungsindex

$n = -\sqrt{\varepsilon_r\mu_r}$

$\lambda \gg L$

Skala



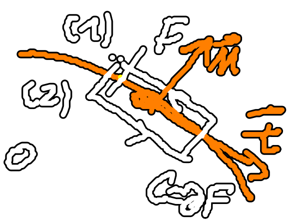


$\nabla\times\vec{E} = -\dot{\vec{B}}$

$\nabla\times\vec{H} = \dot{\vec{D}} + \vec{j}$

$\Downarrow$

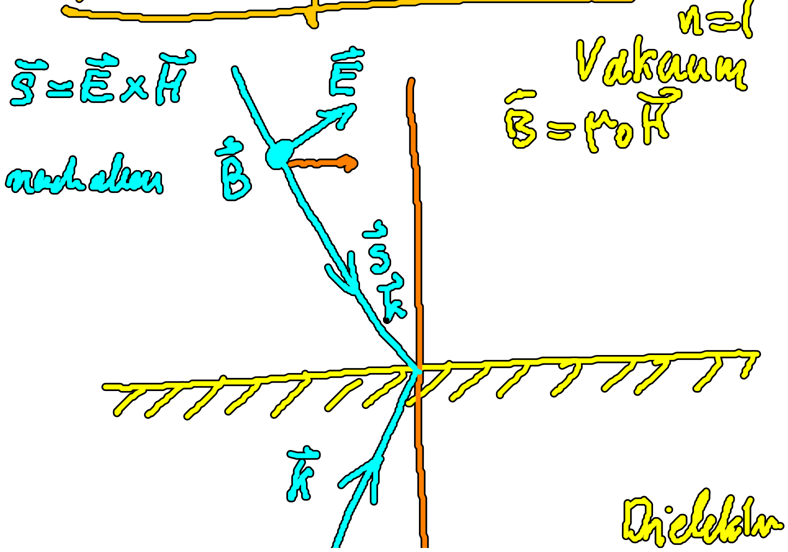
$\vec{E}\cdot\vec{t}$, $\vec{H}\cdot\vec{t}$ stetig



$$\int_F \nabla\times\vec{E}\cdot d\vec{f} = \int_F -\dot{\vec{B}}\,d\vec{f} \to 0$$

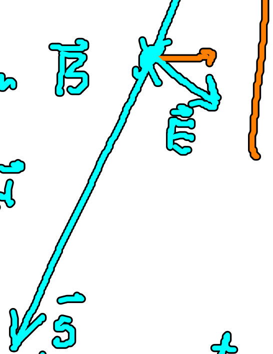
$$\int_{C=\partial F} \vec{E}\cdot d\vec{s} = (-E_1\cdot\vec{t} + E_2\cdot t_2)\,l$$

b) Brechung bei $n=-1$



$$\left.\begin{aligned}\nabla\cdot\vec{B} &= 0\\ \nabla\cdot\vec{D} &= \rho\end{aligned}\right\} \to \vec{B}\cdot\vec{n},\ \vec{D}\cdot\vec{n}\ \text{stetig}$$

nach unten $\vec{B}$



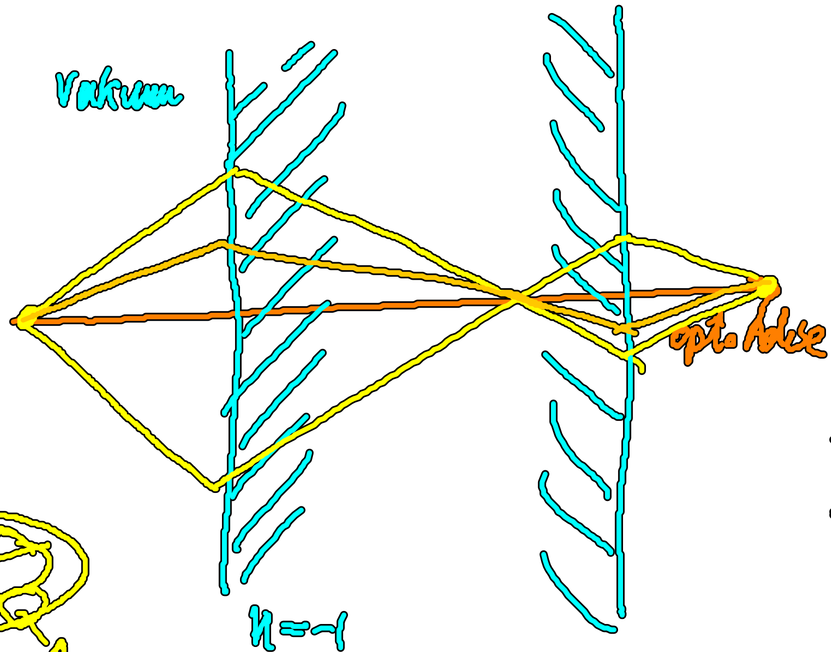
$S = \vec{E} \times \vec{H}$

Energietransport

$n = -1$

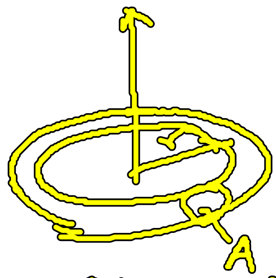
$\nabla \times \vec{E} = -\dot{\vec{B}}$

$ik \times \vec{E} = i\omega \vec{B}$



c) Nanostruktur

$\vec{B}_L$ erzeugt ein I



$\nabla \times \vec{E} = -\dot{\vec{B}}_L$

$$\int_F \nabla \times E \cdot d\vec{A} = \int_{\partial F} \vec{E} \cdot d\vec{r} = U^{ind} = -\frac{d}{dt}\int \vec{B}_L \cdot df = -\dot{\Phi}_L = R I^{ind}$$

σ : elektr. Leitfähigkeit: $R = \frac{\ell^F}{A\sigma}$ $\quad$ | $\ell = 2\pi r$, $F = \pi r^2$, $r\ell = 2F$

elektr. Stromdichte $|\vec{j}| = \frac{I^{ind}}{A} = \frac{U^{ind}}{AR} = \frac{U^{ind}}{\sigma \ell}$

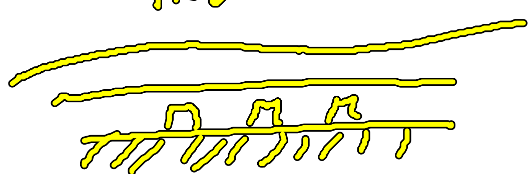
magnet. Moment $\vec{m} = \frac{1}{2}\int \vec{r} \times \vec{j}\, d^3r$ $\quad (\nabla \times \vec{H} = \dot{\vec{D}} + \vec{j} \approx \vec{j})$

$d^3r = A\,dr \Rightarrow |\vec{m}| = \int \frac{1}{2}|\vec{r}||\vec{j}|\, A\,dr = \frac{1}{2} r |\vec{j}| A\, 2\pi r = |\vec{j}| A F = IF$

Lenzsche Regel $\underline{\vec{m} \uparrow\downarrow \vec{H}}$ weil $\chi = \frac{M}{H} = \left(\frac{\partial M}{\partial H}\right)_{H=0}$

$\vec{M} = n^{Nano}\vec{m}$, $\chi = \frac{1}{\mu_r}\vec{B}$ Material $\quad \chi < 0$

$\mu^{Meta.} \approx 1 + \chi < 0$

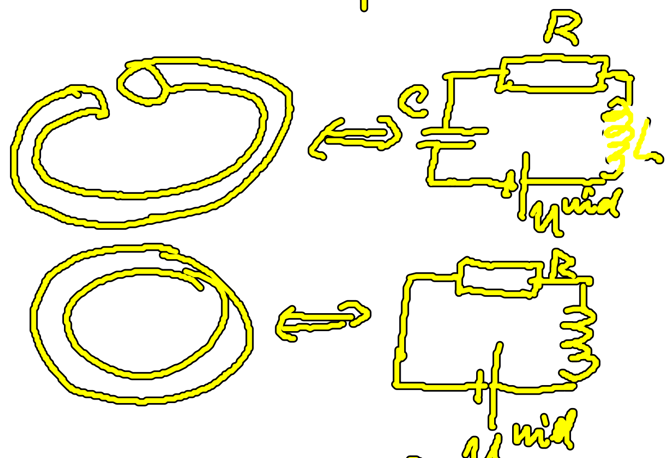


mit den geschlossenen Nanoringen ist $\mu < 0$ nicht erreichbar, aber:

mit einem geschlitzten Ring

Substrat

$\bar{B} = \mu \bar{H}$

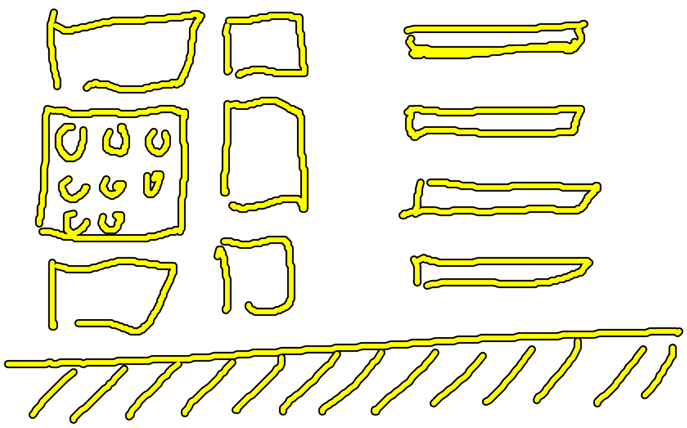


$\circlearrowleft$: $L\dot{I} + RI = U^{ind}$

$\circlearrowleft$ $L\ddot{I} + R\dot{I} + \frac{1}{C} I = \dot{U}^{ind}$

$\omega_{LC} = \frac{1}{\sqrt{LC}}$

$I(t) = I_0 \exp\{-\frac{R}{L} t\}$



Substrat

M. Wegener, S. Linden, Physik Journal 5, 29-35 (?