

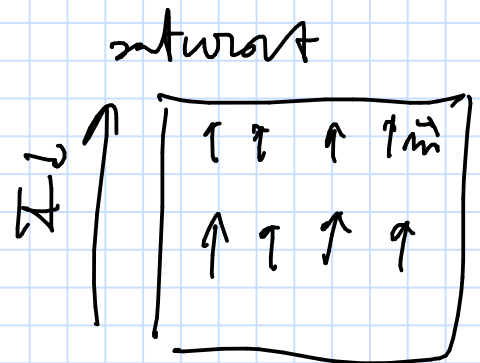
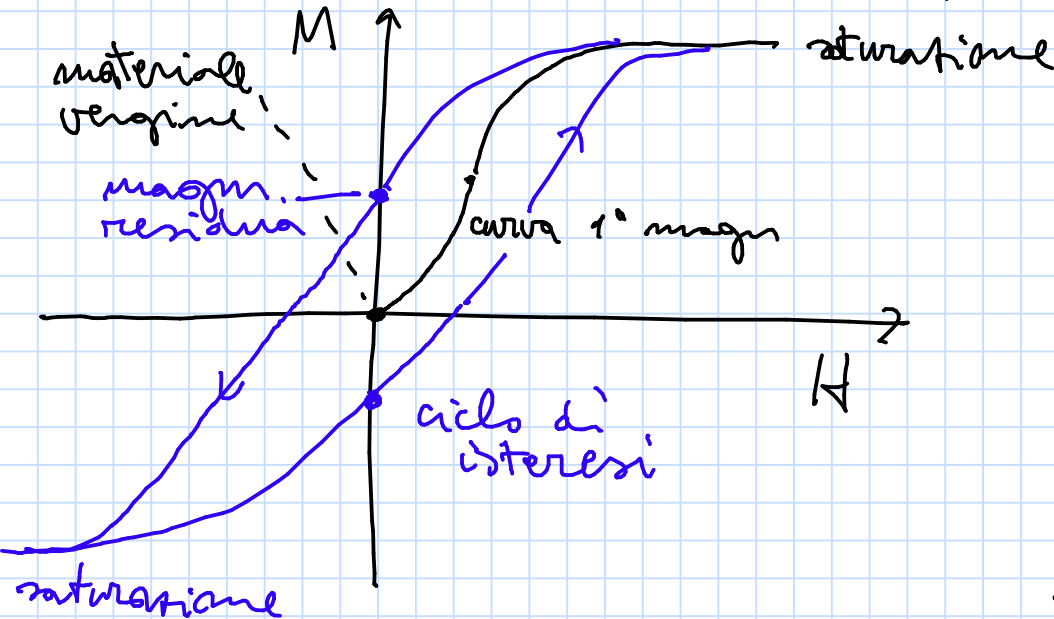
Sostanze ferromagnetiche

χ_m arriva a $\approx 10^4$

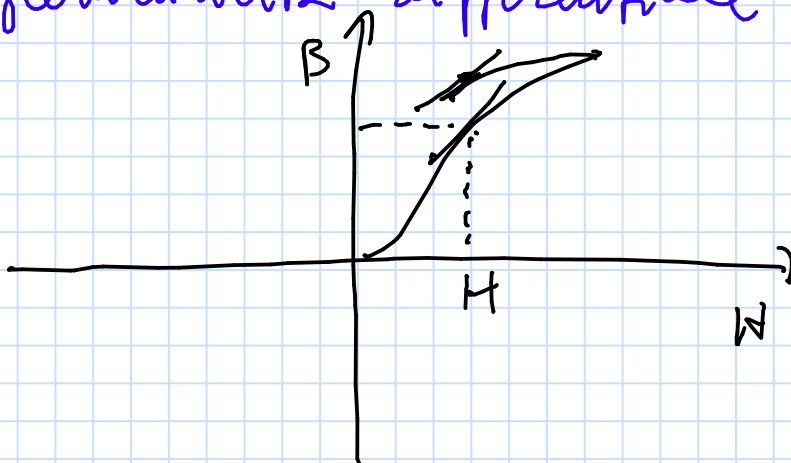
ferro
michel
...

$$K_m = 1 + \chi_m$$

χ_m, K_m non sono costanti, dipendono dalla storia del materiale



permeabilità differenziale

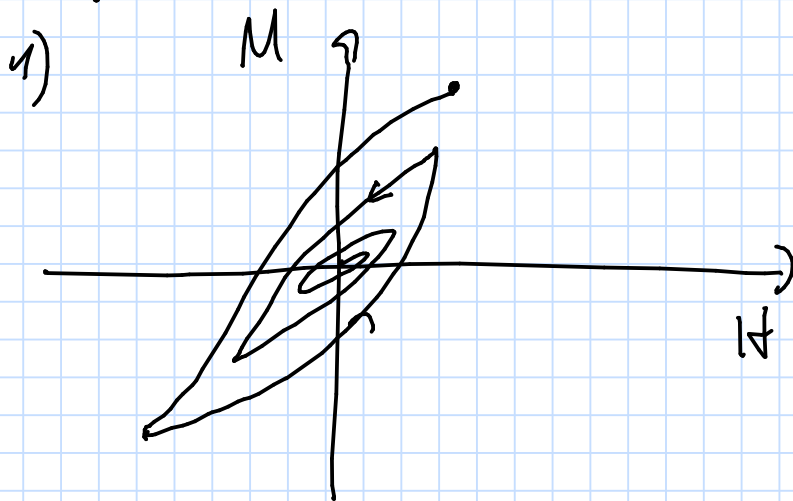


$$\mu_{dm} = \frac{\partial B}{\partial H}$$

$$K_{dm} = \frac{1}{\mu_0} \frac{\partial B}{\partial H}$$

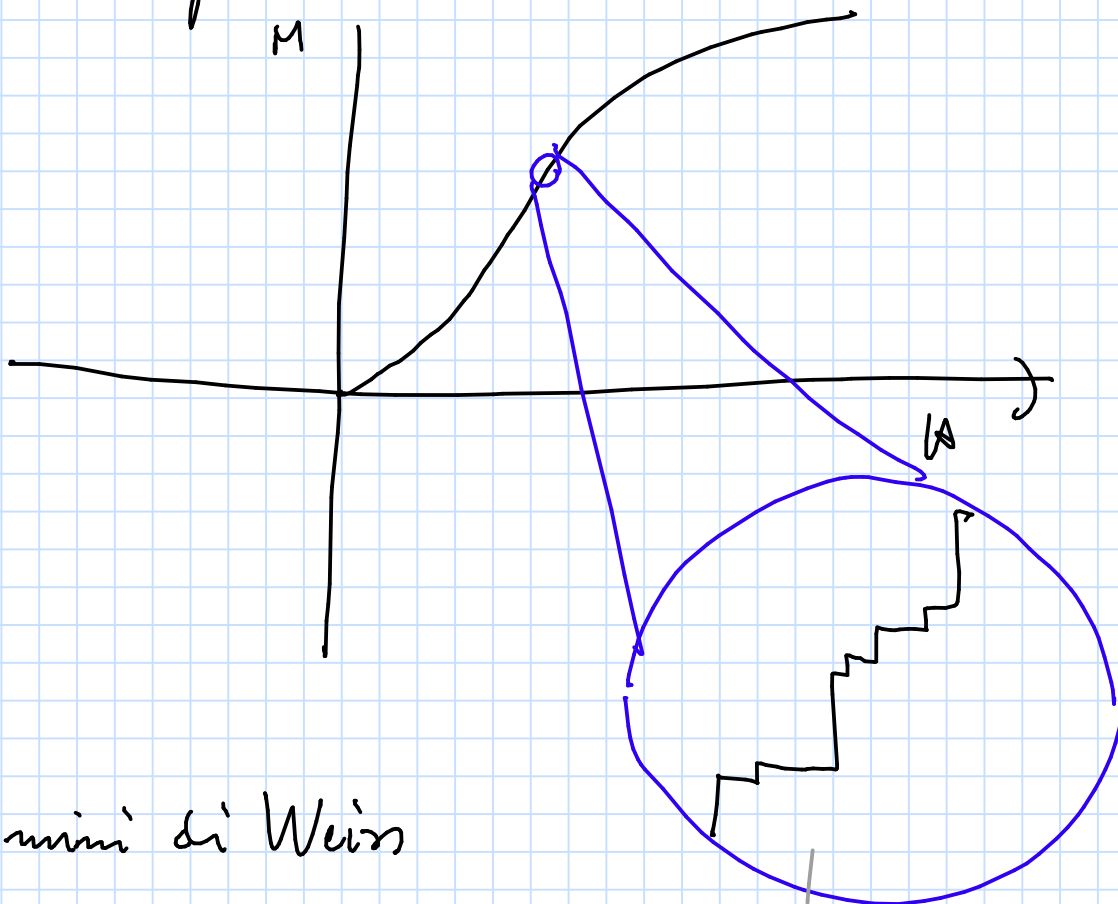
dipende
da
storia

magnetizzazione

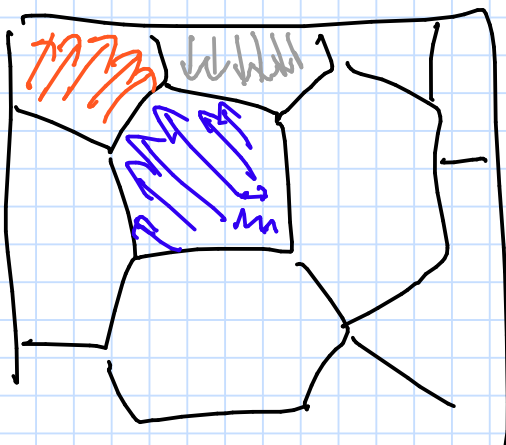


M torna nulla

microscopicamente



Domini di Weiss



gradino = riorientazione
d dominio

legge di Curie

$$\chi_m = \frac{C \rho}{T - T_c}$$

T_c = temp. critica

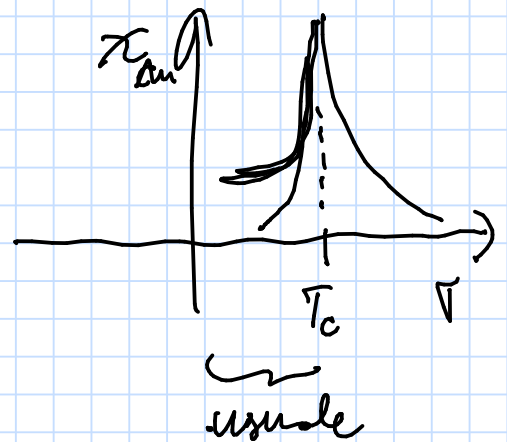
ρ = densità

C = cost Curie

empirica

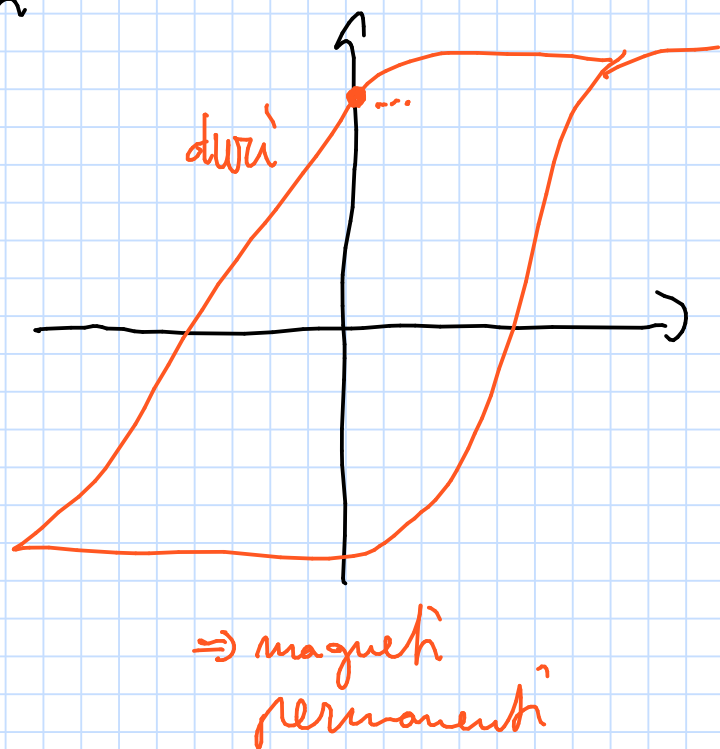
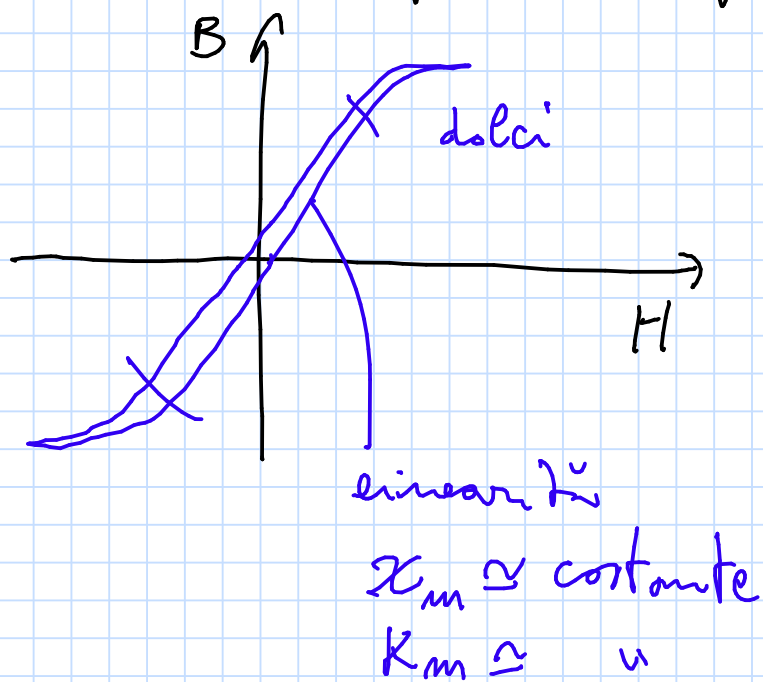
$$\chi_m = \frac{C \rho}{|T - T_c|^\gamma}$$

$\gamma \neq 1$



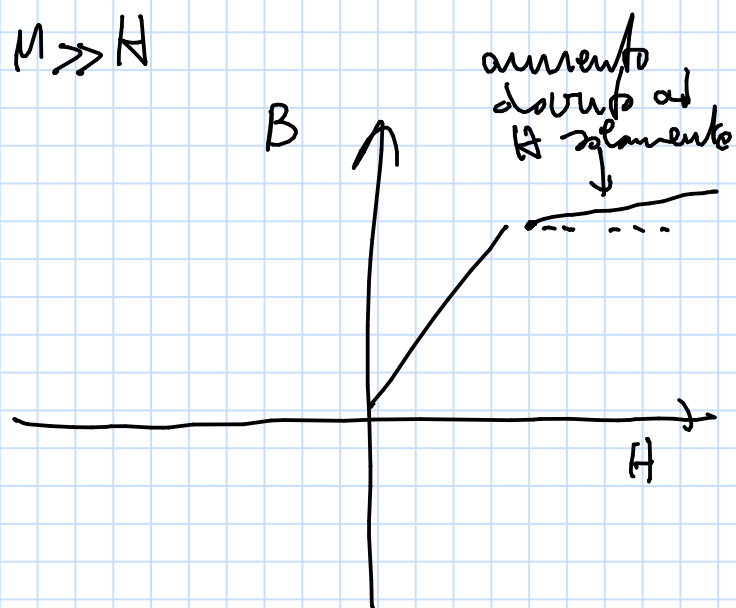
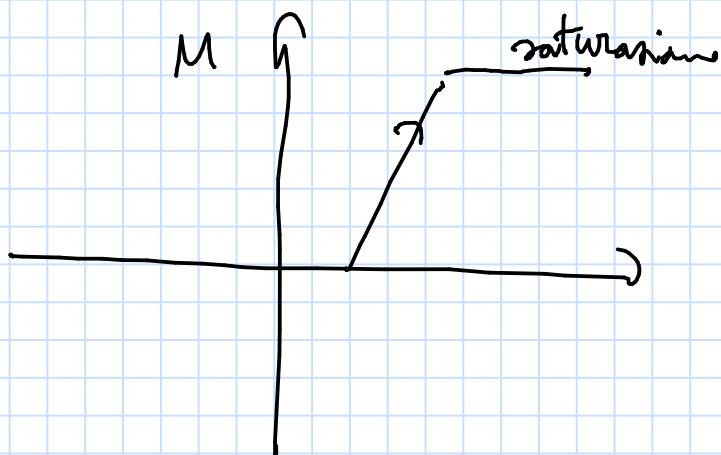
se andiamo sopra T_c
 $\Rightarrow$ magnetizzazione (2° metodo)

2 tipi di ferromagnetici



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

$$M \gg H$$



Dissipazione nel ciclo di isteresi [10.6 MJV]

$$dU_m = H dB$$

variaz.
della
energia
magr

o $H \sim B$ ($B \propto H$) cioè k_m è costante

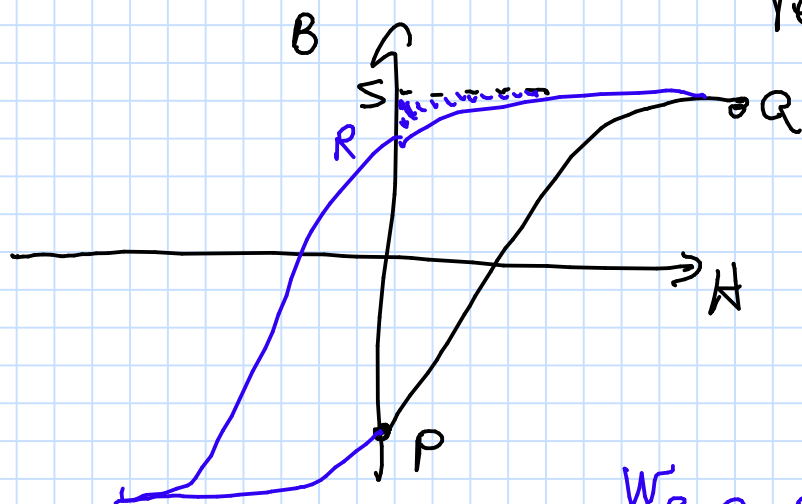
$$\Rightarrow \text{dens. ene magr} \quad U_m = \frac{B^2}{2\mu} = \frac{\mu}{2} H^2 = \frac{1}{2} H B$$

k_m non fissa nel ciclo it.

corso infinitesimo

$$dW_m = H dB$$

(passare a d o δ in
termodin.)



da P a Q

$$W_{PQ} = \int_P^Q H dB$$

= area PQS

$$W_{QR} = \int_Q^R H dB = -\text{area RQS}$$

$$W_{P \rightarrow Q \rightarrow R} = \text{area} \frac{1}{2} \text{ ciclo isteresi}$$



lavoro per un ciclo di isteresi = area del ciclo
unità di volume

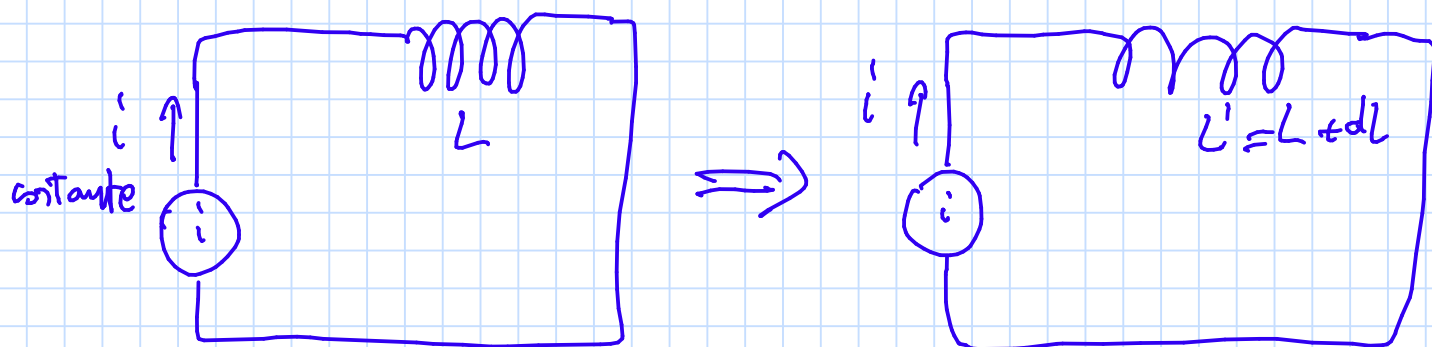
$$W_z = \oint H \cdot dB = 30 \text{ J/m}^3 \text{ ferro puro}$$

$$> 230 \text{ J/m}^3 \text{ ferro magnetici}$$

$$\approx 2$$

Forze su corpi magnetizzati

[10.7]



$$\mathcal{E}_i = - \frac{d}{dt} (L i) = - i \frac{dL}{dt}$$

$$dU_m = \frac{i^2}{2} (L' - L) = \frac{i^2}{2} dL \quad \text{nel circuito}$$

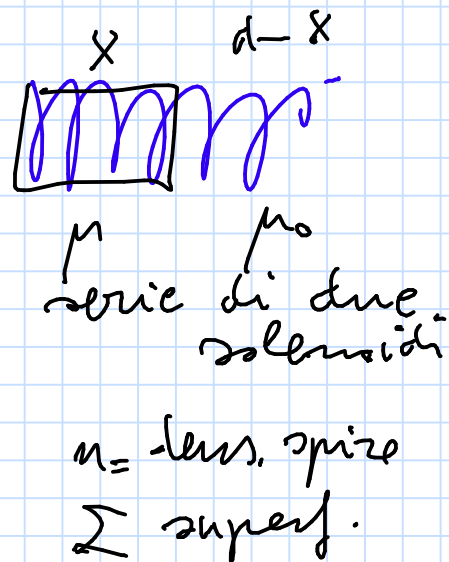
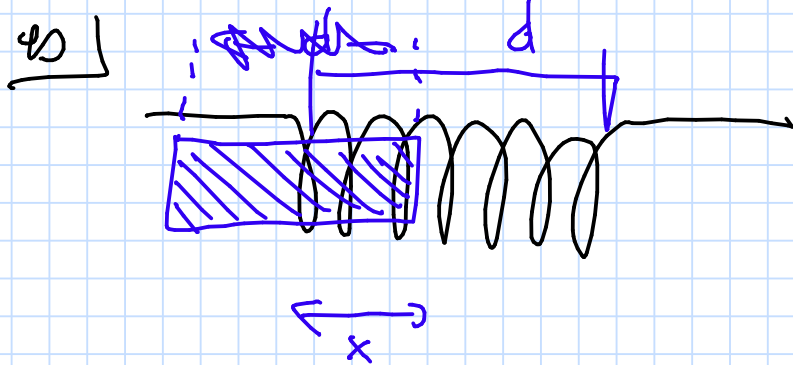
$$\begin{aligned} \text{nel generatore} \quad dW_{gen} &= - \mathcal{E}_i i dt = i^2 dL \\ &= 2 dU_m = - dU_{gen} \end{aligned}$$

in bobine

$$dU = dU_{gen} + dU_m = (-2 + 1) dU_m = - dU_m$$

U varia con x

$$F_x = - \left. \frac{\partial U}{\partial x} \right|_{i=\text{cost}} = \left. \frac{\partial U_m}{\partial x} \right|_{i=\text{cost}} \quad !$$



$$L(x) = \mu n^2 \Sigma x + \mu_0 n^2 \Sigma (d-x)$$

$$\mu = \mu_0 (1 + \chi_m)$$

$$L(x) = \underbrace{\mu_0 n^2 \Sigma d}_{\text{cost}} + \chi_m \mu_0 n^2 \Sigma x$$

$$U_m = \frac{1}{2} L i^2 = \text{cost} + \left(\frac{1}{2} \chi_m \mu_0 n^2 \Sigma i^2 \right) x$$

$$F_x = \left. \frac{\partial U}{\partial x} \right|_{i=\text{cost}} = \frac{1}{2} \chi_m \mu_0 \underbrace{\Sigma n^2 i^2}_{H^2}$$

$\chi_m > 0$ (para, ferro.)

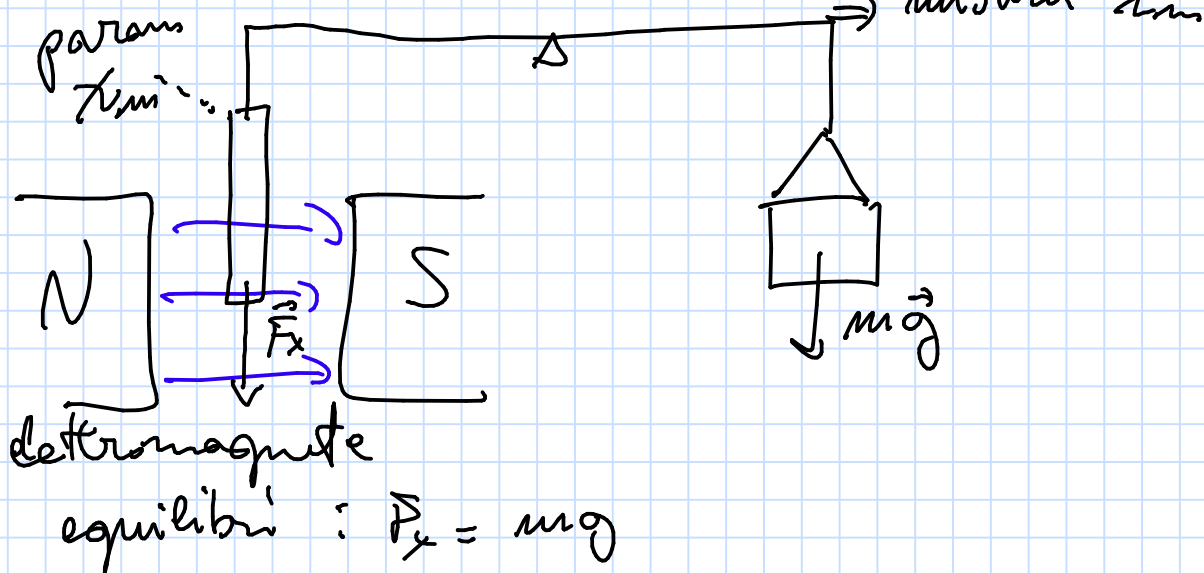
attrazione all'interno

$\chi_m < 0$ (diamagnet.)

espulsione

2.19 MNV p249

apparato di Gauss



$$m = 1.5 \text{ g}$$

raggio cil. $R = 2.5 \text{ mm} \rightarrow \Sigma = \pi R^2$

$$B = 1 \text{ T} \Rightarrow H = \frac{B}{\mu_0}$$

$$\Rightarrow \chi_m = \frac{\Sigma m g}{\mu_0 \Sigma H^2} = \frac{2 \mu_0 m g}{\Sigma B^2} = 1.88 \cdot 10^{-3}$$

esercizio grafite

$$\sigma = 10^5 (\Omega \text{ m})^{-1}$$

$$\kappa_m = 1$$

cal. $\begin{cases} a = 60 \text{ mm} & \text{raggio} \\ L = 1 \text{ m} \end{cases}$

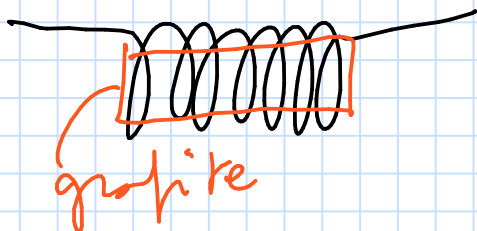
densità

$$n = 5000 \text{ spire / m}$$

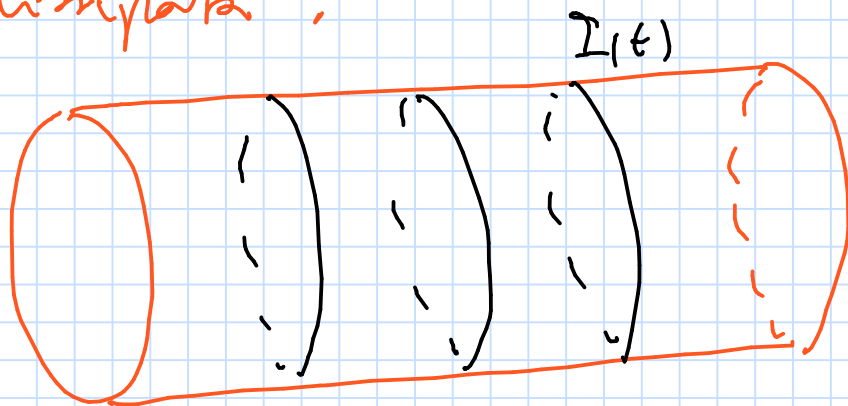
$$I = I_0 \cos \omega t$$

$$I_0 = 60 \text{ A}$$

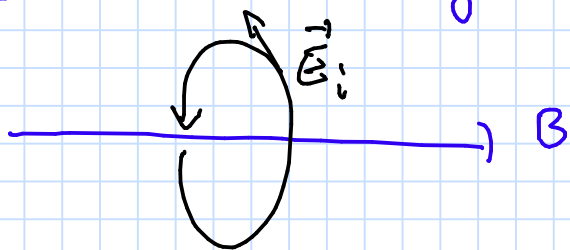
$$\text{freq } \nu = 60 \text{ Hz}$$



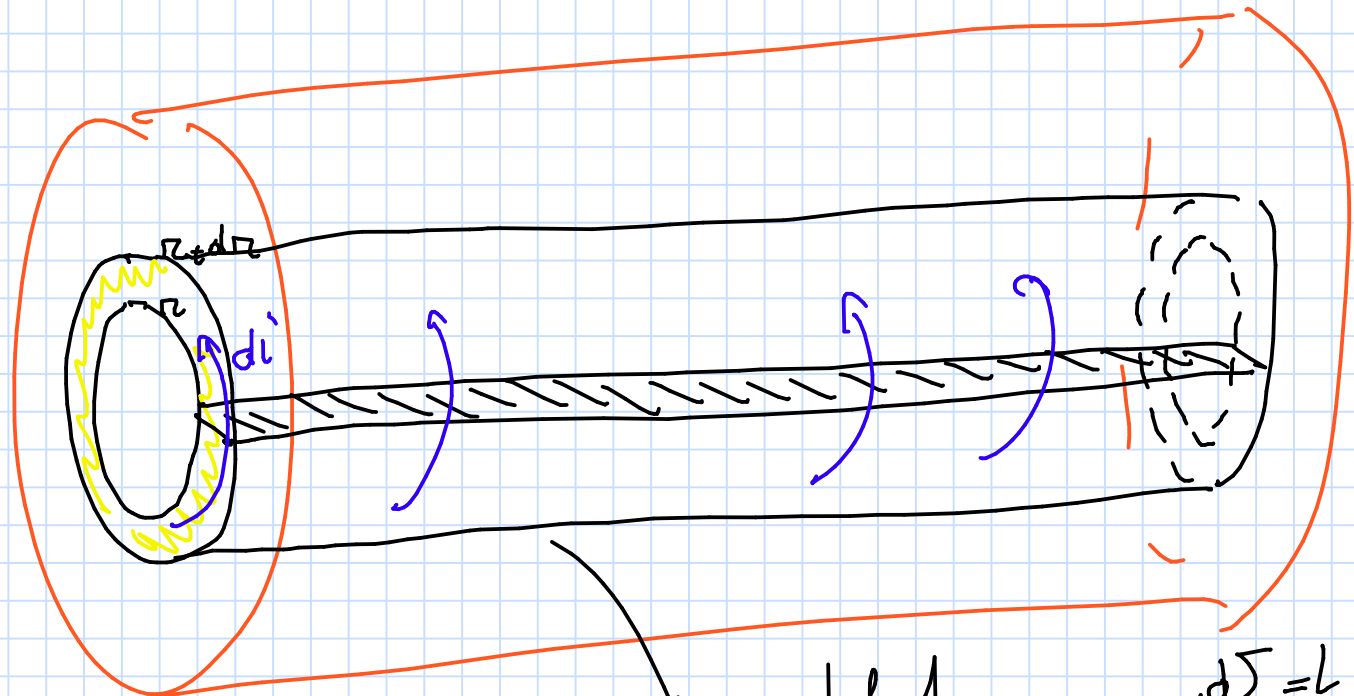
P dissipata?



$\vec{B}$ varia lungo asse ($\parallel$) $\Rightarrow$ f.e.m. indotta
in circonferenze



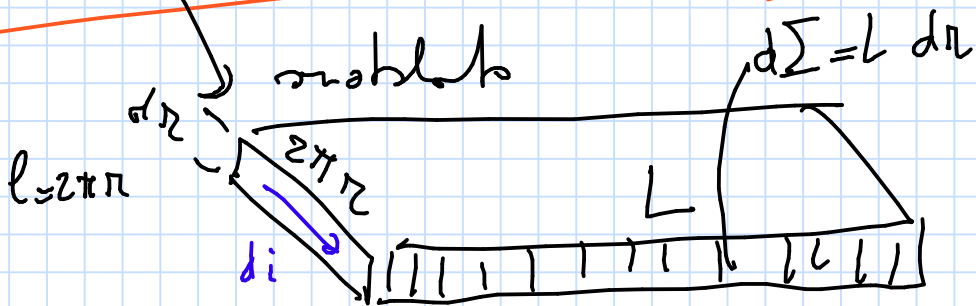
$\vec{E}_i$ tangente
in circonferenze



$$dR = \frac{\rho l}{d\Sigma}$$

conduttanza in p.u.

$$dG = \sigma \frac{d\Sigma}{l} = \frac{\sigma L}{2\pi} \frac{dr}{r}$$

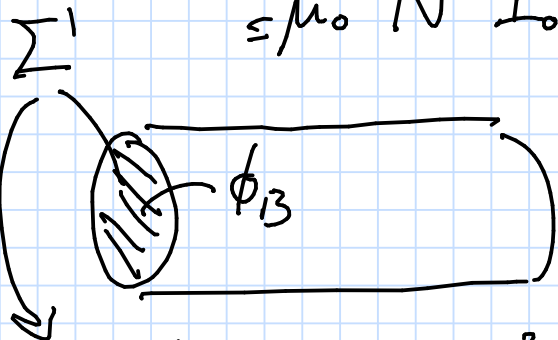


per l.e.m. a raggio r ;

$E_i(r)$ da Faraday

$$B(t) = \mu_0 N I(t) \\ = \mu_0 N I_0 \cos(\omega t)$$

$$N = n$$



$$\begin{aligned} -\frac{d\phi_B(r)}{dt} &= -\pi r^2 \frac{d}{dt} B = -\pi r^2 \mu_0 N I_0 \omega (-\sin(\omega t)) \\ &= \pi r^2 \mu_0 N I_0 \omega \sin(\omega t) = \mathcal{E}_i \end{aligned}$$

$$dP(r) = \varepsilon_0^2(r) dG(r) =$$

$$= \left(\frac{\sigma L}{2\pi} \right) \frac{dr}{r} \left(\pi r^2 \right)^2 \mu_0^2 N^2 I_0^2 \omega^2 \sin^2(\omega t)$$

$$= \dots r^3 dr$$

$$P_{\text{tot}}(t) = \int_{r=0}^{r=a} dP(r) = \frac{1}{8} \sigma L \left(\mu_0 N I_0 \omega a^2 \right)^2 \sin^2 \omega t$$

$$P_{\text{tot}}(t) = \underbrace{3272}_{P_{\text{max}}} \sin^2 \left((377 \cdot 10^3) t \right) \text{ W}$$

$\omega = 2\pi \cdot 60$