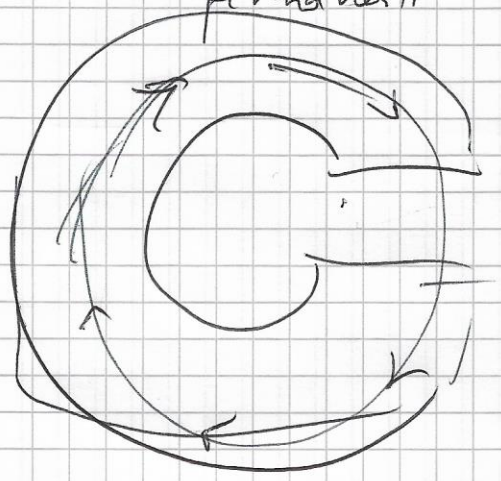
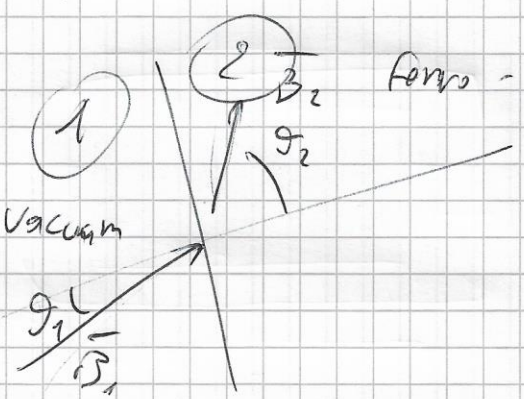
#29 Elettromagneti - magneti permanenti - forze su magneti

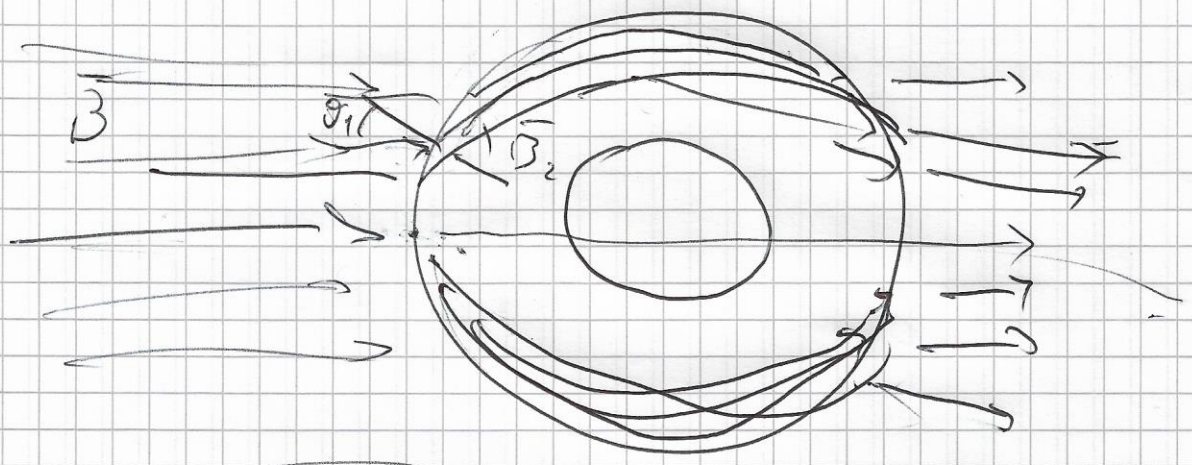




$$\frac{tg\,\vartheta_1}{tg\,\vartheta_2} = \frac{\mu_1}{\mu_2} \rightarrow \phi$$

$\vartheta_2 \rightarrow$ ⊘ ϕ

schermo magnetico

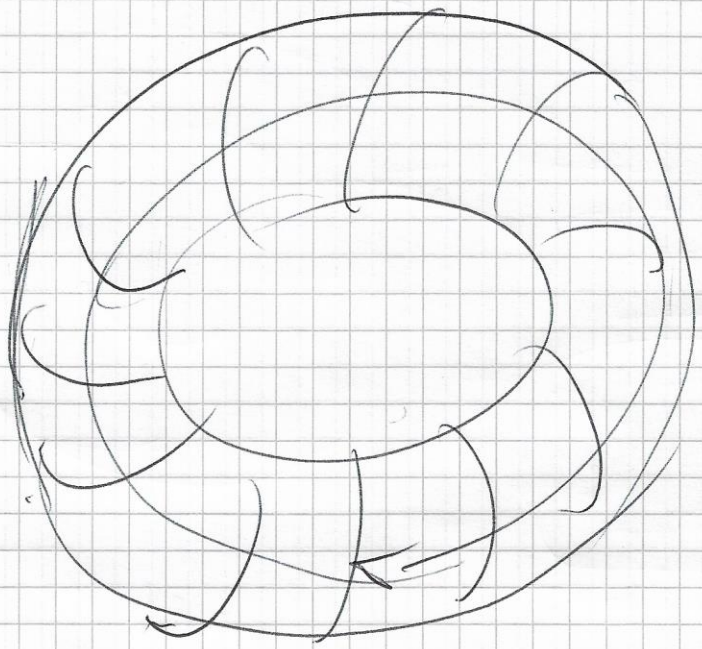


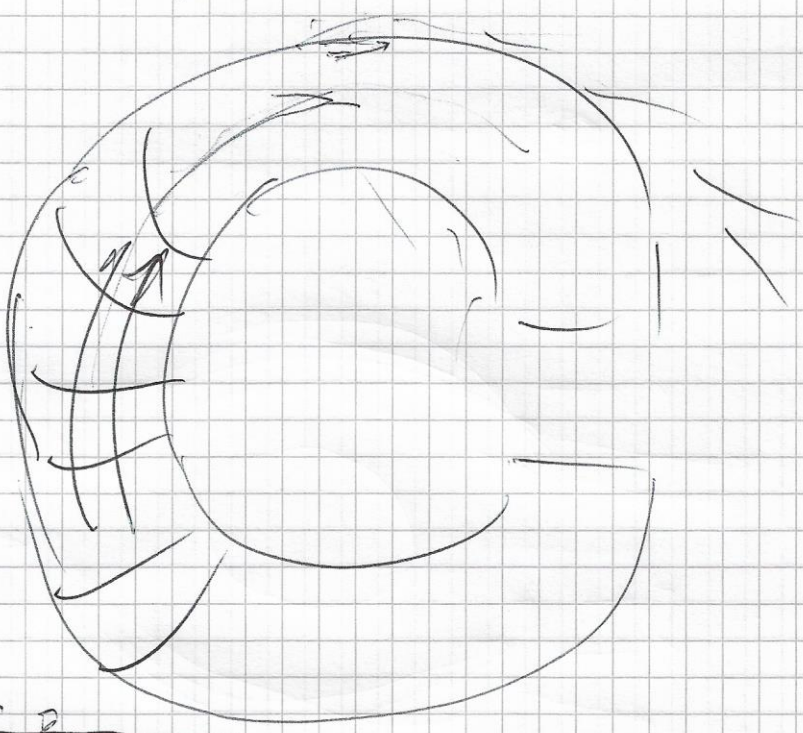
$$H_{1,2} = H_{1t}, H_{2,t}$$

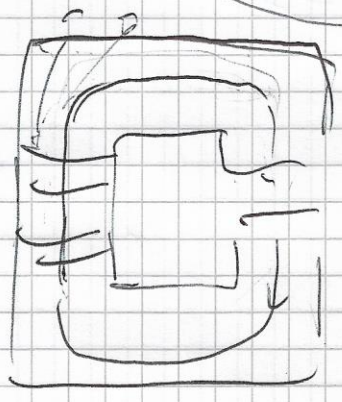
$$H_{1t} = H_2$$

$$\frac{B_1}{\mu_1} = \frac{B_2}{\mu_2} \rightarrow B_1 = \frac{\mu_1}{\mu_2} B_2$$

$\rightarrow p$







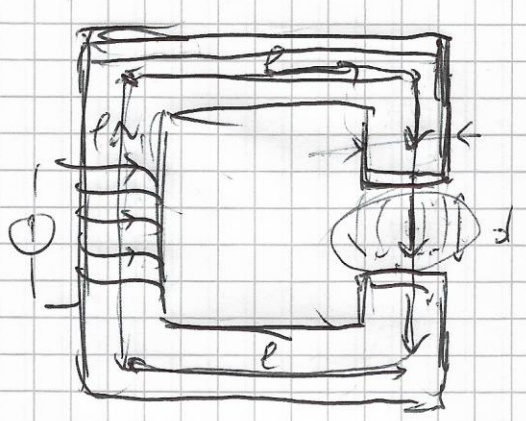
Trascuriamo ϕ disperso

$$\nabla \times \bar{H} = \bar{J}_c$$

$$\int \bar{H} \cdot d\bar{l} = \iint \bar{J}_c \cdot d\bar{S} = I_{concat}$$

$$\int \bar{H} \cdot d\bar{l} = \phi$$

(20-4)

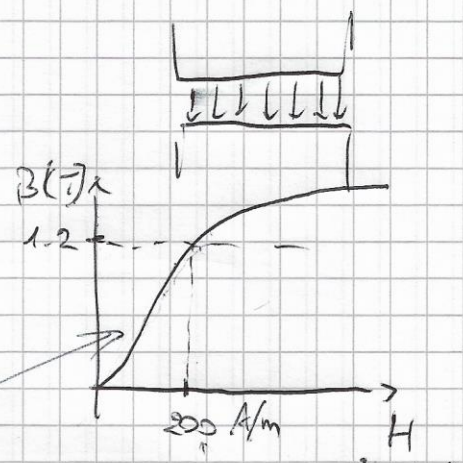


$l = 25\ cm$

$d = 5\ cm$

$N = 60\ spire$

$B_0 = 1.2\ T$



(3)

① $\oint \bar{H} \cdot d\bar{l} = N\bar{I}$

② proprietà materiale (μ_r : curva)

$B = B_0 = 1.2\ T \rightarrow H_0 = \frac{B_0}{\mu_0}$

$L = 4l - d$

H = (dalla curva) $= 200\ A/m$

$\oint \bar{H} \cdot d\bar{l} = H \cdot L + H_0 \cdot d = NI$

$I = \frac{HL}{N} + \frac{H_0 \cdot d}{N} = \frac{HL}{N} + \frac{B_0 d}{\mu_0 N} = 3.17 + 735.77 = 738.84\ A$

$H \cdot 4l = N\bar{I} \rightarrow I = \frac{H \cdot 4l}{N} = 3.33\ A$

$NI = R_{eq} \cdot \Phi$ (f. $R \cdot I$)

$R_{eq} = \frac{L}{\mu S} + \frac{d}{\mu_0 S}$

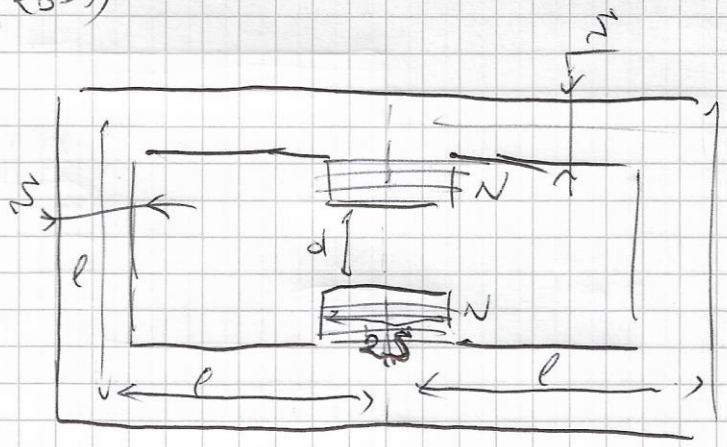
$\bar{B} = \mu \bar{H}$ $\quad \mu = \frac{B}{H} = 6 \cdot 10^{-3} \rightarrow \mu_r = 4772.65$

$R_f = 158.33/S\ \ A/Wb$

$R_L = 3.98 \cdot 10^4/S\ \ A/Wb$

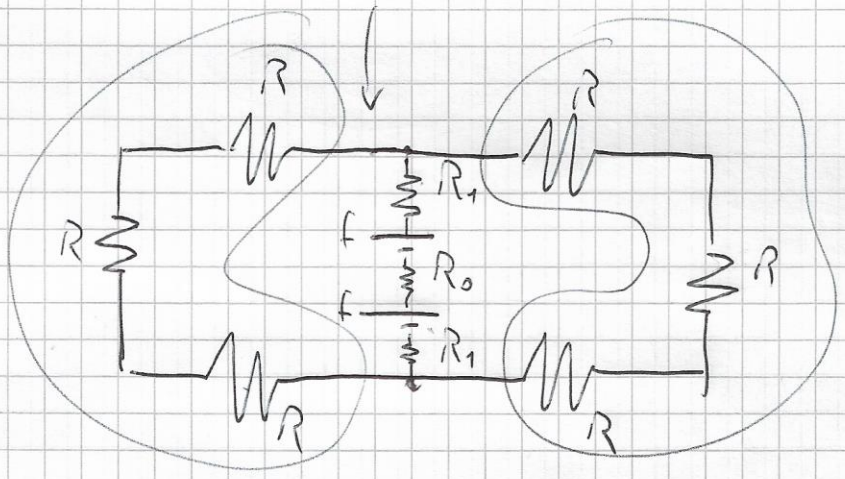
$NI = R_{eq}\Phi = \frac{1}{S}\left(\frac{L}{\mu} + \frac{d}{\mu_0}\right) B S = \frac{BL}{\mu} + \frac{Bd}{\mu_0} = HL + H_0 d$

(20-5)

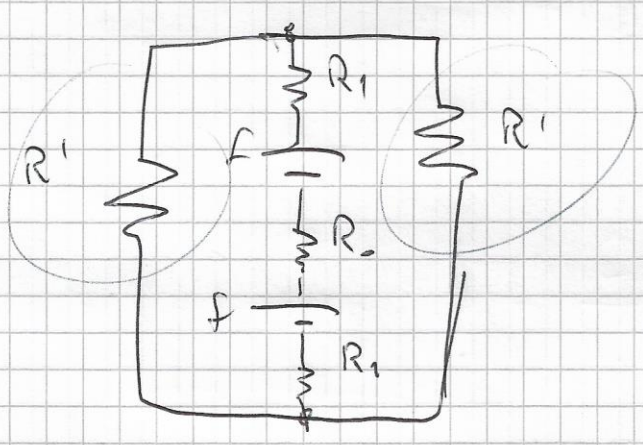


μ_r

$B_0 = ?$



$R' = 3R$



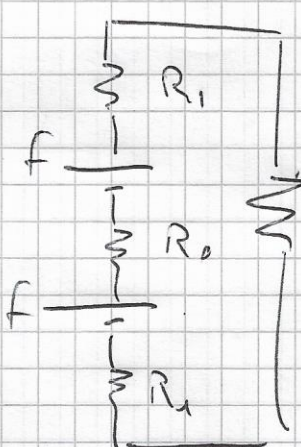
$\mathcal{F} = NI$

$$R = \frac{\ell}{\mu S}$$

$$R_0 = \frac{d}{2\mu_0 S}$$

$$R_1 = \frac{K}{2\mu S}$$

$$K = \frac{\ell - d}{\ell}$$



$R'/2 = \frac{3R}{\ell}$

$\ell = 0.5\ m$

$d = 0.1\ mm$

$N = 600$ spire

$I = 20\ A$

$\mu_r = 1000$

$$2\mathcal{F} = \left(R_0 + 2R_1 + 3R/\ell\right)\Phi$$

$$2NI = \left(\frac{d}{2\mu_0 S} + \frac{2K}{2\mu S} + \frac{3}{2}\frac{\ell}{\mu S}\right)\Phi(B) \hookrightarrow B \cdot S_{el}$$

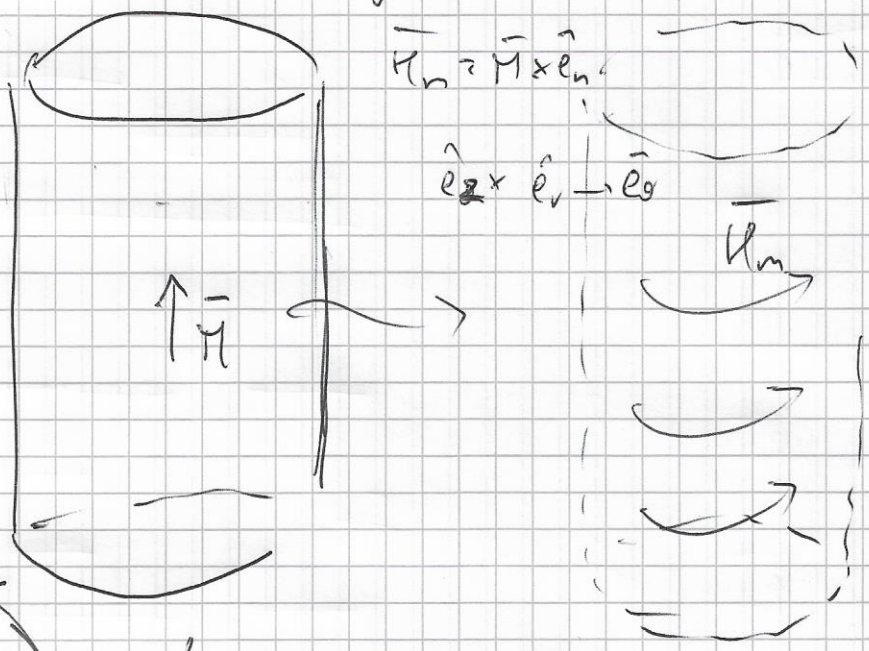
$$B_0 = \frac{\Phi}{2S} = 2NI \Big/ \left(\frac{d}{\mu_0} + \frac{2K}{\mu} + \frac{3\ell}{\mu}\right) = 0.3\ T$$

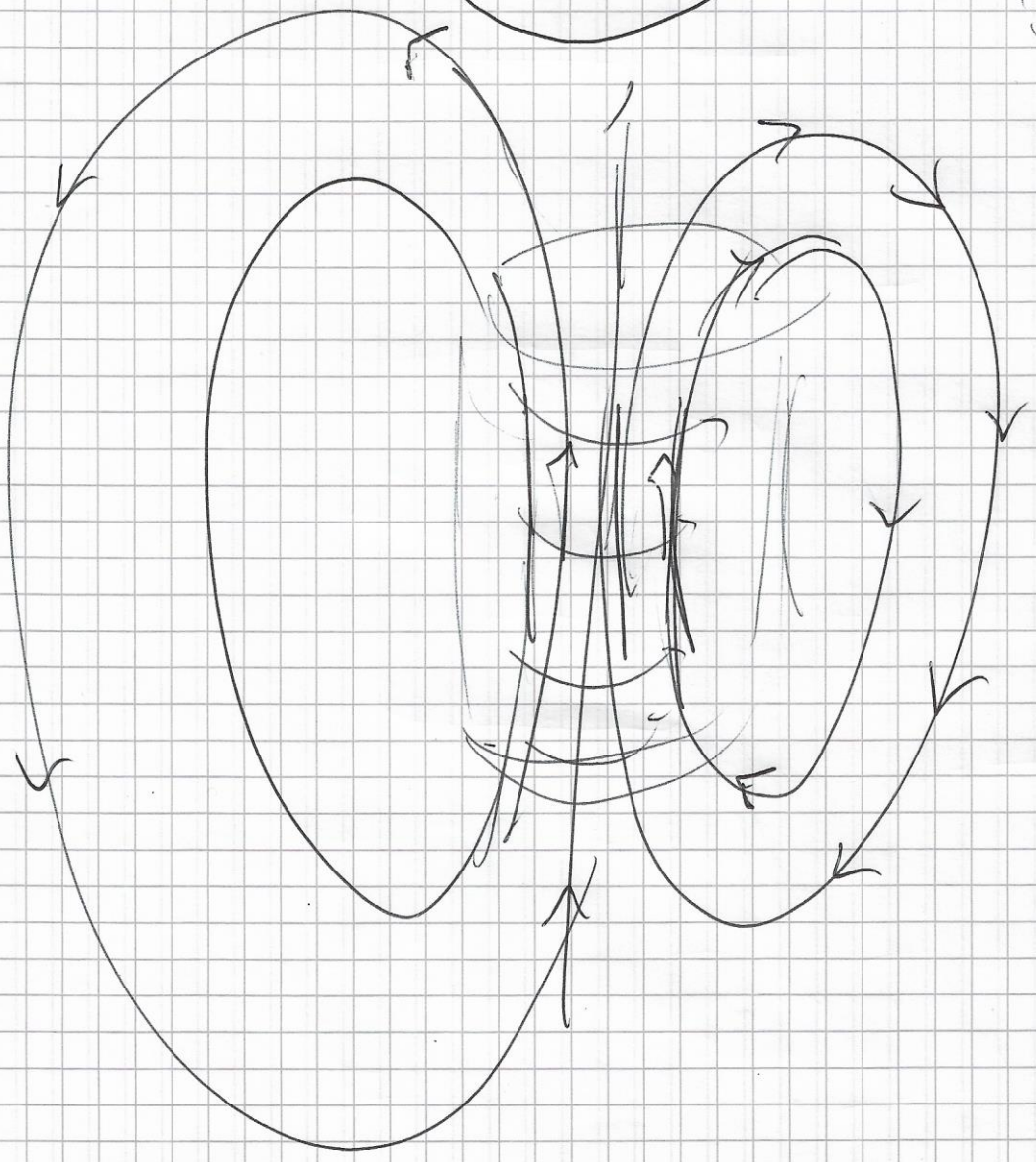
$\bar{M} = M_0 \hat{e}_z$

$\bar{J}_m = \bar{\nabla} \times \bar{M} = \phi$

$\bar{K}_m = \bar{M} \times \hat{e}_n$

$\hat{e}_z \times \hat{e}_r = \hat{e}_\phi$





$\bar{H} = ?$

$\bar{B} = \mu_0 (\bar{H} + \bar{M})$

$\bar{H} = \left(\bar{B}/\mu_0 - \bar{M} \right)$

$$\bar{B} = \mu(\bar{H} + \bar{M})$$

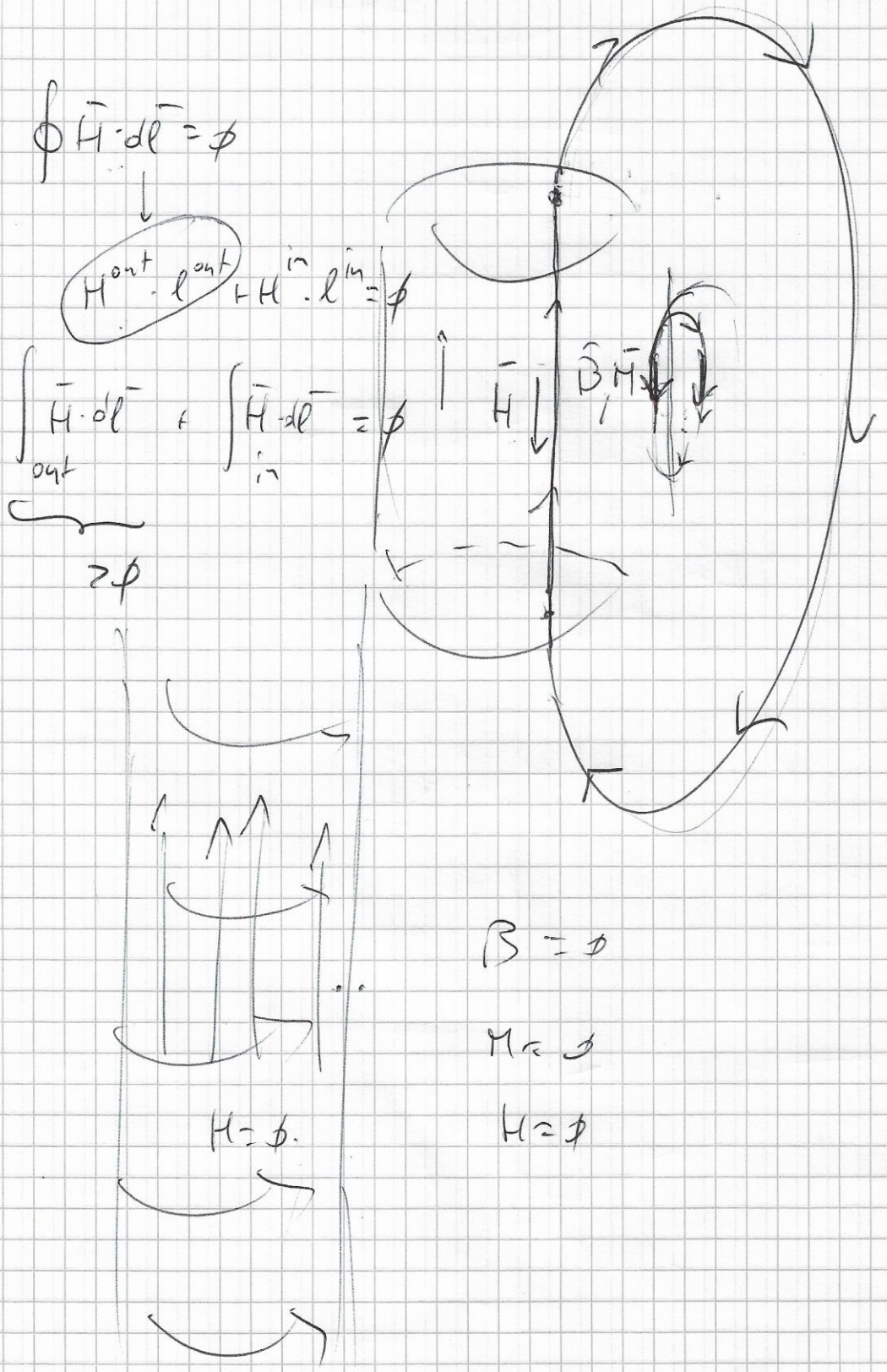
$$\bar{B} = \mu_0 \bar{H}$$

$$\oint \bar{H} \cdot d\bar{\ell} = \phi$$

$$H^{out} \cdot \ell^{out} + H^{in} \cdot \ell^{in} = \phi$$

$$\int_{out} \bar{H} \cdot d\bar{\ell} + \int_{in} \bar{H} \cdot d\bar{\ell} = \phi$$

$$= \phi$$



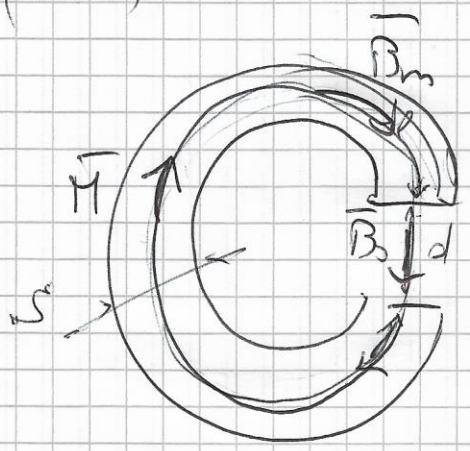
$B = \phi$

$M = \phi$

$H = \phi$

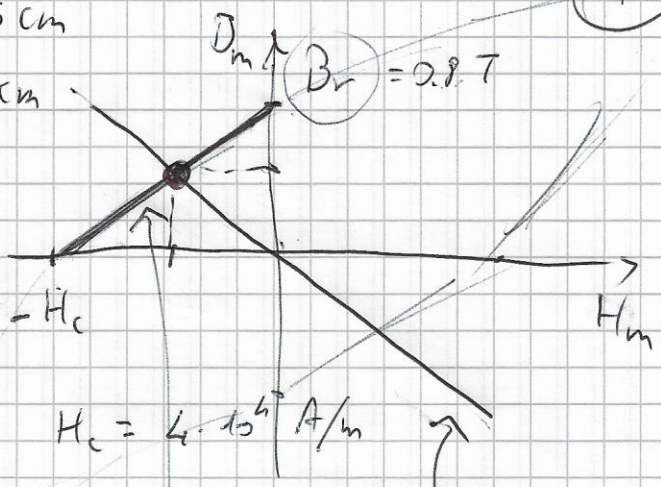
$H = \phi$

(20-6)



$\ell = 85\ cm$

$d = 5\ cm$



$H_c = 4 \cdot 10^4\ A/m$

7

$$\int \bar{H} \cdot d\bar{\ell} = H_m \ell + H_0 d =$$

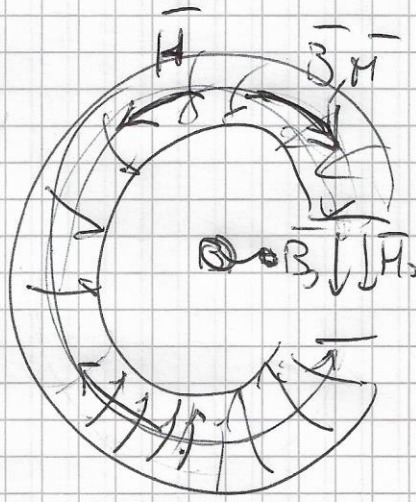
$$= H_m \ell + \frac{B_0}{\mu_0} d = \phi$$

$B_0 = B_m$

$$\begin{cases} B_m = -\frac{\mu_0 \ell}{d} H_m \\ B_m = \frac{B_r}{H_c} H_m + B_r \end{cases}$$

$$B_m = B_r \Big/ \left[1 + \frac{B_r}{H_c} \frac{d}{\mu_0 \ell} \right] = 0.35\ T$$

$$H_m = -2.24 \cdot 10^4\ A/m$$



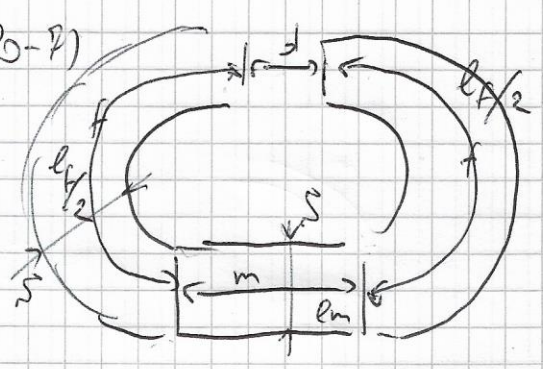
$$B_m = \frac{\mu_0}{d} H_c \ell \Big/ \left(1 + \frac{\mu_0 \ell}{d} \frac{H_c}{B_r} \right)$$

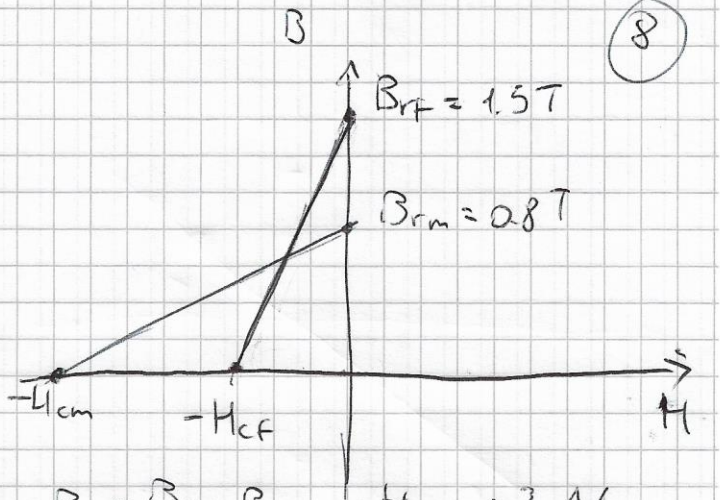
$\bar{D} = \mu_0 (\bar{H} + \bar{M})$ $\rightarrow$ $\bar{H} = \frac{\bar{B}_m}{\mu_0} - \bar{H}$ $\quad H = 3.0 \cdot 10^5\ A/m$

$\bar{J}_m = \bar{\nabla} \times \bar{M} = \phi$ $\quad \bar{M} = \bar{M} \times \hat{e}_n$ $\quad M_m = 3 \cdot 10^5\ A/m$

$I_{m_s} = M_m \cdot \ell = 7.5 \cdot 10^4\ A$

(2-2)





$$\oint \vec{H}\cdot d\vec{\ell} = H_m \ell_m + H_f \ell_f + H_0 d =$$

$$= H_m \ell_m + H_f \ell_f + \frac{B_0}{\mu_0} d = \phi$$

$B_0 = B_f = B_m$

$H_{cf} = 10^3\ A/m$

$H_{cm} = 4\cdot 10^4\ A/m$

$$\begin{cases} B = -\dfrac{\mu_0}{d}(H_m \ell_m + H_f \ell_f) \quad \text{(Ampère)} \\ B = \dfrac{B_{rm}}{H_{cm}} H_m + B_{rm} \longrightarrow H_m = \dfrac{H_{cm}}{B_{rm}}(B - B_{rm}) \\ B = \dfrac{B_{rf}}{H_{cf}} H_f + B_{rf} \longrightarrow H_f = \dfrac{H_{cf}}{B_{rf}}(B - B_{rf}) \end{cases}$$

$$B = \frac{\mu_0}{d}\left(H_{cm}\ell_m + H_{cf}\ell_f\right) \Big/ \left[1 + \frac{\mu_0}{d}\left(\frac{H_{cm}\ell_m}{B_{rm}} + \frac{H_{cf}\ell_f}{B_{rf}}\right)\right] = 0.24\ T$$

$\ell_m = 10\ cm$

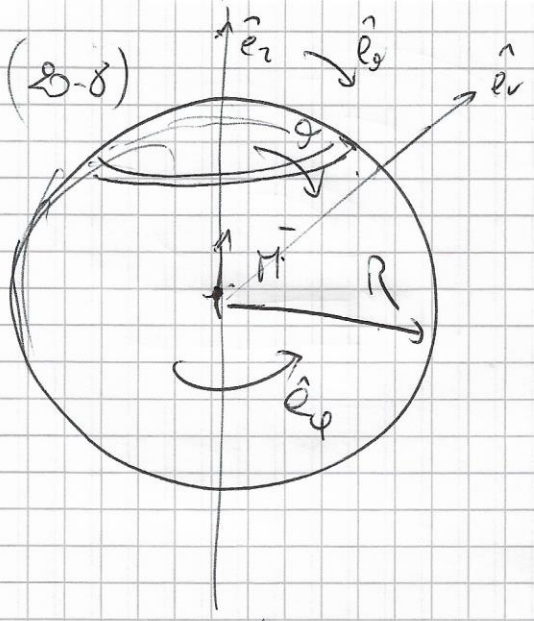
$\ell_f = 30\ cm$

$d = 2\ cm$

$$\mu_{rf} = \frac{B_{rf}}{H_{cf}} \gg \mu_{rm}$$

$$B = \frac{\mu_0}{d} H_{cm}\ell_m \Big/ \left[1 + \frac{\mu_0}{d}\frac{H_{cm}\ell_m}{B_{rm}}\right] = 0.205\ T$$

(2-8)

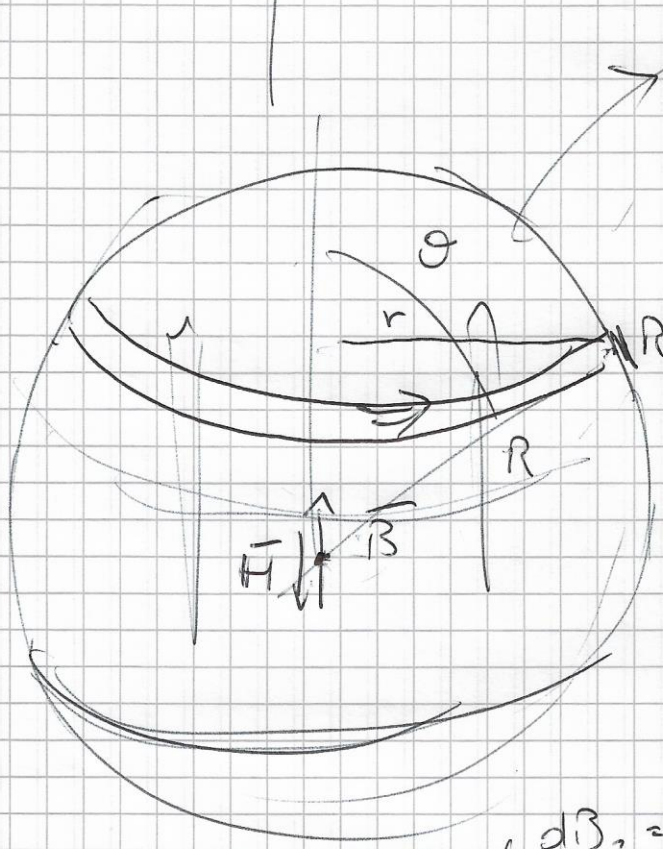


ϑ

$\bar{M} = M\hat{e}_z$

$\bar{j}_m = \bar{\nabla} \times \bar{M} = 0$

$\bar{K}_m = \bar{M} \times \hat{e}_n = M\hat{e}_z \times \hat{e}_r = M\sin\vartheta\, \hat{e}_\varphi$



$r = R\sin\vartheta$

$dI_{ms} = K_m R d\vartheta = MR\sin\vartheta d\vartheta$

$\left(I_{ms} = \int_0^{\pi} MR\sin\vartheta d\vartheta = 2MR \right)$

$B_z = \frac{\mu_0 I}{2} \frac{r^2}{R^3} \left(\rightarrow R^2\sin^2\vartheta \right)$

$dB_z = \frac{\mu_0 dI_{ms}}{2} \frac{R^2\sin^2\vartheta}{R^3} = \frac{\mu_0}{2} M\sin^3\vartheta d\vartheta$

$B_z(\varphi) = \int_{\varphi}^{\pi} \frac{\mu_0 M}{2} \sin^3\vartheta d\vartheta = \frac{2\mu_0}{3} M \qquad \bar{B}(\varphi) = \frac{2\mu_0}{3}\bar{M}$

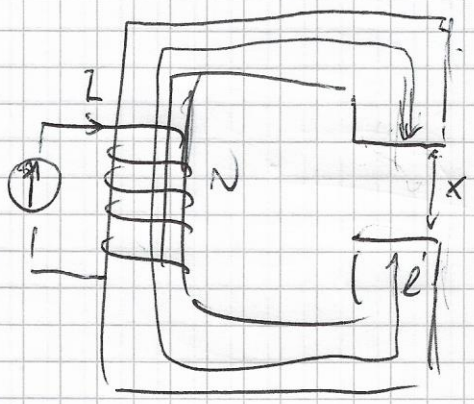
$\left(\frac{4}{3} \right) \qquad \bar{H}(\varphi) = \frac{\bar{B}}{\mu_0} - \bar{M} = -\frac{1}{3}\bar{M}$

$\bar{M} = \frac{\langle \bar{m} \rangle}{Vol} \qquad \bar{m} = \bar{M} \cdot Vol \qquad \bar{m} = \frac{4\pi}{3} R^3 \bar{M}$

$dm = dI_{ms} \cdot \underbrace{\pi r^2}_{\pi R^2 \sin^2\vartheta} = \pi R^3 M \sin^3\vartheta d\vartheta$

$m = \int dm = \pi R^3 M \int_{\varphi}^{\pi} \sin^3\vartheta d\vartheta = \frac{4\pi}{3} R^3 M$

(20-17)



μ_r

$B = B_0$

$$NI = Hl + H_0 x = \frac{B}{\mu_0 \mu_r} l + \frac{B}{\mu_0} x$$

$$NI = \frac{1}{\mu_0}\left(\frac{l}{\mu_r} + x\right) B$$

$$B = \frac{\mu_0 NI}{l/\mu_r + x}$$

$$U_m = U_{mf} + U_{mt} = u_{mf} V_f + u_{mt} V_t =$$

$$\left(u_m = \frac{1}{2\mu_0} B^2 \longrightarrow \frac{1}{2} BH = \frac{1}{2\mu} B^2 \right)$$

$$\rightarrow \frac{1}{2} \frac{B^2}{\mu_0 \mu_r} S l + \frac{1}{2} \frac{B^2}{\mu_0} S x = \frac{1}{2\mu_0} B^2 S \left(l/\mu_r + x\right) =$$

$$= \frac{1}{2\mu_0} S \left(\frac{\mu_0 NI}{l/\mu_r + x}\right)^2 (l/\mu_r + x) \Rightarrow U_m = \frac{\mu_0}{2} \frac{N^2 I^2 S}{l/\mu_r + x}$$

$$f_x = \left.\frac{\partial U_m}{\partial x}\right|_{I=\text{cost.}} = -\frac{\mu_0}{2} \frac{N^2 I^2 S}{(l/\mu_r + x)^2} = -\frac{1}{2} \frac{B^2}{\mu_0} S \quad \Phi$$

$\mu_r = 1000$
$l = 5{,}0$ cm
$x = 5$ cm
$S = 10$ cm^2

$N = 5000$, $I = 1$ A $\rightarrow$ $B = 0.124$ T

$f_x = -61.6$ N (~ 6.3 kg)

$x = 2.9$ cm $B = 0.246$ T

$f_x = -241.6$ N