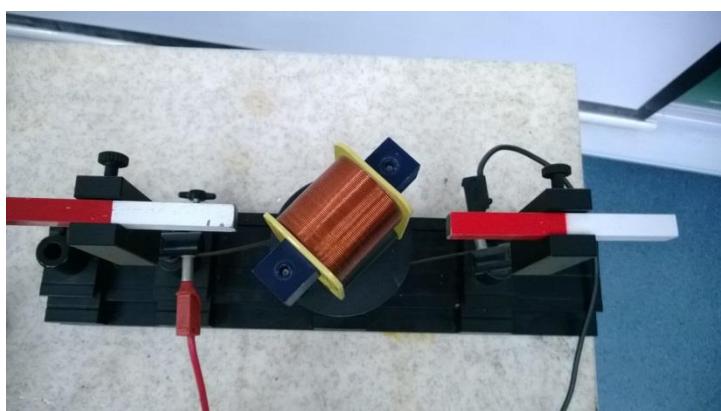
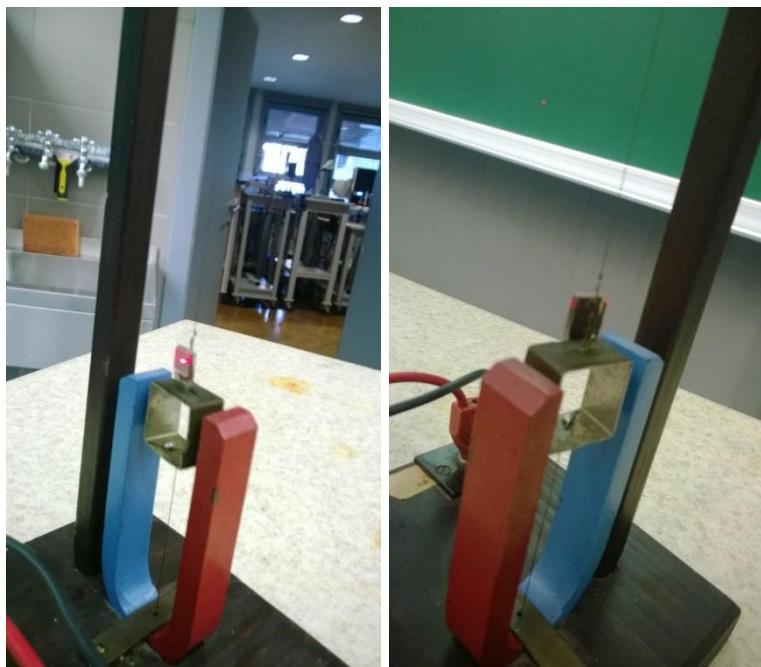


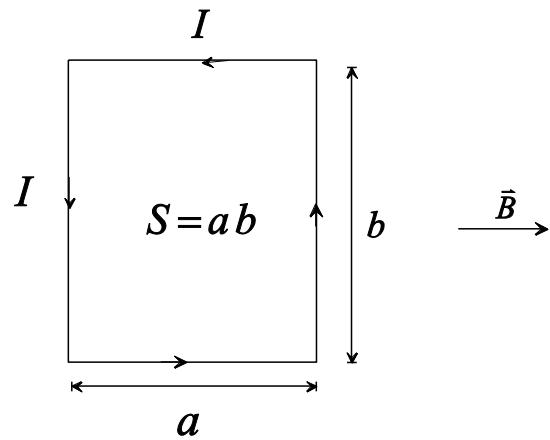
NAVOR NA TOKOVNO ZANKO





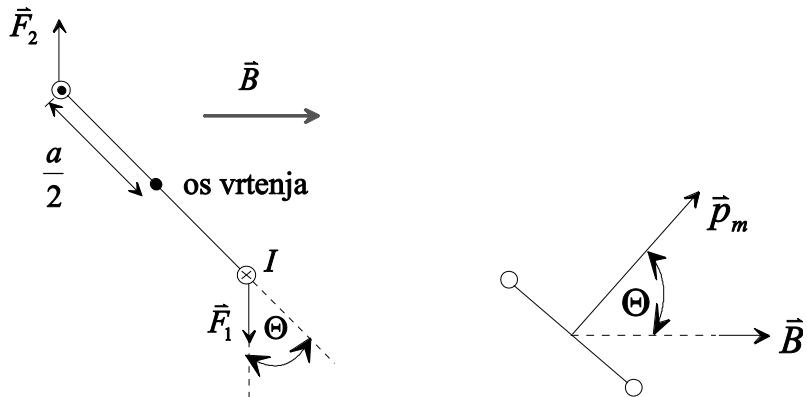
ZANKA V OBLIKI PRAVOKOTNIKA

Tloris:



Navor $\vec{M} = \vec{r} \times \vec{F}, \quad \vec{F} = I \vec{l} \times \vec{B}$

$$\vec{M} = \vec{r} \times \vec{F}, \quad \vec{F} = I \vec{l} \times \vec{B} \quad \text{stranski pogled :}$$



$$F_1 = I b B$$

$$F_2 = I b B$$

$$M = F_1 \frac{a}{2} \sin \Theta + F_2 \frac{a}{2} \sin \Theta = \frac{a}{2} (F_1 + F_2) \sin \Theta = \frac{a}{2} (2 I b B) \sin \Theta = I a b B \sin \Theta$$

$$ab = S \quad (\text{površina tokovne zanke})$$

$$M = I S B \sin \Theta$$

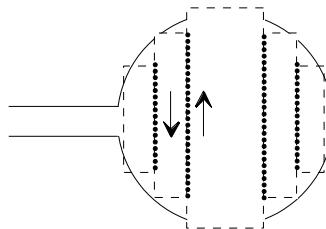
magnetski dipolni moment tokovne zanke :

$$\vec{p}_m = I \vec{S}$$

$$\vec{M} = \vec{p}_m \times \vec{B}$$

POLJUBNA OBLIKA ZANKE :

(posplošitev: po pikčastih črtah gre tok enkrat gor, drugič dol, tako, da je vsota nič)



$$M = I S B \sin \Theta = p_m B \sin \Theta$$

$$\vec{M} = \vec{p}_m \times \vec{B}$$

Več zank druga na drugi:

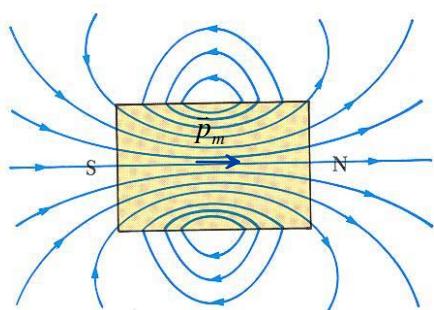
$$\vec{p}_m = N I \vec{S}$$

POSKUS: tuljava se zasuče v zemeljskem polju, ko spustimo skozi tuljavo električni tok

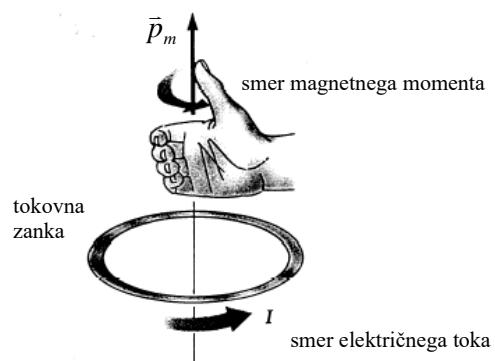
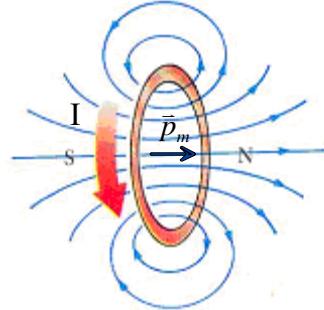


PODOBOST med magnetnim poljem paličastega permanentnega magneta in magnetnim poljem tokovne zanke

permanentni magnet

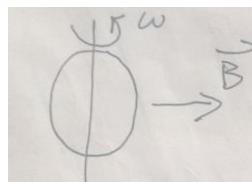


tokovna zanka



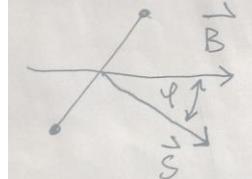
Delo, ki je potrebno za vrtenje generatorja (ploščate tuljave) izmeničnega toka v magnetnem polju B :





$\varphi = \omega t, \omega = \text{konst.}$

$\phi_m = N \vec{B} \cdot \vec{S} = NBS \cos(\omega t)$



$U_i = - \frac{d\phi_m}{dt} = \omega NBS \sin(\omega t)$

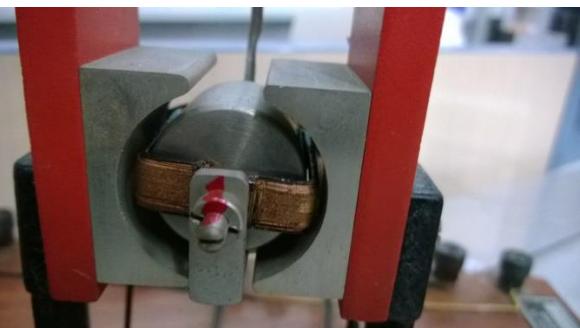
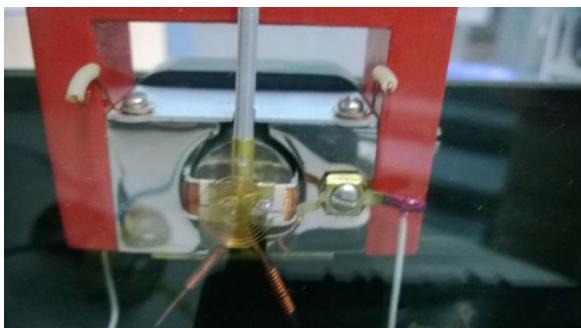
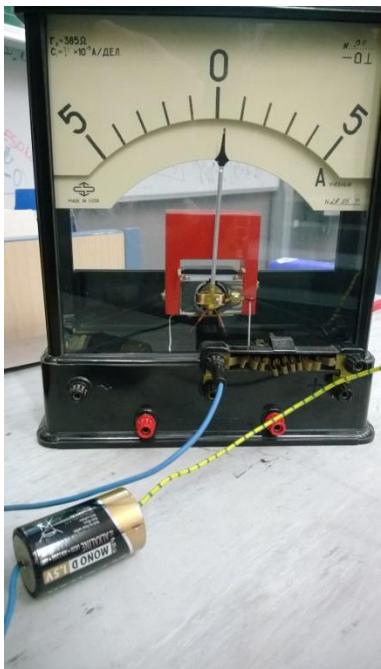
↑

$I = \frac{U_i}{R} = \frac{NBS\omega}{R} \sin(\omega t)$

R = električni upor, ω = kotna hitrost, S = površina ene zanke, N = število zank v tuljavi

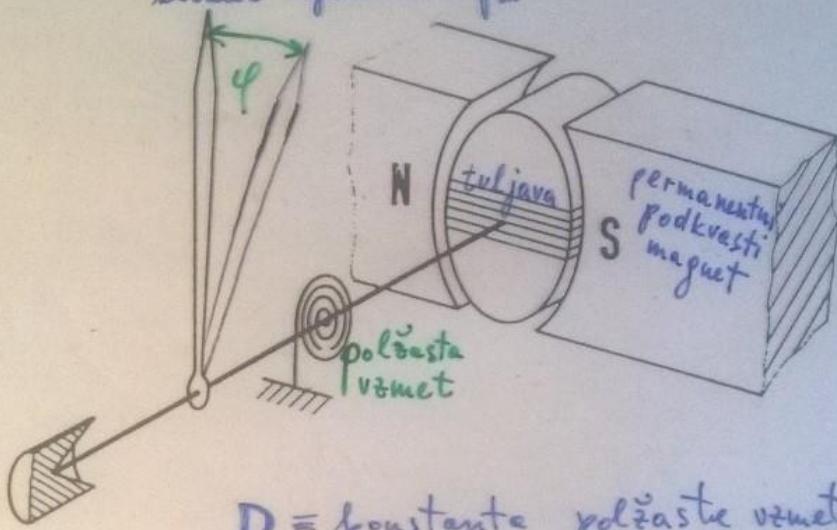
$$\begin{aligned}
 M &= p_m B \sin(\omega t) = N I B S \sin(\omega t) = \frac{N^2 B S \omega}{R} S B \sin^2(\omega t) = \\
 &= \frac{N^2 B^2 S^2 \omega}{R} \sin^2(\omega t) \\
 A &= \int_0^{2\pi} M d\varphi = \frac{N^2 B^2 S^2 \omega}{R} \underbrace{\int_0^{2\pi} \sin^2 \varphi d\varphi}_{\pi} = \pi \frac{N^2 B^2 S^2 \omega}{R}
 \end{aligned}$$

SLIKA: INŠTRUMENT NA VRTLJIVO TULJAVICO (meritev konstantnega električnega toka - inštrument uporabimo kot balistični galvanometer)

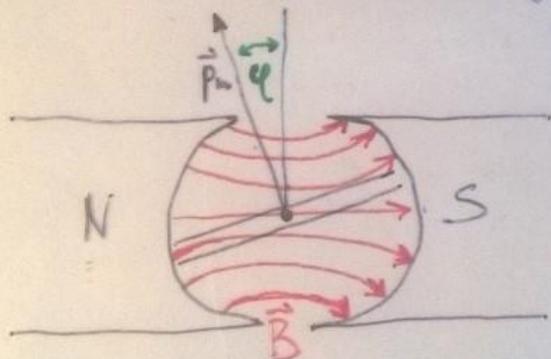




kezalec vstopeden $\Rightarrow \vec{p}_m$



$D = \text{konstanta polžaste vezeti}$



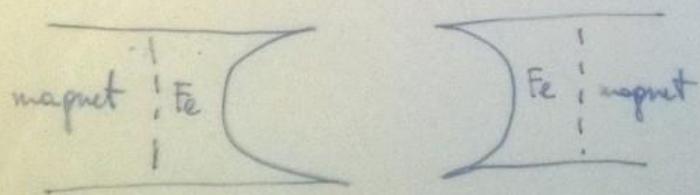
za majhne odmike
približno velje:

$$\vec{p}_m \perp \vec{B}, \tilde{\varphi} = 90^\circ$$

$$M = p_m B \underbrace{\sin \tilde{\varphi}}_{\approx 1} \approx p_m B$$

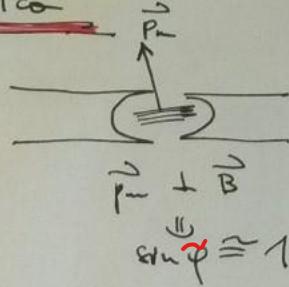
$\tilde{\varphi} = \text{kot med } \vec{p}_m \text{ in } \vec{B}$

silnice pravokotne na
mejo \Rightarrow polji radialno



- Galvanski metar na vrtljivo teljevište

4
3



- mjerjenje konstantnega toka

$$I = \text{konst}$$

ravnovesje: $\int p_m B \sin \varphi = D\varphi$

$$NJSB = D\varphi \Rightarrow \boxed{\varphi = \frac{NJSB}{D}}$$

- mjerjenje fokalnega snnika $\int J dt$

$$\int M dt = \Delta \Gamma = \int \omega_0$$

$$\int p_m B dt = \int \omega_0$$

$$\int NJSB dt = \int \omega_0$$

$$NSB \int J dt = \int \varphi_0 \left(\frac{2\pi}{t_0} \right) \leftarrow \left(\frac{2\pi}{t_0} \right) = \sqrt{\frac{D}{J}}$$

$$NSB \int J dt = \int \varphi_0 \sqrt{\frac{D}{J}} = \varphi_0 \sqrt{DJ}$$

$$\boxed{\varphi_0 = \frac{NSB \int J dt}{\sqrt{DJ}}}$$

(balistični galvanski metar)

NIHAJNI ČAS NIHALA NA SOČNO VZMET:

$$M = J \ddot{\varphi}$$

$$-D\varphi = J \ddot{\varphi}$$

$$-\frac{D}{J}\varphi = \ddot{\varphi}$$

$$\left(\frac{2\pi}{t_0} \right)^2 = \frac{D}{J}$$

$$\varphi = \varphi_0 \sin \left(\frac{2\pi}{t_0} \cdot t \right)$$

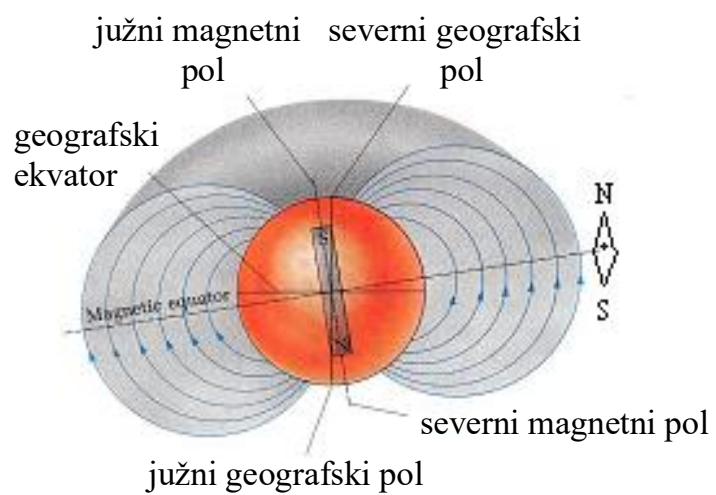
$$\omega = \dot{\varphi} = \underbrace{\varphi_0 \left(\frac{2\pi}{t_0} \right)}_{\omega_0} \omega \left(\frac{2\pi}{t_0} \cdot t \right)$$

$$\boxed{\omega_0 = \varphi_0 \left(\frac{2\pi}{t_0} \right)}$$

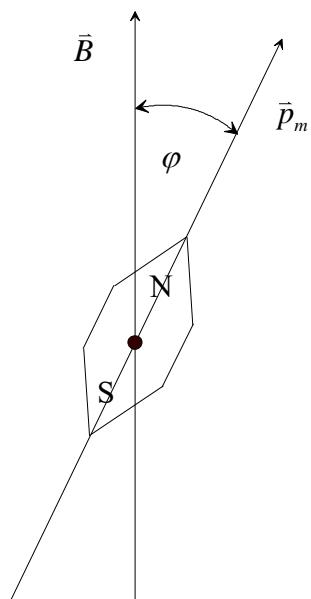
SLIKA: navor na zanko v vrtečem se magnetnem polju (elektromotorji na trofazni tok)



NIHANJE MAGNETNICE V ZEMELJSKEM MAGNETNEM POLJU



Silnice zemeljskega magnetnega polja (Serway, 1992)



$$M = J \alpha \quad \alpha = \frac{d^2\varphi}{dt^2}$$

$$-p_m B \sin \varphi = J \frac{d^2\varphi}{dt^2}.$$

za majhne odmike ($\varphi \ll 1$): $\sin \varphi \approx \varphi$:

$$-p_m B \varphi \approx J \frac{d^2\varphi}{dt^2} \quad -\left[\frac{p_m B}{J} \right] \varphi = \frac{d^2\varphi}{dt^2}$$

$$-\left[\frac{p_m B}{J} \right] \varphi = \frac{d^2 \varphi}{dt^2}$$

rešitev :

$$\varphi = \varphi_0 \sin \left[\left(\frac{2\pi}{t_0} \right) t + \delta \right] \quad \frac{d^2 \varphi}{dt^2} = -\varphi_0 \left(\frac{2\pi}{t_0} \right)^2 \sin \left[\left(\frac{2\pi}{t_0} \right) t + \delta \right].$$

$$\left(\frac{2\pi}{t_0} \right)^2 = \frac{p_m B}{J},$$

$$t_0 = 2\pi \sqrt{\frac{J}{p_m B}} \quad \text{najhajni čas magnetne igle}$$



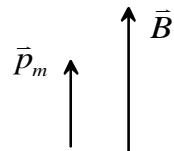
ENERGIJA MAGNETNICE V ZUNANJEM MAGNETNEM POLJU

$$\vec{M} = \vec{p}_m \times \vec{B}$$

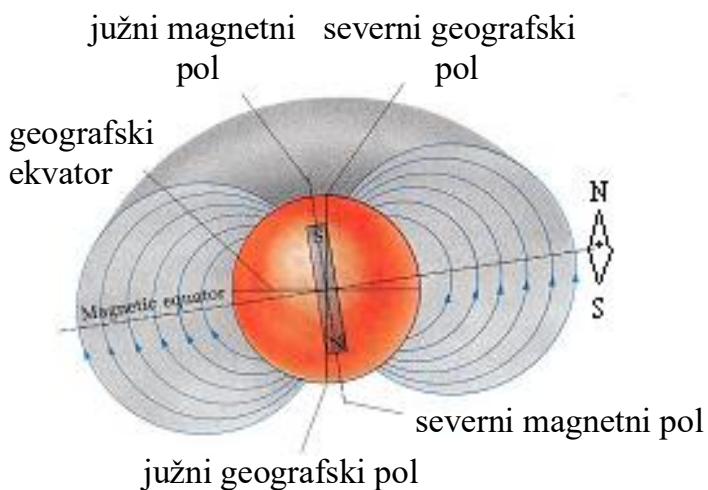
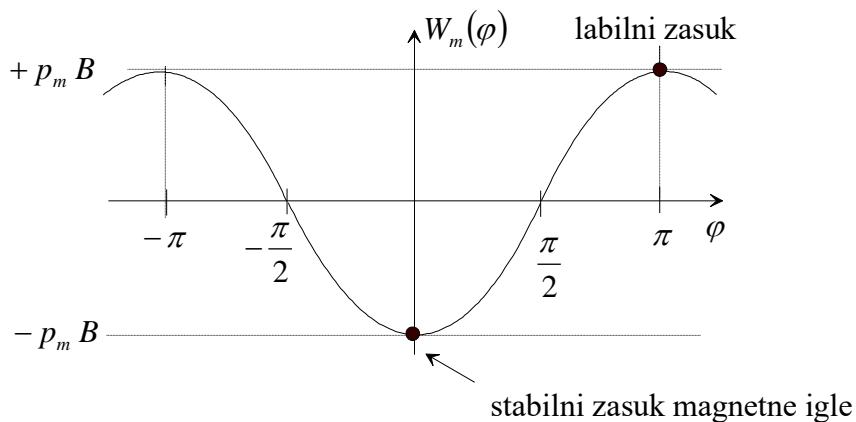
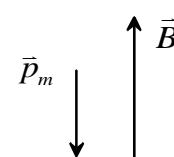
$$A = \int_{\varphi_1}^{\varphi_2} M \, d\varphi = \int_{\varphi_1}^{\varphi_2} p_m \sin \varphi B \, d\varphi = -p_m B \cos \varphi_2 - (-p_m B \cos \varphi_1) = \Delta W_m,$$

$$W_m = -p_m B \cos \varphi = -\vec{p}_m \cdot \vec{B}$$

$\varphi = 0 : W_m = -p_m B$ (energijski minimum) :

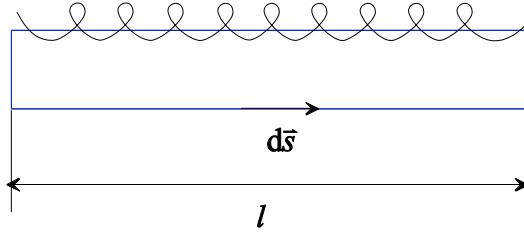


$\varphi = \pi : W_m = +p_m B$ (energijski maximum) :



ENERGIJA MAGNETNEGA POLJA⁺

(primer dolge tuljave z gostim navitjem)



Amperov zakon

$$\oint \bar{B} \cdot d\bar{s} \cong Bl = \mu_0 N I \quad B = \mu_0 \frac{NI}{l}$$

Med naraščanjem električnega toka skozi tuljavo, mora generator opravljati delo:

$$A = \int U_L I dt = \int L \frac{dI}{dt} I dt = \int_{I_{zač}}^{I_{kon}} LI dI = L \frac{I^2}{2} \Big|_{I_{zač}}^{I_{kon}} = L \frac{I_{kon}^2}{2} - L \frac{I_{zač}^2}{2}$$

Prejeto delo **ni** odvisno od tega kako narašča tok po tuljavi, ampak samo od začetnega in končnega toka. Zato **definiramo magnetno energijo tuljave**:

$$W_m = L \frac{I^2}{2} = \mu_0 \frac{N^2 S}{l} \frac{I^2}{2} = \mu_0 \frac{N^2 S}{l} \frac{l}{2} \frac{I^2}{2} = \frac{1}{2} \mu_0 (S l) \left(\frac{NI}{l} \right)^2 = \frac{1}{2} \mu_0 H^2 V = \frac{1}{2} HBV$$

kjer je $V = S l \quad B = \mu_0 H$

gostota energije magnetnega polja w_m (predpostavka: magnetno polje **samo** znotraj tuljave)

$$w_m = \frac{1}{2} \mu_0 H^2 = \frac{1}{2} HB = \frac{1}{2} \frac{B^2}{\mu_0}$$

