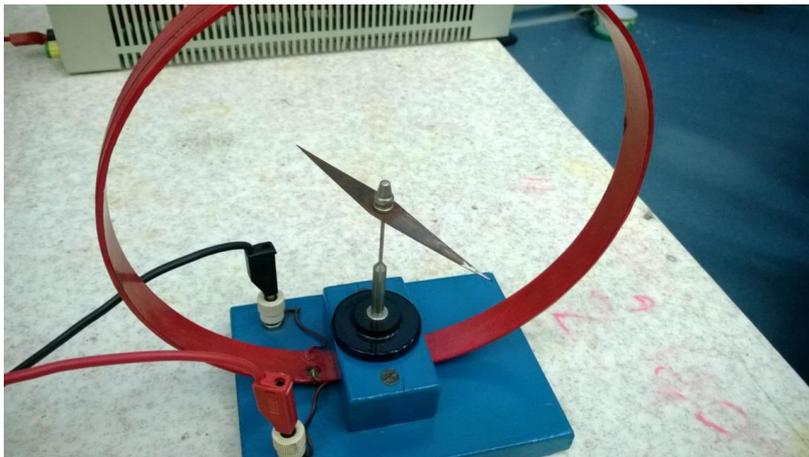


MAGNETNO POLJE

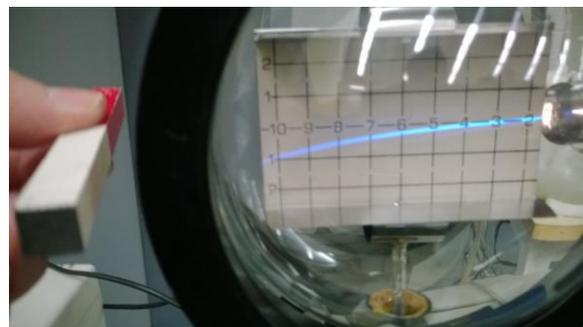
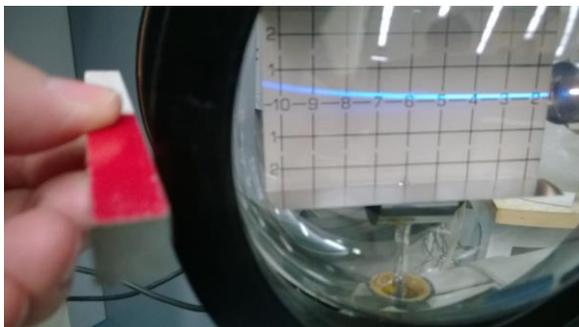
OERSTEDOV POSKUS (električni tok po ravnem vodniku povzroči odklon magnetne igle)



MAGNETNA IGLA V TOKOVNI ZANKI

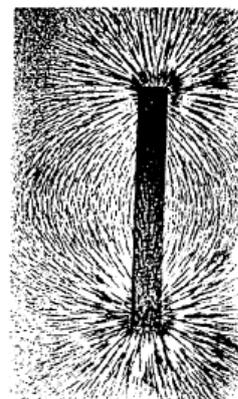
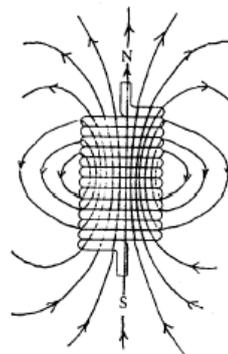
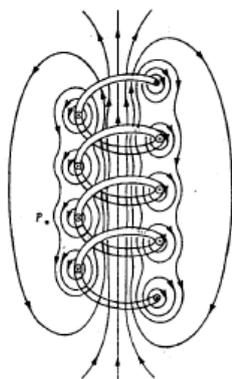
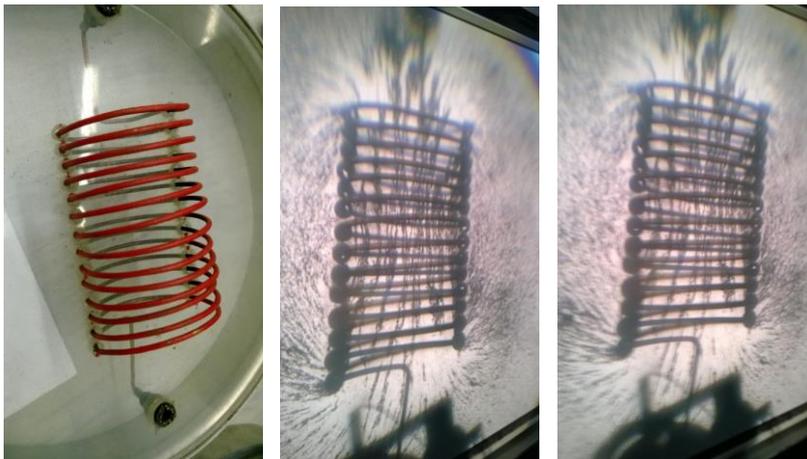


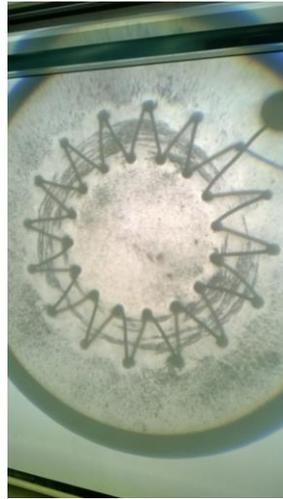
Curek elektronov lahko premikamo s paličastim magnetom



Urejanje železnih opilkov v bližini permanentnih magnetov in električnih vodnikov, tabla z majhnimi magnetnicami

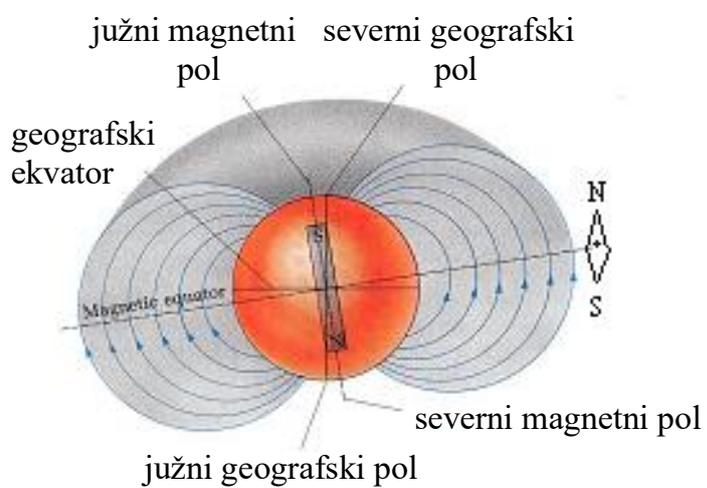
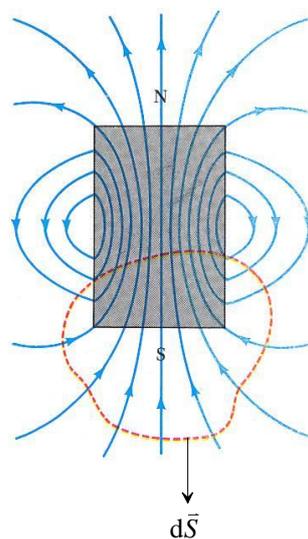
Tuljave in permanentni paličasti magnet (primerjava):





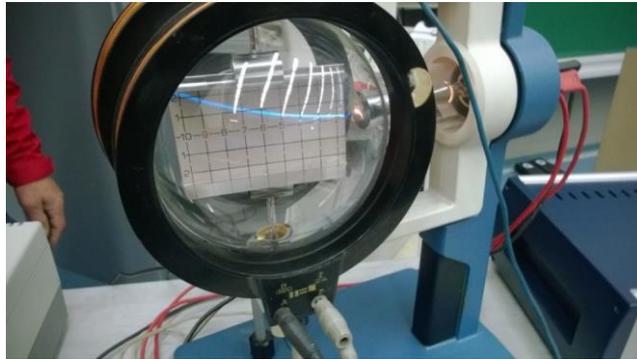
oznake : N \equiv severni magnetni pol
S \equiv južni magnetni pol

N \equiv severni pol
S \equiv južni pol



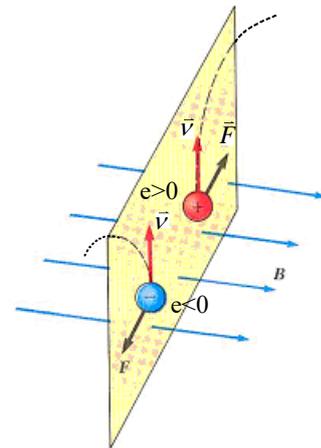
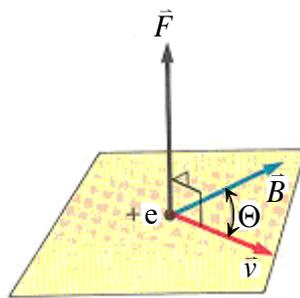
DEFINICIJA GOSTOTE MAGNETNEGA POLJA

Gostoto magnetnega polja \vec{B} definiramo preko sile na gibajoči nabiti delec:



$$\vec{F} = e \vec{v} \times \vec{B}$$

smer sile: pravilo
desnosučnega vijaka



$$\vec{F} = e \vec{v} \times \vec{B}$$

$$B \propto \frac{F}{ev} = \frac{\text{Ns}}{\text{As m}} = \frac{\text{N}}{\text{A m}} = \frac{\text{Nm}}{\text{A m}^2} = \frac{\text{J}}{\text{A m}^2} = \frac{\text{VAs}}{\text{A m}^2} = \frac{\text{Vs}}{\text{m}^2} = 1\text{T}$$

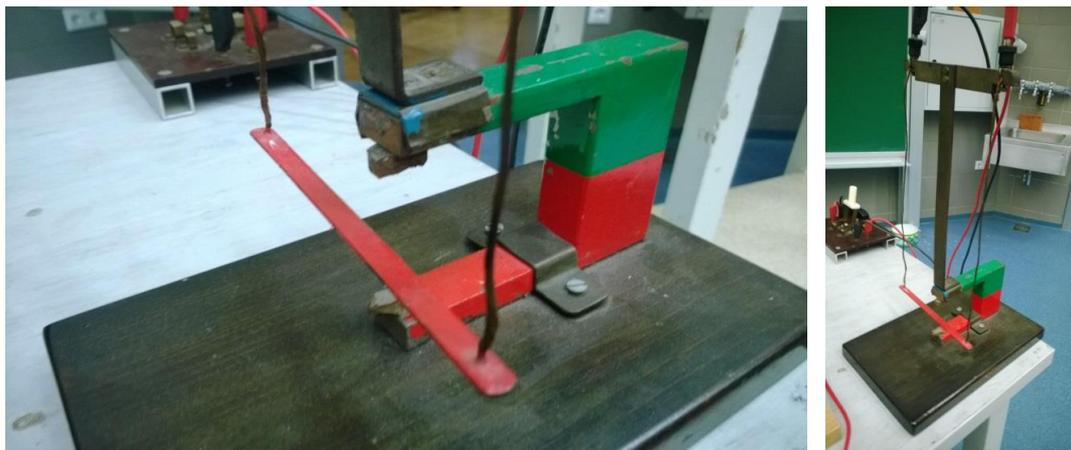


Nikola Tesla
(1856 – 1943)

$$\frac{\text{Vs}}{\text{m}^2} = 1\text{T (Tesla)}$$

IZVOR	NEVTRONSKA ZVEZDA	ELEKTRO-MAGNET	POVRŠINA ZEMLJE	MEDZVEZDNI PROSTOR
B	10^8 T	10T – 1T	10^{-4} T	10^{-10} T

Sila na vodnik v magnetnem polju



Sila, ki deluje na nosilce naboja v vodniku se prenese na vodnik, ker nosilci ne morejo ubežati iz vodnika

sila na gibajoči se točkasti naboj $\vec{F} = e \vec{v} \times \vec{B}$

namesto e vzamemo infinitezimalni naboj de , ki teče po žici s hitrostjo $\vec{v} \equiv \langle \vec{v} \rangle$

$$d\vec{F} = de \vec{v} \times \vec{B} \quad \leftarrow \{de = I dt\}$$

Sila na odsek vodnika dolžine $d\vec{l}$

$$d\vec{F} = I dt \vec{v} \times \vec{B} = I d\vec{l} \times \vec{B} \quad \leftarrow \{ \vec{v} dt = d\vec{l} \}$$

$$\vec{F} = I \int d\vec{l} \times \vec{B}$$

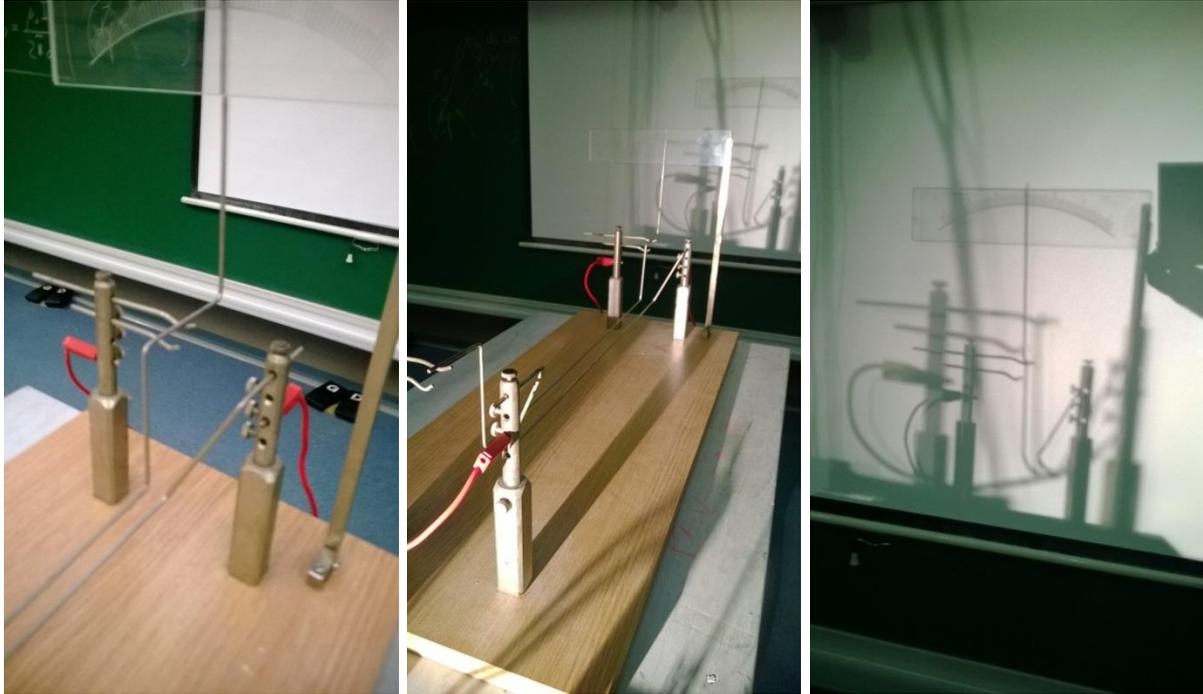
Poseben primer: vodnik je raven in polje homogeno:

$$\vec{F} = I \vec{l} \times \vec{B}$$

Če je polje znotraj vodnika nehomogeno:

$$d\vec{F} = dI\vec{l} \times \vec{B} = jdS\vec{l} \times \vec{B}, \quad \text{kjer } dI = jdS \text{ in } j \text{ ploskovna gostota toka.}$$

SILA MED ELEKTRIČNIMA VODNIKOMA (vzporedna tokova, nasprotno usmerjena električna tokova)



tokove tečeta v isto smer

tokove tečeta v nasprotnih smereh

SILA JE PRIVLAČNA (a)

SILA JE ODBOJNA (b)

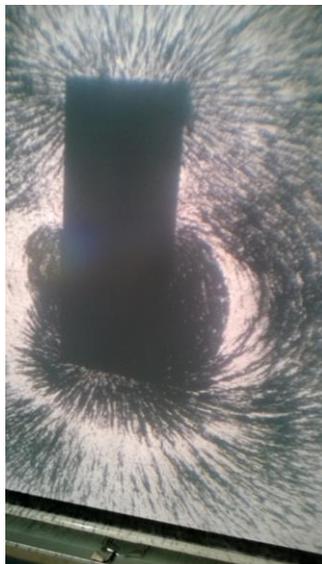
Sila med vzporednima dolgima ravnima vodnikoma v razdalji r , po katerih tečeta tokova I_1 in I_2 v isto smer (a) in v nasprotnih smereh (b). Velikost gostote magnetnega polja prvega vodnika s tokom I_1 na kraju drugega vodnika je $B_1 = \mu_0 I_1 / 2\pi r$, velikost sile na dolžinsko enoto drugega vodnika pa je $F/l = I_2 B_1 = \mu_0 I_1 I_2 / 2\pi r$

ZAKON O MAGNETNEM PRETOKU

ni monopolov

ni izvorov

ni ponorov

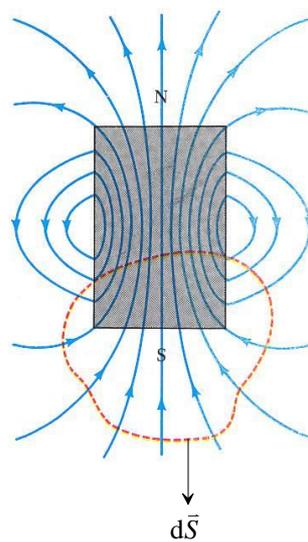


Magnetni pretok

$$\Phi_m = \int \vec{B} \cdot d\vec{S}$$

N ≡ severni pol
S ≡ južni pol

$$\oint_S \vec{B} \cdot d\vec{S} = 0$$



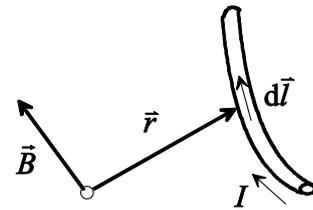
AMPEROV ZAKON



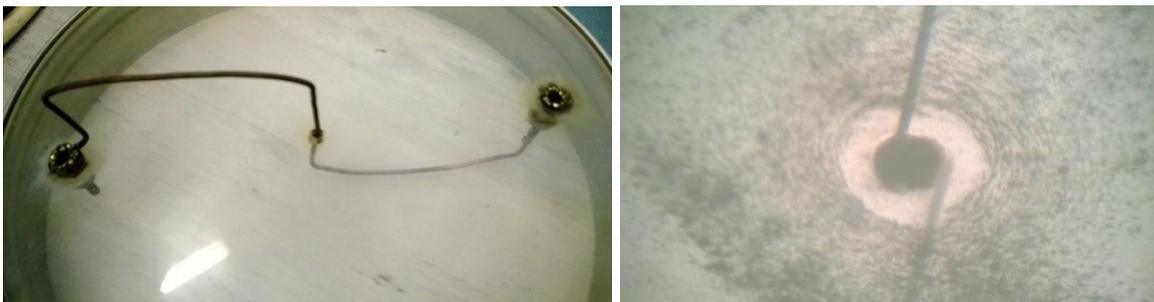
André – Marie Ampère
(1775 – 1836)

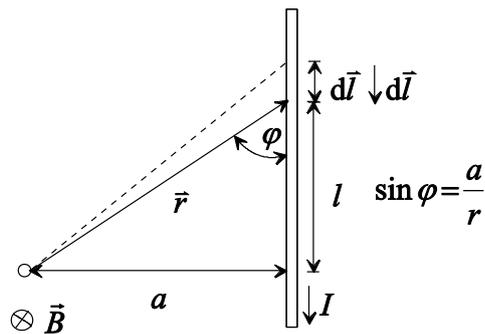
Biot – Savartov zakon:

$$\vec{B} = \frac{\mu_0 I}{4\pi} \int \frac{\vec{r} \times d\vec{l}}{r^3}$$



Primer: magnetno polje zelo dolgega ravnega vodnika

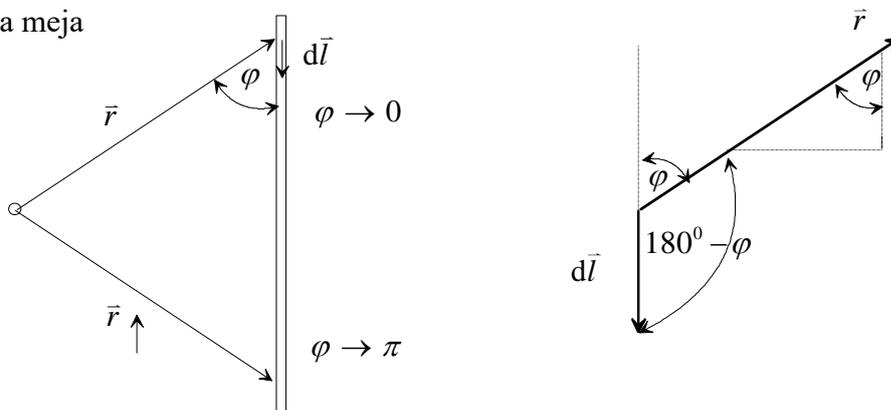




$$\sin \varphi = \frac{a}{r} \Rightarrow \boxed{r = \frac{a}{\sin \varphi}}$$

Velja: $\text{ctg } \varphi = \frac{l}{a} \Rightarrow l = a \text{ctg } \varphi \Rightarrow \boxed{dl = \frac{-a}{\sin^2 \varphi} d\varphi}$

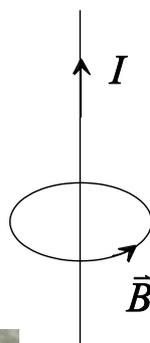
integracijska meja
za kot φ :



$$\begin{aligned} B &= \frac{\mu_0 I}{4\pi} \int \frac{r dl \sin(180^\circ - \varphi)}{r^3} = \frac{\mu_0 I}{4\pi} \int \frac{r dl \sin \varphi}{r^3} = \frac{\mu_0 I}{4\pi} \int \frac{dl \sin \varphi}{r^2} = \\ &= -\frac{\mu_0 I}{4\pi} \int_{\pi}^0 \frac{a \sin^2 \varphi \sin \varphi d\varphi}{\sin^2 \varphi a^2} = -\frac{\mu_0 I}{4\pi a} \int_{\pi}^0 \sin \varphi d\varphi = -\frac{\mu_0 I}{4\pi a} (-\cos \varphi) \Big|_{\pi}^0 = \\ &= \frac{\mu_0 I}{4\pi a} \cos \varphi \Big|_{\pi}^0 = \frac{\mu_0 I}{4\pi a} 2 = \frac{\mu_0 I}{2\pi a} \end{aligned}$$

silnice so koncentrični krogi:

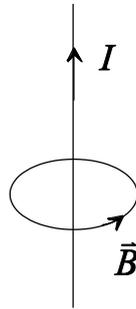
$$\boxed{B = \frac{\mu_0 I}{2\pi a}}$$



Amperov zakon (zakon o magnetni napetosti po zaključeni poti)

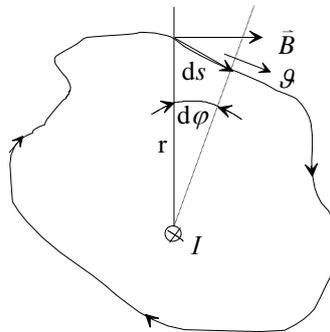
poseben primer : magnetno polje dolgega ravnega vodnika.

$$B = \frac{\mu_0 I}{2\pi r}$$



$$\oint \vec{B} \cdot d\vec{s} = ?$$

tloris:



$$\begin{aligned} \oint \vec{B} \cdot d\vec{s} &= \oint B \underbrace{ds \cos \vartheta}_{r d\varphi} = \oint B r d\varphi = \oint \frac{\mu_0 I}{2\pi r} r d\varphi = \oint \frac{\mu_0 I}{2\pi} d\varphi = \\ &= \frac{\mu_0 I}{2\pi} \oint d\varphi = \frac{\mu_0 I}{2\pi} 2\pi = \mu_0 I . \end{aligned}$$

$$\oint \vec{B} \cdot d\vec{s} = \mu_0 I$$

$$\oint \vec{H} \cdot d\vec{s} = I$$

$$B = \mu_0 H$$

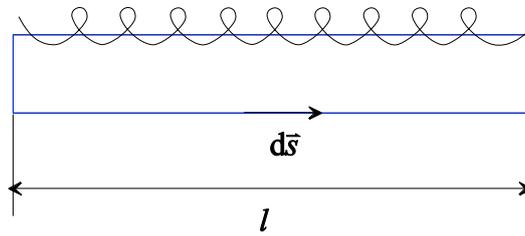
če upoštevamo tudi premikalni tok $I_p = \int_s \frac{\partial \vec{D}}{\partial t} \cdot d\vec{s}$:

Amperov zakon

$$\oint \vec{H} \cdot d\vec{s} = \int_s \vec{j} \cdot d\vec{s} + \int_s \frac{\partial \vec{D}}{\partial t} \cdot d\vec{s}$$

PRIMER:

Primer: dolga tuljava z gostimi navoji po kateri teče električni tok I



$l \equiv$ dolžina tuljave

$N \equiv$ število ovojev tuljave

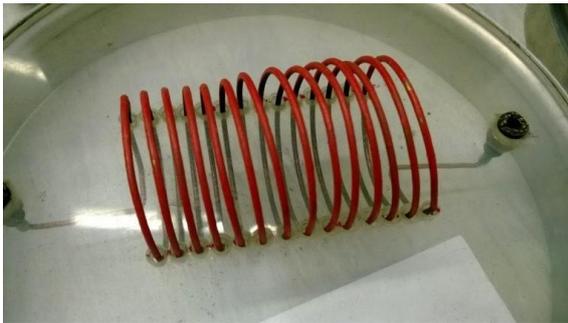
$S \equiv$ površina enega ovoja

predpostavka: magnetno polje je samo znotraj tuljave

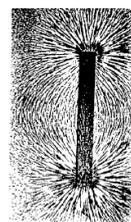
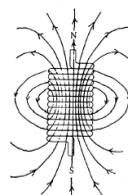
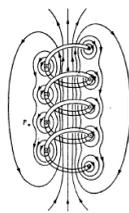
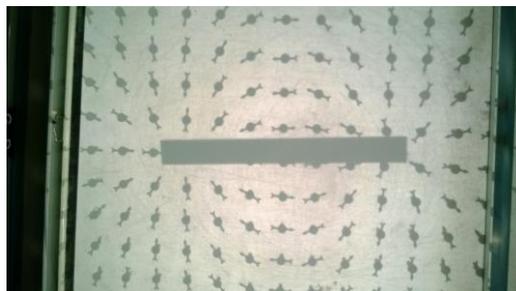
Amperov zakon

$$\oint \vec{B} \cdot d\vec{s} \cong B l = \mu_0 N I$$

$$B \cong \mu_0 \frac{N I}{l}$$



Magnetno polje tuljav in permanentnih paličastih magnetov (primerjava):

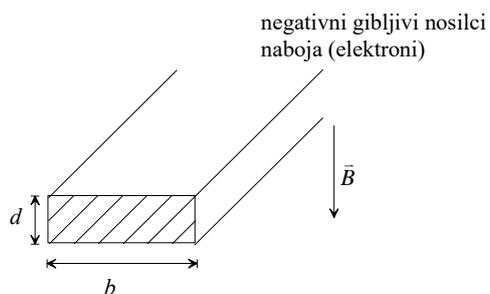


HALLOV POJAV

Hallova sonda



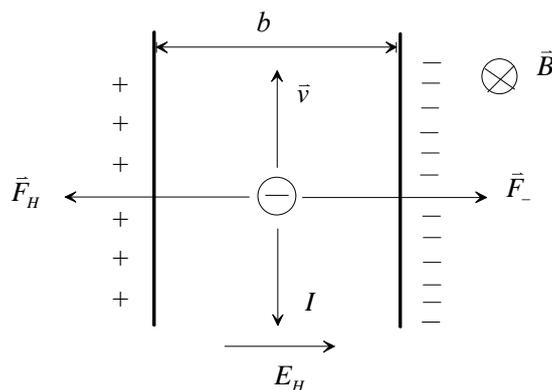
Električni tok po **vodniku s pravokotnim presekom**, ki se nahaja v magnetnem polju



$$\vec{F}_- = (-e_0)\vec{v} \times \vec{B}$$

$$\vec{F}_H = -e_0 \vec{E}_H$$

Stacionarno stanje



$$\vec{F}_- + \vec{F}_H = \vec{0}$$

$$e_0 E_H = e_0 v B$$

$$e_0 E_H = e_0 v B$$

upoštevamo tudi :

$$v \equiv \langle \vec{v} \rangle, \quad j \equiv n e_0 \langle \vec{v} \rangle = n e_0 v, \quad n = \frac{N}{V}, \quad j = \frac{I}{S} = n e_0 v$$

Hallova napetost :

$$E_H = \frac{U_H}{b} \qquad \Downarrow \qquad v = \frac{I}{S n e_0}$$

$$F_H = F_-$$

$$e_0 E_H = e_0 v B$$

$$e_0 \frac{U_H}{b} = \frac{I}{S n} B \qquad S = b d$$

$$B = \frac{e_0 S n U_H}{I b}$$