Elektrika

- elektron (grška beseda za jantar). Z drgnenjem koščka jantarja z blagom se jantar naelektri. 600 BC Jantar lahko privlači delčke suhega sena - slame.
- Tedaj so poznali tudi že magnet (Magnesia) grška pokrajina. Vendar niso poznali povezave med magnetom ter el tokom tja do leta 1820
- 1820 Hans Cristian Oersted - tok po prevodniku lahko ukloni magnetno iglo

Naboj

- Poznamo dve vrsti nabojev: pozitivni in negativni
- Privlak med raznovrstnimi ter odboj med istovrstnimi naboji
- Ohranitev naboja

$\Rightarrow e_1 + e_2 = e$

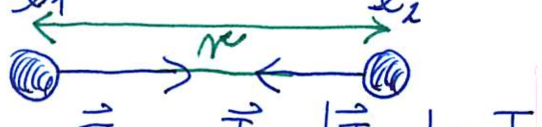
Prevodniki	Izolatorji
Kovine - del elektronov je skoraj prosto gibajoč	Elektroni niso prosto gibljivi - vezani na pozitivne ione

- Naboj je kvantiziran: $e_0 = 1{,}6 \cdot 10^{-19} As$ ← Amper! André-Marie (1775-1836)

Coulombov zakon

Električna sila med dvema točkastima nabojema:

$$F = \frac{e_1 e_2}{4\pi \varepsilon_0 r^2}$$



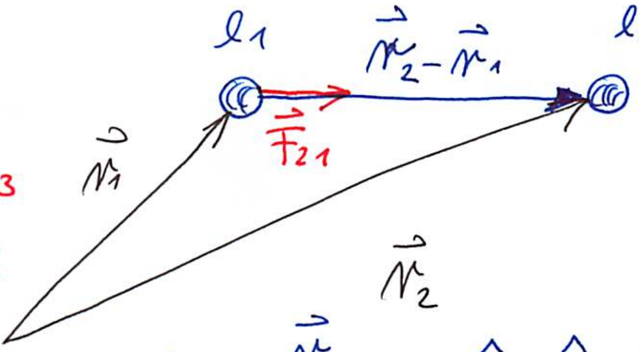
$\vec F_{21} = -\vec F_{12}$; $|\vec F_{12}| = F$

ε_0: dielektrična konstanta $= 8,9 \cdot 10^{-12}$ As/Vm

e_1, e_2 električna naboja v enotah [As]

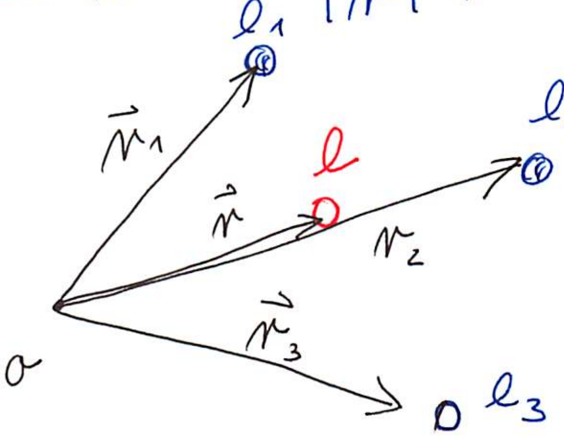
Zapis z vektorji:

$$\vec F_{21} = \frac{e_1 e_2}{4\pi \varepsilon_0} \frac{\vec r_1 - \vec r_2}{|\vec r_1 - \vec r_2|^3}$$



Sila drugega naboja na prvi naboj.

Enotski vektor v smeri $\vec r$: $\hat n = \frac{\vec r}{|\vec r|}$; $\hat n \cdot \hat n = 1 = \frac{\vec r \vec r}{r^2} = \underline{\underline{1}}$

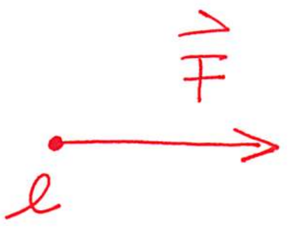


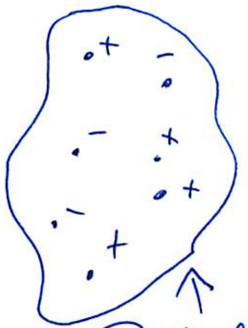
$$\vec F_{\vec r} = \sum_i \frac{e\, e_i}{4\pi \varepsilon_0} \frac{\vec r - \vec r_i}{|\vec r - \vec r_i|^3}$$

i teče po vseh nabojih $e_1, e_2, \ldots$, razen po $\vec r$!

Sila na izbrani naboj e v točki $\vec r$ kot posledica vseh ostalih nabojev.

Jakost električnega polja





Poljubna porazdelitev nabojev

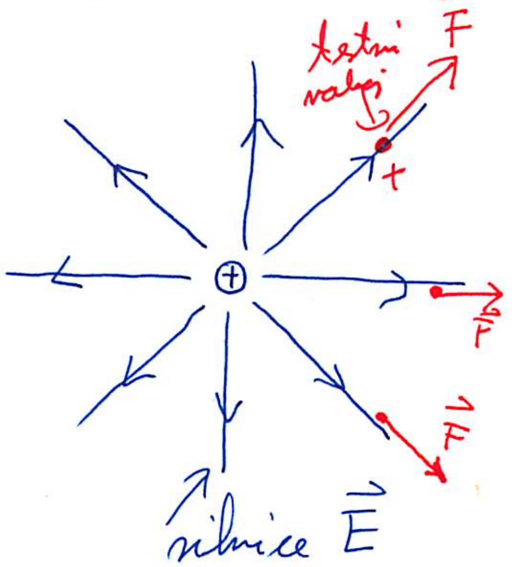
Električno polje povzroči silo na naboj: $\vec{F} = e\,\vec{E}$

$E\left[\frac{V}{m}\right]$ enota: V - Volt (Alessandro Volta 1745–1827)

Italianski fizik

Izumitelj prve kemične baterije.

Električno polje obdaja nabite delce. Smer silnic $\vec{E}$ polja napoveduje smer sile na testni pozitivni električni naboj.



Električno polje točkastega naboja:

$$E = \frac{e}{4\pi\varepsilon_0 r^2}$$

Zapis z vektorji:

$$\vec{E}(\vec{r}) = \frac{e}{4\pi\varepsilon_0 r^2}\boxed{\vec{e}_r}$$

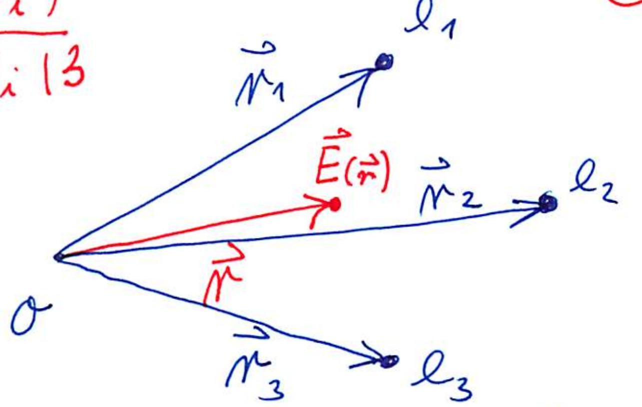
če je izhodišče koord. sistema v $\vec{r}=0$!

smerni vektor v radialni smeri.

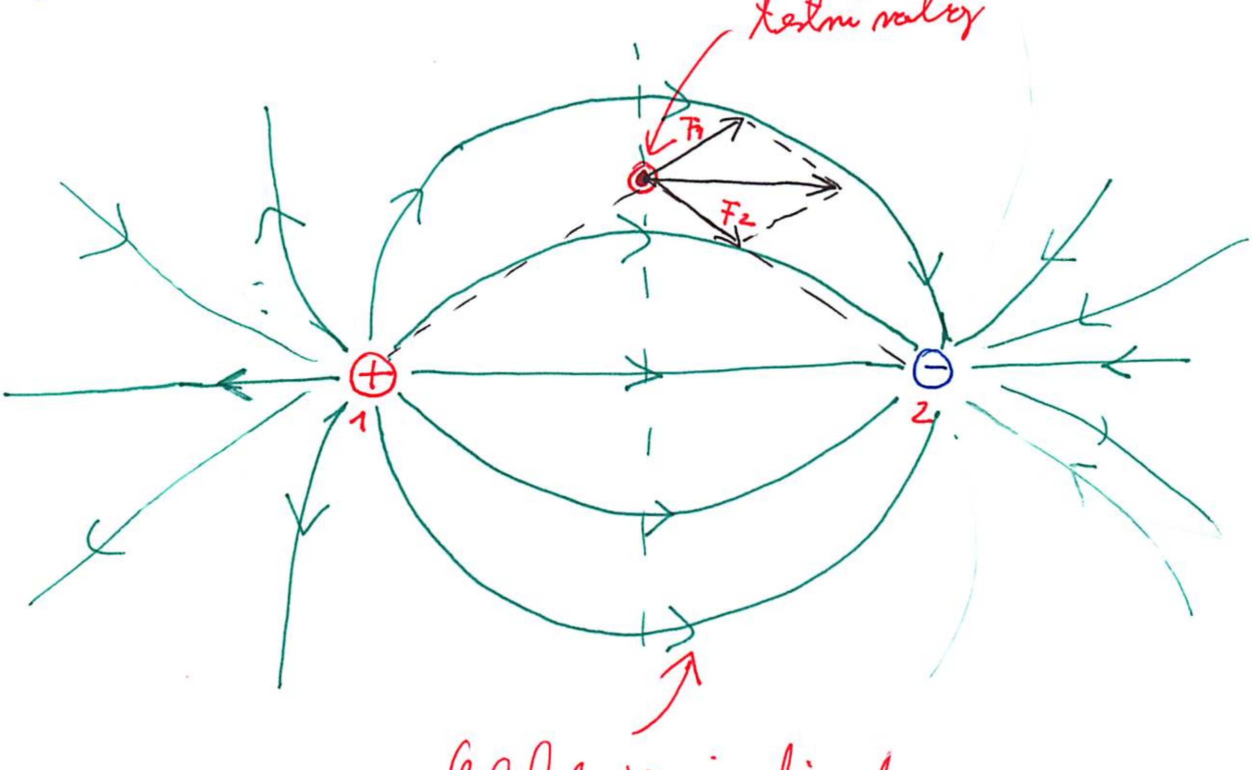
Prispevki $\vec{E}$ polj različnih točkastih nabojev se seštevajo!

$$\vec{E}(\vec{r}) = \sum_{i} \frac{e_i}{4\pi\varepsilon_0} \frac{(\vec{r}-\vec{r}_i)}{|\vec{r}-\vec{r}_i|^3}$$

po vseh nabojih

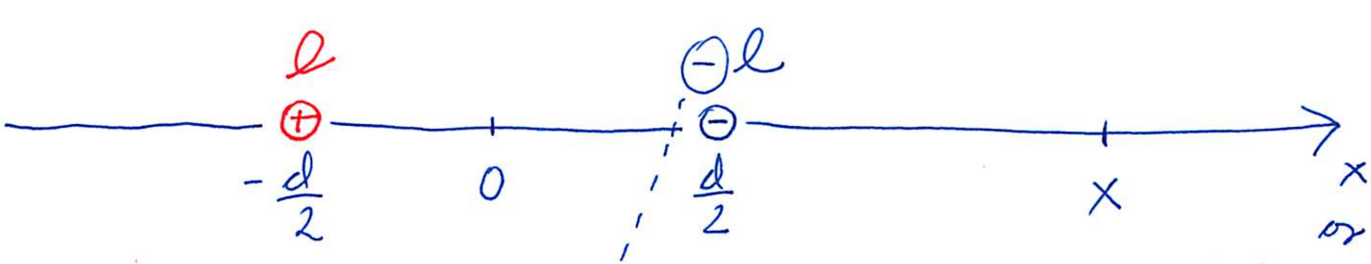


Slika silnic v okolici dveh nasprotno enakih nabojev: e ter -e



Električni dipol

El. polje elekt. dipola



$$E(x) = \frac{e}{4\pi\varepsilon_0}\left(\frac{1}{(x+\frac{d}{2})^2} \ominus \frac{1}{(x-\frac{d}{2})^2}\right) = \frac{e}{4\pi\varepsilon_0}\frac{-2dx}{(x^2-\frac{d^2}{4})^2} \Rightarrow$$

$$E(x) \simeq \frac{-e}{4\pi\varepsilon_0}\,\frac{2dx}{x^4 - \underbrace{\frac{x^2d^2}{2}+\cdots}}$$

zanemarimo za $x \gg d$!

$$E(x) = -\frac{\boxed{ed}}{2\pi\varepsilon_0 x^3} = -\frac{p}{2\pi\varepsilon_0 x^3}$$

p: električni dipolni moment!

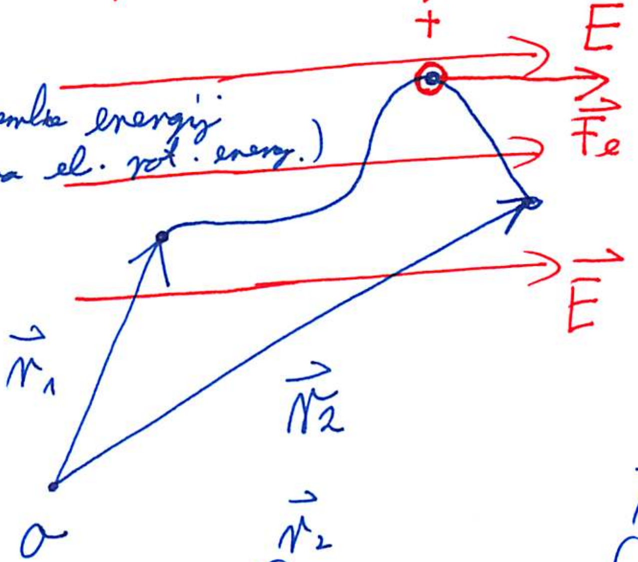
—— o ——

Električna pot. energija

$A + A_{el} = \Delta W$ ← sprememba energij (ne zajema el. pot. energ.)

↑ delo električne sile

↑ delo vseh ostalih sil



$$A = \underbrace{-A_{el}}_{\Delta W_{el}} + \Delta W \;; \qquad A_{el} = \int_{\vec{r}_1}^{\vec{r}_2} \vec{F}_e\, d\vec{s} = e\int_{\vec{r}_1}^{\vec{r}_2} \vec{E}\, d\vec{s}$$

$$\Delta W_{el} = -e\int_{\vec{r}_1}^{\vec{r}_2} \vec{E}\, d\vec{s} = e\,\underbrace{U(\vec{r}_2,\vec{r}_1)} = \underbrace{eV(\vec{r}_2)} - eV(\vec{r}$$

↑ napetost med $\vec{r}_2$ in $\vec{r}_1$

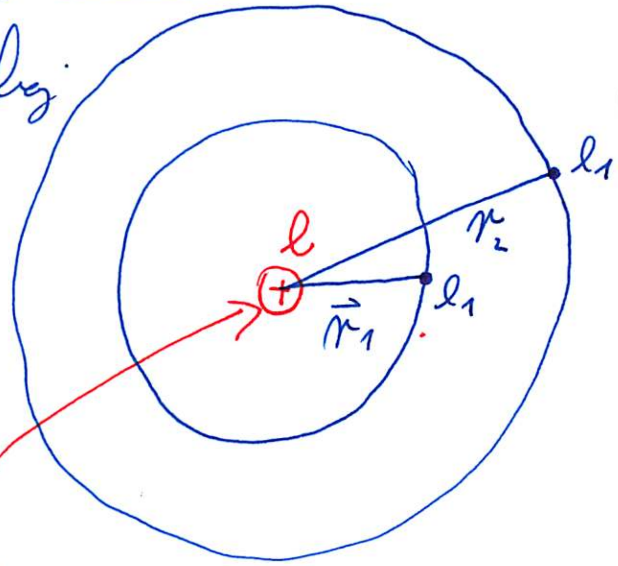
električna potencialna energija

$W_{el} = e V$; $V(\vec{r})$ ÷ električni potencial

$U(\vec{r}_2, \vec{r}_1) = V(\vec{r}_2) - V(\vec{r}_1)$

Napetost je vedno definirana med dvema točkama! Enote: U in V [V = Volt]

Primer: Točkasti naboj



Sprememba el. pot. energije naboja e_1 v polju naboja e:

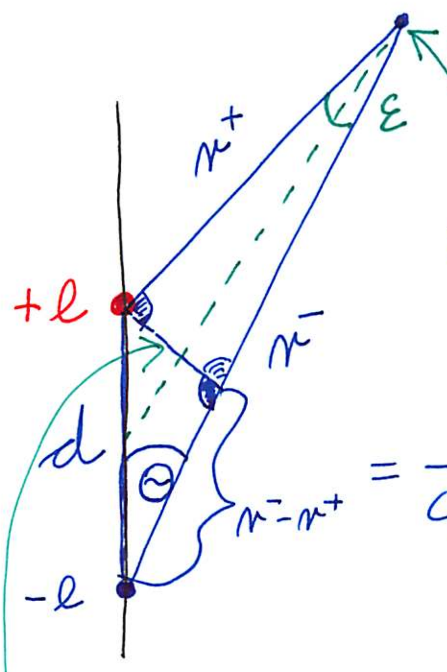
$$\Delta W_{el} = -e_1 \int_{r_1}^{r_2} \frac{e\, dr}{4\pi\varepsilon_0 r^2} = e_1 \left[\frac{e}{4\pi\varepsilon_0 r_2} - \frac{e}{4\pi\varepsilon_0 r_1}\right]$$

$= e_1\left(V(r_2) - V(r_1)\right)$, pri čemer velja:

$$\boxed{V(r) = \frac{e}{4\pi\varepsilon_0 r}}$$

Električni potencial električnega točkastega naboja!

Električni potencial elekt. dipola



opazovana točka:

$$V = \frac{e}{4\pi\varepsilon_0}\left(\frac{1}{r^+} - \frac{1}{r^-}\right) =$$

$$= \frac{e}{4\pi\varepsilon_0}\ \frac{r^- - r^+}{r^+ \cdot r^-} \simeq \frac{e\, d \cos\Theta}{4\pi\varepsilon_0\, r^2}$$

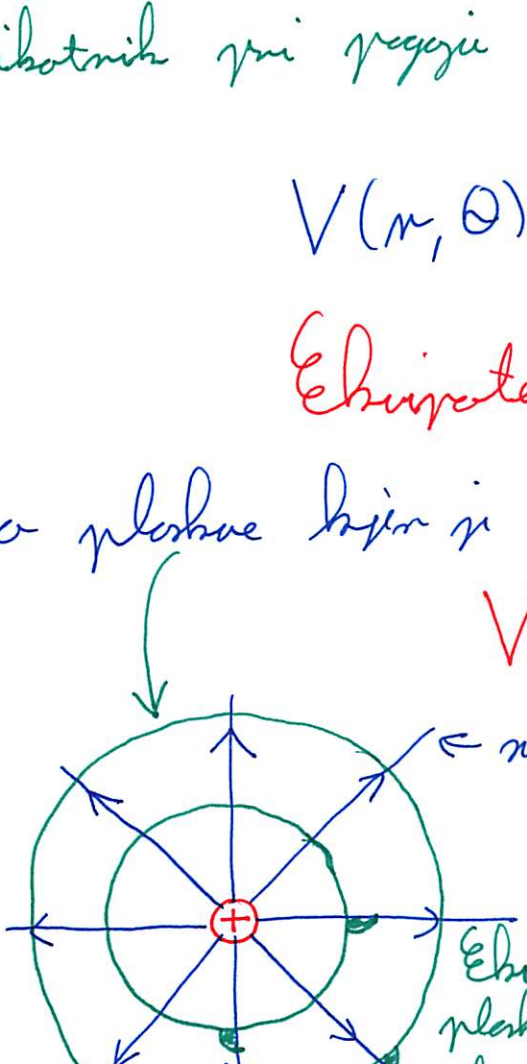
„prava kota" le približno, saj gre za enakokraki trikotnik pri pogoju $d << r^+, r^-$ oziroma $\varepsilon << \frac{\pi}{2}$

$$V(r,\Theta) = \frac{\overset{\text{električni dipol}}{p}\ \cos\Theta}{4\pi\varepsilon_0\ r^2}$$

Ekvipotencialne ploskve:

So ploskve kjer je el. potencial konstanten:

$$V(\vec{r}) = V_0 \text{ (konstanta)}$$



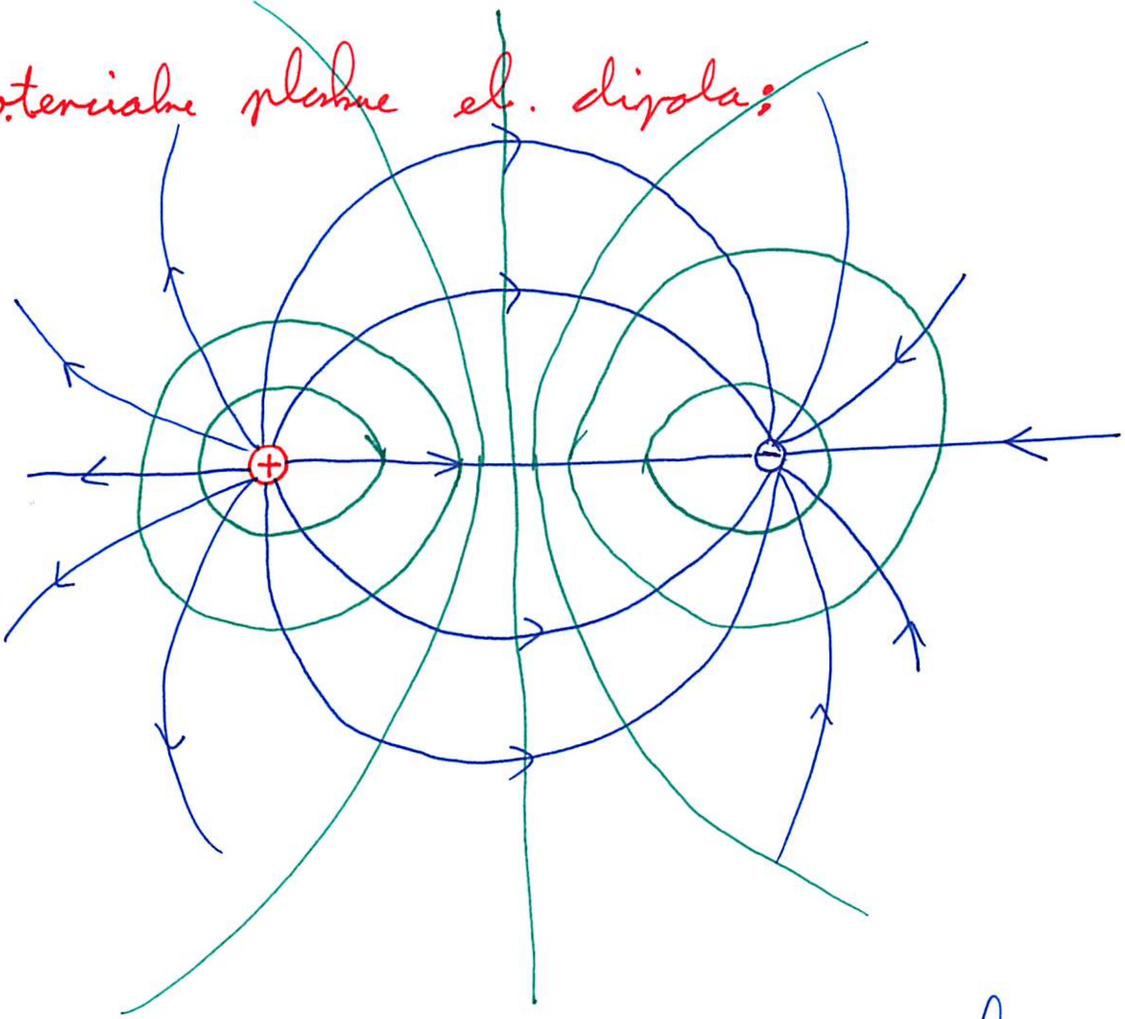
Ekvipotencialne ploskve so vedno ⊥ na silnice $\vec{E}$!

$$\frac{e}{4\pi\varepsilon_0 r} = V_0 = \text{konstanta}$$

velja če je $r = r_0$!

Ta pa je krogla z radijem r_0 !

Ekvipotencialne ploskve el. dipola:



Če se nabit delec giblje vzdolž ekvipotencialnih ploskev, se mu ne spremeni električna potencialna energija.

* * *

Neobvezno: Kako izračunamo $\vec{E}$, če poznamo $V(\vec{r})$?

$$-\int_{\vec{r}_1}^{\vec{r}_2} \vec{E}\, d\vec{r} = V(\vec{r}_2) - V(\vec{r}_1) \Rightarrow \vec{E} = -\underset{\substack{\uparrow \\ \text{gradient}}}{\vec{\nabla}} V(\vec{r})$$

$\vec{\nabla} = \left(\frac{\partial}{\partial x}, \frac{\partial}{\partial y}, \frac{\partial}{\partial z}\right)$ oziroma $\vec{\nabla} V(r) = \left(\frac{\partial V}{\partial x}, \frac{\partial V}{\partial y}, \frac{\partial V}{\partial z}\right)$

Primer: $V(r) = \frac{e}{4\pi\varepsilon_0 r}$; $\frac{\partial V}{\partial x} = \frac{\partial V}{\partial r}\frac{\partial r}{\partial x}$

$r = \sqrt{x^2+y^2+z^2}$; $\frac{\partial r}{\partial x} = \frac{2x}{2\sqrt{x^2+y^2+z^2}} = \frac{x}{r}$

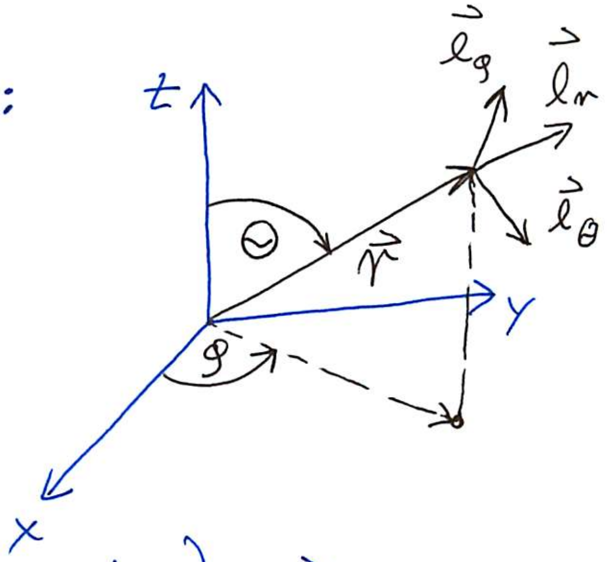
$$\vec{E} = -\vec{\nabla} V(r) = -\frac{e}{4\pi\varepsilon_0} \underbrace{\frac{\partial}{\partial r}}_{-\frac{1}{r^2}} \left(\frac{\partial r}{\partial x}, \frac{\partial r}{\partial y}, \frac{\partial r}{\partial z}\right) =$$

$$= \frac{e}{4\pi\varepsilon_0 r^2}\left(\frac{x}{r}, \frac{y}{r}, \frac{z}{r}\right) \Rightarrow$$

$$\boxed{E = \frac{e}{4\pi\varepsilon_0 r^2}\frac{\vec{r}}{r}} \quad \checkmark$$

Drugi primer:

$$V(\vec{r}) = \frac{e\,d}{4\pi\varepsilon_0}\frac{\cos\Theta}{r^2} \; ;$$



$$\vec{\nabla} = \frac{\partial}{\partial r} e_r + \frac{1}{r\sin\theta}\frac{\partial}{\partial\varphi}\vec{e}_\varphi + \frac{1}{r}\frac{\partial}{\partial\theta}\vec{e}_\theta$$

ali

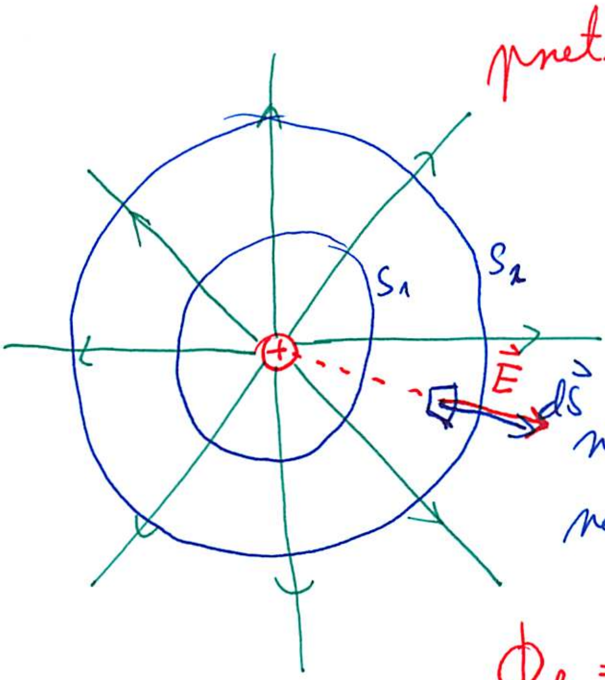
$$\vec{\nabla} V = \frac{\partial V}{\partial r}\vec{e}_r + \frac{1}{r\sin\theta}\frac{\partial V}{\partial\varphi}\vec{e}_\varphi + \frac{1}{r}\frac{\partial V}{\partial\theta}\vec{e}_\theta \; ; \text{ ta } V(\vec{r})$$

2

$$= -\frac{p}{2\pi\varepsilon_0}\frac{\cos\theta}{r^3}\vec{e}_r - \frac{p}{2\pi\varepsilon_0 r^3}\sin\theta\,\vec{e}_\theta$$

$$\vec{E}(r,\theta) = \frac{p}{2\pi\varepsilon_0 r^3}\left(\cos\theta\,\vec{e}_r + \sin\theta\,\vec{e}_\theta\right)$$

Zakon o električnem pretoku



Število silnic, ki prebada S_1 ali S_2 je enako.

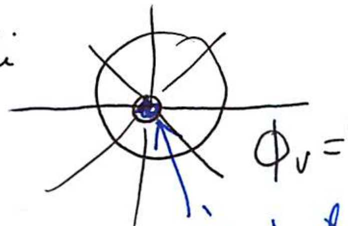
Ali iz oblike ~~silnic~~ porazdelitve silnic lahko sklepamo na porazdelitev naboja?

$$\Phi_e = \varepsilon_0 \oint \vec{E}\, d\vec{S} = e$$

električni pretok je enak naboju, ki ga objamemo z zaključeno ploskvijo

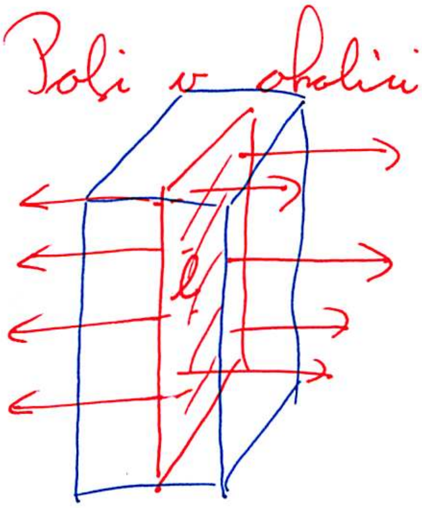
Podobno kot tokovnice pri pretoku tekočine, si lahko mislimo, da tudi el. silnice predstavljajo tok električnega polja. $\Phi_v = \vec{v} \cdot \vec{S}$; $\Phi_e = \varepsilon_0 \oint \vec{E}\, d\vec{S}$

ali



$$\Phi_v = \oint \vec{v}\, d\vec{S}$$

Polje v okolici ravne plošče:



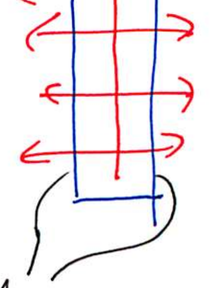
$\vec{E}$

$$e = \varepsilon_0 \oint \vec{E}\, d\vec{S}$$

$$e = \varepsilon_0\, E \cdot 2S$$

$$\boxed{E = \frac{e}{\varepsilon_0 2S}} = \frac{\sigma}{2\varepsilon_0}$$

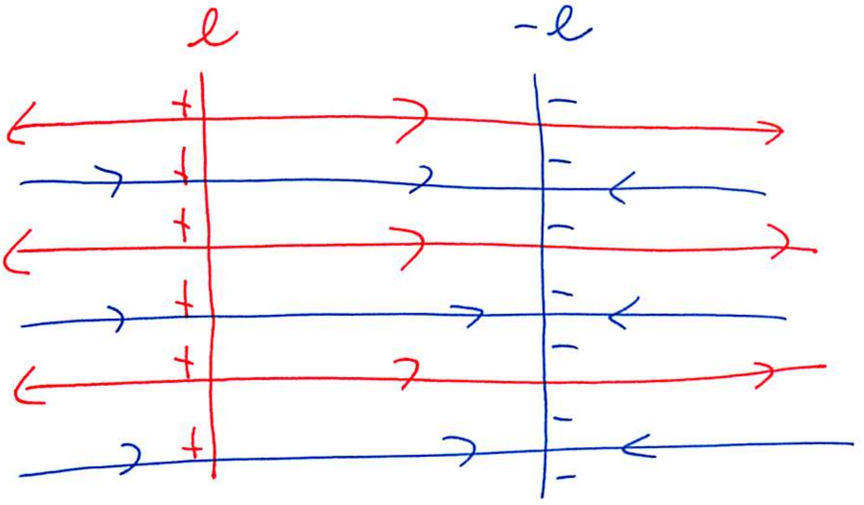
Pogled od strani



dve strani => 2S

$\sigma = \frac{e}{S}$: površinska gostota naboja 0.

Kondenzator



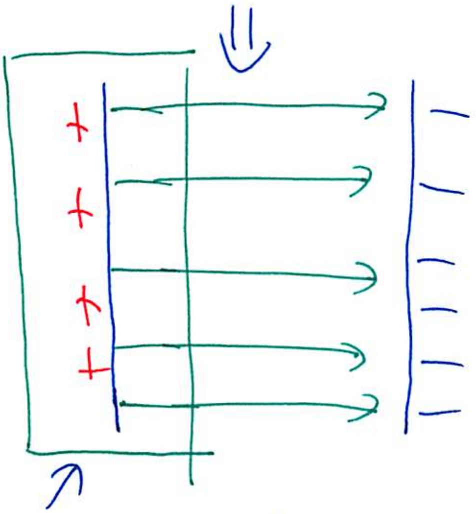
$$\boxed{E = \frac{\sigma}{2\varepsilon_0} - \frac{-\sigma}{2\varepsilon_0} = \frac{\sigma}{\varepsilon_0}}$$

Prispevek ⊕ plošče

Prispevek ⊖ plošče

oziroma: $\boxed{E = \frac{e}{\varepsilon_0 S}}$

$\Downarrow$

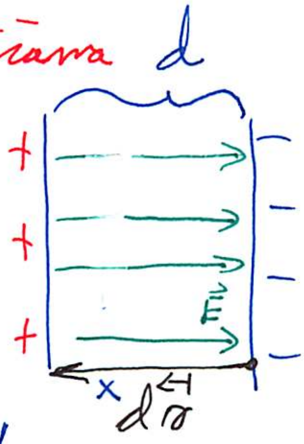


Zunaj ni $\vec{E}$ polja!

alternativna izpeljava: $e = \varepsilon_0 \oint \vec{E}\, d\vec{S} = \varepsilon_0 E S$

$\Rightarrow E = \frac{e}{\varepsilon_0 S}$; le en S, saj zunaj ni el. polja!

Napetost med ploščama kondenzatorja?



$\Rightarrow U = Ed = \frac{e\,d}{\varepsilon_0 S}$

$U = -\int_{\ominus} \vec{E}\, d\vec{r} = Ed$

od ⊖ do ⊕ druge plošče

$e = C\,U$; $\boxed{C = \frac{\varepsilon_0 S}{d}}$

$$U = -\int \vec{E}\, d\vec{r} = \int_{\ominus\, 0}^{\oplus\, d} E\, dx = Ed$$

Kapaciteta kondenzatorja

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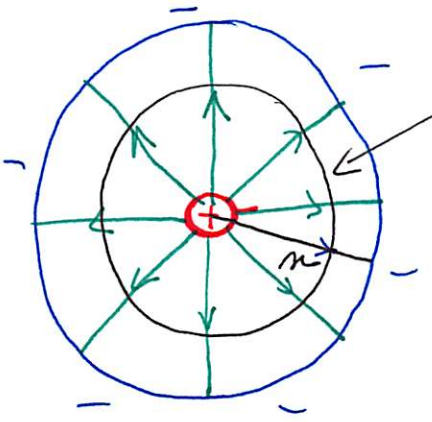
Kapaciteta valjastega kondenzatorja



$$e = \varepsilon_0 \int \vec{E}\, d\vec{S} = \varepsilon_0 E\, 2\pi r\, l$$

$E(r)$ je konstanten pri fiksnem r

l: dolžina kondenzatorja

$$E = \frac{e}{2\pi \varepsilon_0 r\, l}$$

Velja za $\vec{E}$ polje v valjastem kondenzatorju!

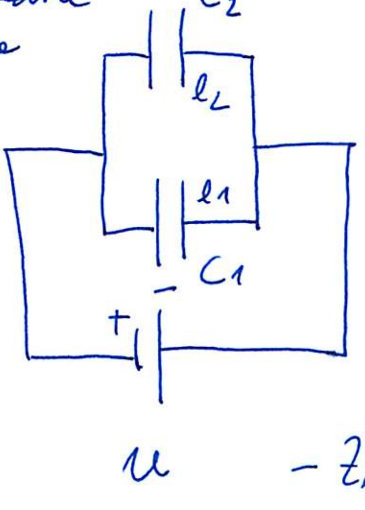
$$U = -\int_R^r \vec{E}\, d\vec{r} = -\frac{e}{2\pi\varepsilon_0 l}\int_R^r \frac{dr}{r} = \frac{e}{2\pi\varepsilon_0 l} \ln\frac{R}{r}$$

$$e = \frac{2\pi\varepsilon_0 l}{\ln\frac{R}{r}}\, U \Rightarrow \boxed{C = \frac{2\pi\varepsilon_0 l}{\ln\frac{R}{r}}}$$

Kapaciteta valjastega kondenzatorja

Vezava kondenzatorjev

- Vzporedna vezava



$e_1 = C_1 U$

$e_2 = C_2 U$

Nadomestna kapaciteta

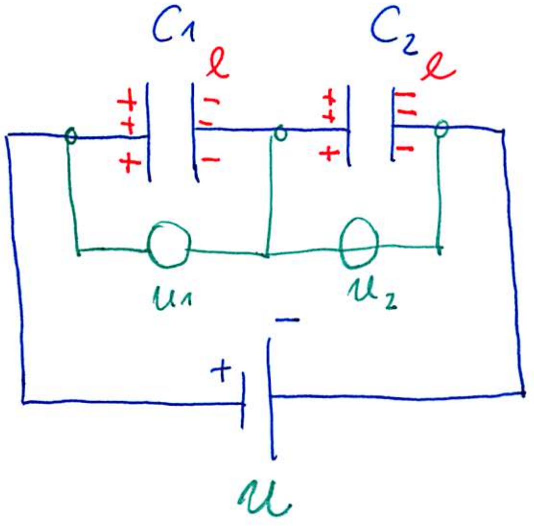
$$C_n = C_1 + C_2$$

$$e_1 + e_2 = (C_1 + C_2)\, U = \textcircled{e}$$

celotni naboj na obeh kondenzat.

- Zdi se, kot da bi se seštevale površine!

Zaporedna vezava:



$$e = C_1 U_1$$

$$e = C_2 U_2$$

$$\frac{e}{C_1} + \frac{e}{C_2} = U_1 + U_2 = U$$

$$\frac{e}{C_n} = U \Rightarrow$$

Napetost se razdeli: $U = U_1 + U_2$

$$C_n = \left(\frac{1}{C_1} + \frac{1}{C_2}\right)^{-1}$$

Energija kondenzatorja:

$A = e U$: delo je enako spremembi el. pot. energiji

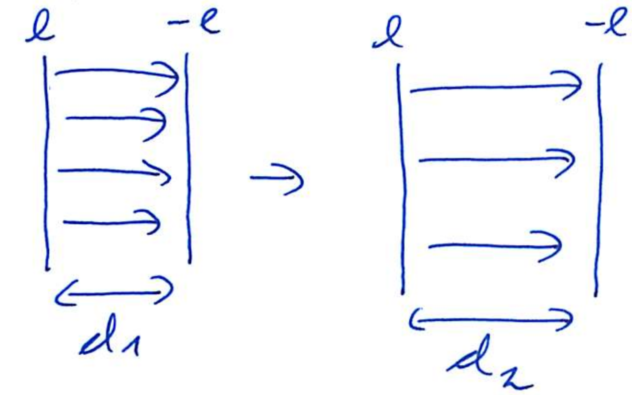
Toda $U = U(e)$; saj velja $U = \frac{e}{C}$

$$\Rightarrow A = \int_{e_1}^{e_2} U \, de = \int_{e_1}^{e_2} \frac{e \, de}{C} = \frac{e_2^2}{2C} - \frac{e_1^2}{2C} = W_{c_2} - W_{c_1}$$

$$W_c = \frac{e^2}{2C} = \frac{C}{2} U^2 = \frac{Ue}{2}$$

Energija kondenzatorja (nabitega)

Primer: Koliko dela opravimo, če razmaknemo dve izolirani, nabiti plošči kondenzatorja



$$A = W_{c_2} - W_{c_1} =$$

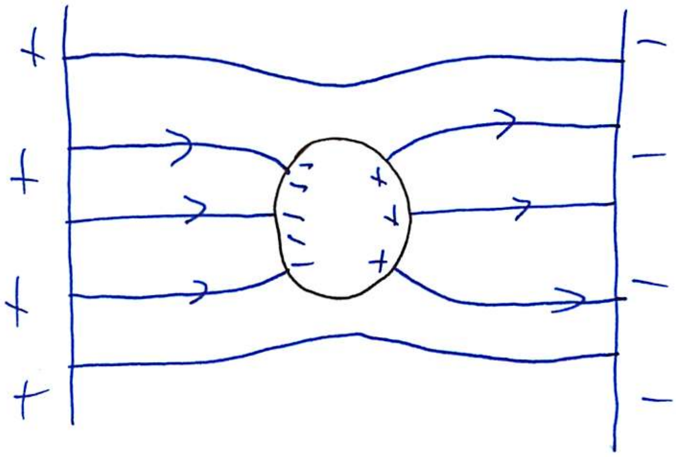
$$= \frac{e^2}{2}\left(\frac{1}{C_2} - \frac{1}{C_1}\right) =$$

$$= \frac{e^2}{2\varepsilon_0 S}(d_2 - d_1)$$

Snov v električnem polju:

a.) Prevodnik

- V kovini ni $\vec{E}$ polja če ni el. toka
- Silnice so ⊥ na površino kovine

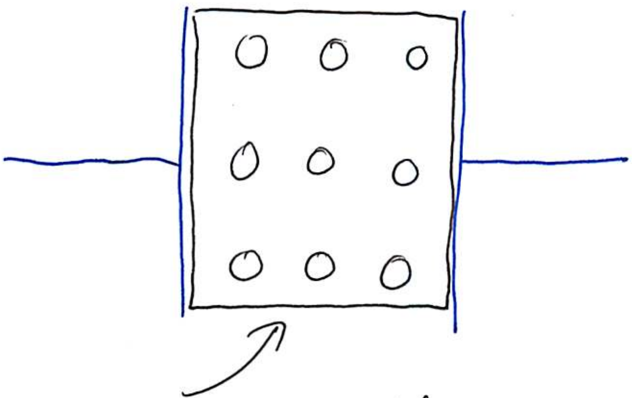


- V notranjosti kovine ni $\vec{E}$ polja (zaradi influence) in če ni nabojev!

— o —

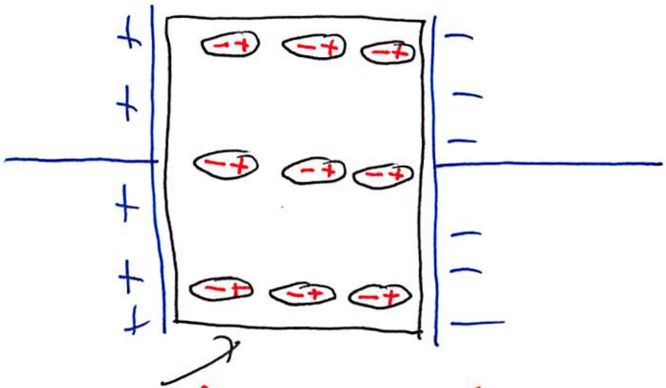
b.) Izolator:

ni $\vec{E}$ polja



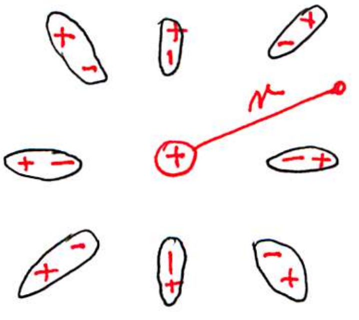
nepolarne molekule

je $\vec{E}$ polje



molekule se polarizirajo ⇒ $\vec{E}$ polje se "zasenči" ali zmanjša

el. naboj v dielektriku



$$E = \frac{e}{4\pi\varepsilon\varepsilon_0 r^2}$$

$$\vec{E} = \frac{e}{\varepsilon\varepsilon_0 S}$$

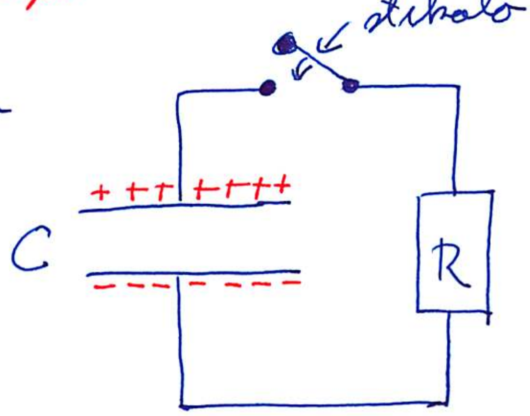
ε: dielektričnost

snov	ε
steklo	5-7
voda	81

Praznenje in polnenje kondenzatorja

– Praznenje

Kako hitro se sprazni kondenzator preko upora in določi I(t)

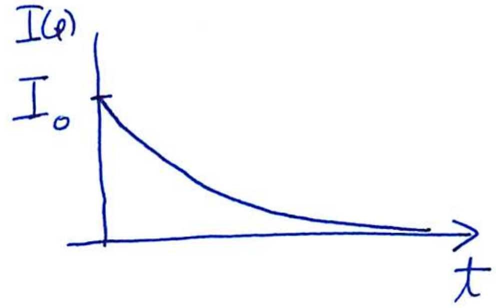


$$U_c + U_R = 0$$

$$\frac{e}{C} + IR = 0 \quad \Big| \frac{d}{dt}$$

$$\frac{I}{C} + \frac{dI}{dt}R = 0 \Rightarrow \int_{I_0}^{I} \frac{dI}{I} = -\int_{0}^{t} \frac{dt}{RC} = -\frac{t}{RC}$$

$$\ln\frac{I}{I_0} = -\frac{t}{RC} \Rightarrow I = I_0 e^{-\frac{t}{RC}}$$



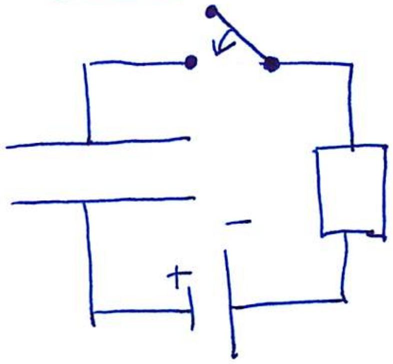
Kaj pa I_0?

$$I(t=0) = I_0 \Rightarrow \boxed{I_0 = -\frac{e}{RC}}$$

– Polnenje:

$$U = IR + \frac{e}{C} \;;\; U = \text{konst}$$

$$0 = \frac{dI}{dt}R + \frac{I}{C} \Rightarrow I = I_0 e^{-\frac{t}{RC}}$$

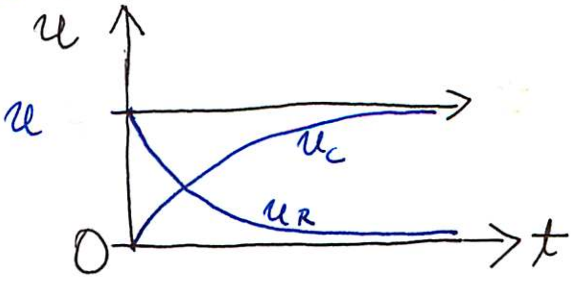


$$U_c = U - IR = U - I_0 R e^{-\frac{t}{RC}}$$

$$U_c(t=0) = 0 \Rightarrow U_c(t=0) = U - I_0 R = 0 \Rightarrow I_0 = \frac{U}{R}$$

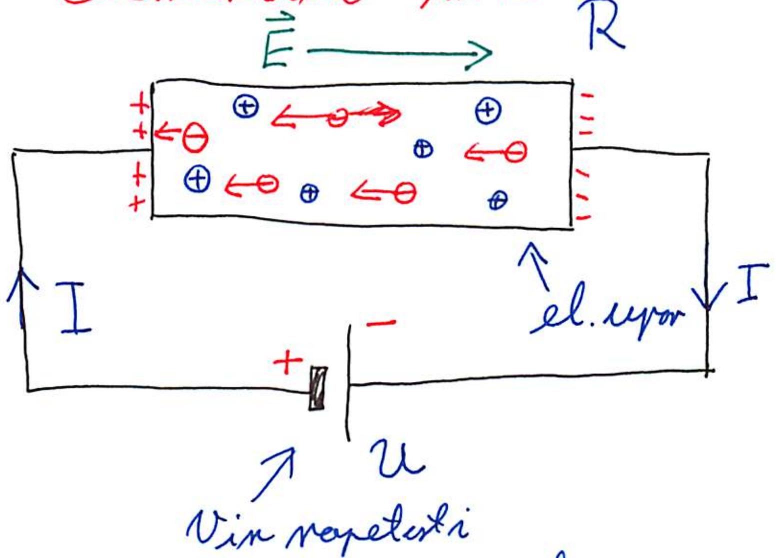
$$U_c = U\left(1 - e^{-\frac{t}{RC}}\right)$$

$$U_R = +U e^{-\frac{t}{RC}}$$



Električni tok

Model

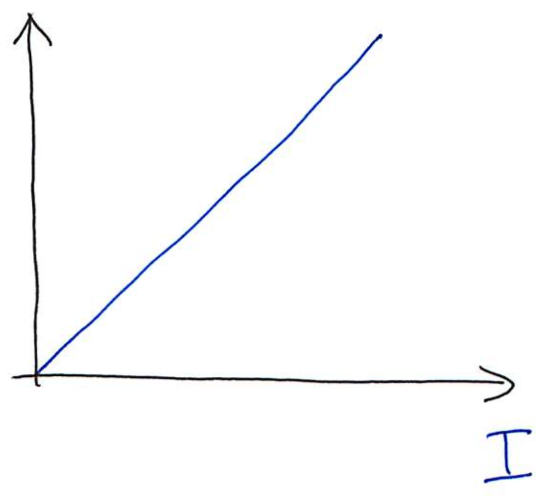


- Po vezju teče električni tok I

$I = \frac{de}{dt}$ $\left[\frac{As}{s} = A \right]$; I: množina naboja, ki gre skozi presek žice (upora) na časovno enoto

- V snovi (prevodniku) po katerem teče el. tok je električno polje E
- V trdni snovi se premikajo le elektroni (e^-) z negativnim nabojem ter v obratni smeri električnega toka
- Kljub konstantni sili na e^- se e^- v povprečju premikajo enakomerno!

$$U = I R$$



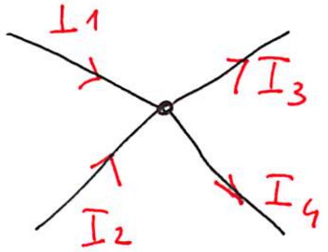
Ohmov zakon; R $\left[\frac{V}{A} = \Omega \right]$

Ω: 1 Ohm! enota za upor.

Kirchhoffovi zakoni

a.) Za tokove:

$$I_1 + I_2 = I_3 + I_4$$



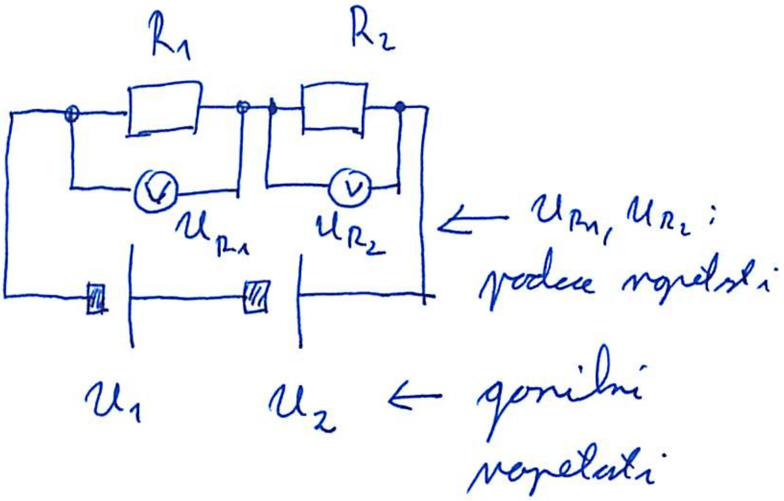
Vsota tokov, ki tečejo v razvejišče je enaka vsoti tokov, ki tečejo iz razvejišča!

b.) Za napetosti

$$\sum U_g = \sum U_p$$

g: vsota gonilnih napetosti

p: vsota padcev napetosti



Vezave uporov:

a.) Zaporedna vezava:

indeks!

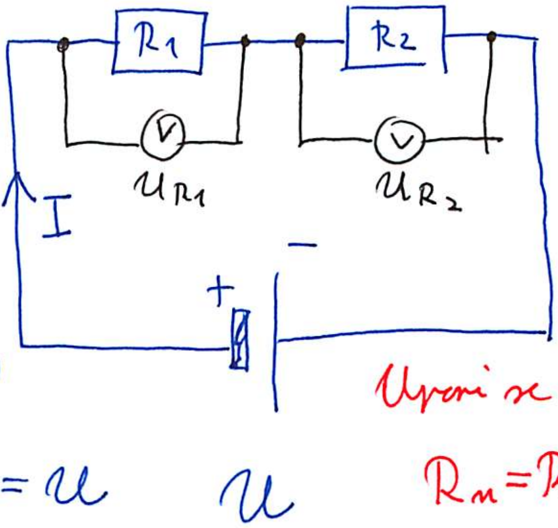
$$U_{R_1} + U_{\boxed{R_2}} = U$$

Kirchhoffov zakon za napetosti!

$$U_{R_1} = I \cdot R_1 ; \quad U_{R_2} = I \cdot R_2$$

Ohmova zakona za posamezni upor!

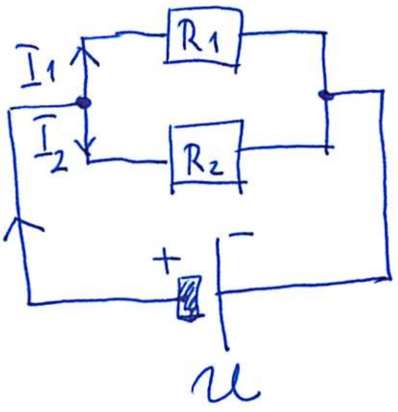
$$IR_1 + IR_2 = U \Rightarrow \overbrace{(R_1 + R_2)}^{R_n} I = U$$



Upori se seštevajo

$$R_n = R_1 + R_2$$

b.) Vzporedna vezava:



$I = I_1 + I_2$ Kirch. zak. za tokove

$U_{R_1} = U$ in $U_{R_2} = U$

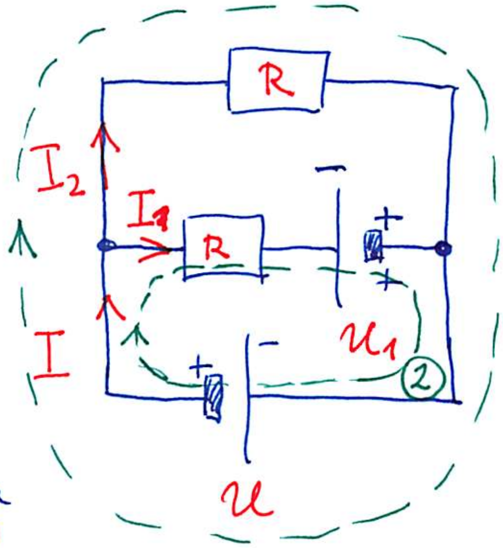
Na vsakem uporu je padec napetosti enak napetosti na izviru (gonilni napetosti)

$$(I = I_1 + I_2)$$

$$\left.\begin{aligned} U &= U_{R_1} = I_1 \cdot R_1 \\ U &= U_{R_2} = I_2 R_2 \end{aligned}\right\} \quad I = \frac{U}{R_1} + \frac{U}{R_2} = \underbrace{\left(\frac{1}{R_1}+\frac{1}{R_2}\right)}_{\frac{1}{R_n}} U$$

$\frac{1}{R_n} = \frac{1}{R_1} + \frac{1}{R_2}$ Seštevajo se recipročne vrednosti uporov!

c.) Zgled - primer več gonilnih napetosti



$I = I_1 + I_2$

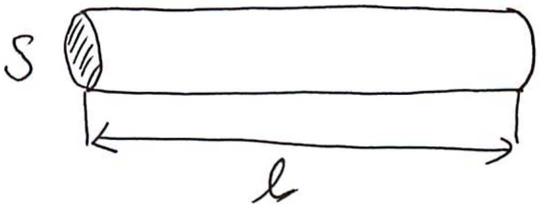
① $U = I_2 \cdot R$ Kirch. zakona za dva tokokroga!

② $U + U_1 = I_1 R - \cancel{I_2 R}$

Podatki: U, U_1 in R

$$I = \frac{U+U_1}{R} + \frac{U}{R} = \frac{2U+U_1}{R}$$

Specifični upor:



$R = \rho \frac{l}{S}$;

	ρ	$[\Omega mm^2/m]$
Ag	0,015	
Cu	0,017	
Al	0,026	
Fe	0,1	

* * *

Električna moč:

$A = U \cdot e$ Delo električne sile

$dA = U\, de \; /: dt$

$P = U I$

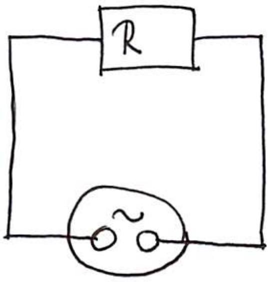
$\frac{dA}{dt} = P = U \frac{de}{dt} = U \cdot I$ ↑ električna moč

Pomembno: $P = U \cdot I$, U: padec napetosti na porabniku ter I: el. tok skozi porabnik!

Če upoštevamo še $U = I R$, velja tudi:

$$P = U I = \frac{U^2}{R} = I^2 \cdot R \; !$$

Izmenična napetost in tok - Ohmski upor



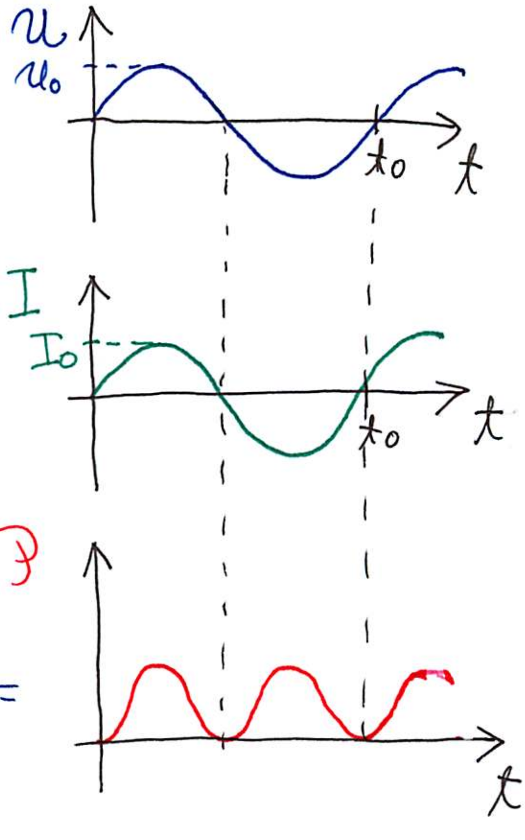
$U = U_0 \sin \omega t$

$$U = I \cdot R$$

$$U_0 \sin \omega t = I \cdot R$$

$$I = \frac{U_0}{R} \sin \omega t = I_0 \sin \omega t$$

U in I nihata v fazi → sočasna



Moč: $P = U \cdot I$

$$P(t) = U_0 I_0 \sin^2 \omega t$$

Moč niha v času, vendar $P(t) > 0$!

Povprečna moč:

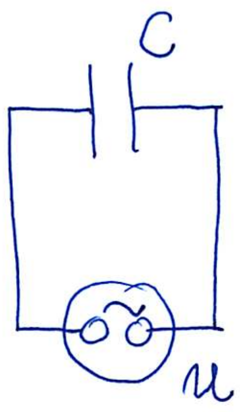
$$\overline{P} = \frac{1}{t_0} \int_0^{t_0} P(t)\, dt = \frac{U_0 I_0}{t_0} \int_0^{t_0} \sin^2(\omega t)\, dt =$$

$$= \frac{U_0 I_0}{t_0} \int_0^{t_0} \frac{1}{2}(1 - \cos 2\omega t)\, dt = \frac{U_0 I_0}{t_0} \left[\frac{t}{2} - \frac{\sin 2\omega t}{2 \cdot 2\omega} \right]_0^{t_0} =$$

$\omega = \frac{2\pi}{t_0}$!

$$= \frac{U_0 I_0}{2} \; ; \; \overline{P} = \frac{U_0 I_0}{2} = \frac{U_0}{\sqrt{2}} \frac{I_0}{\sqrt{2}} = U_{ef} I_{ef}$$

Izmenični tok skozi kondenzator



$u = u_0 \sin\omega t$

$$u = \frac{e}{C} \quad \text{oziroma} \quad e = C\cdot u$$

napetost na izviru ↑ u

padec napetosti na kondenzatorju ↑ $\frac{e}{C}$

$$e = C\cdot u \,\Big|\, \frac{d}{dt} \quad ; \quad I = \frac{de}{dt} \,!$$

$$I = C\,\frac{du}{dt} = C\omega u_0 \cos\omega t = I_0 \cos\omega t$$

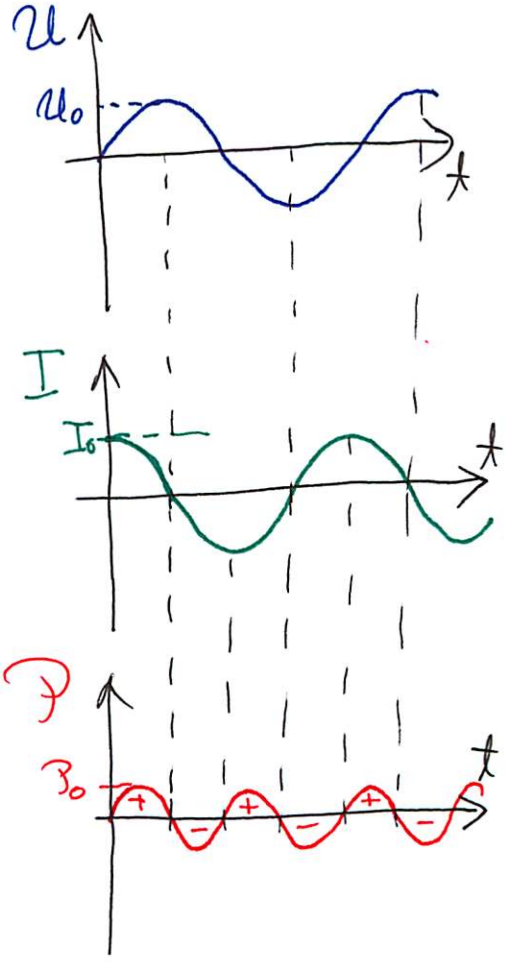
$$\Rightarrow \quad u_0 = \frac{I_0}{C\omega} = R_C I_0 \; ; \quad \boxed{R_C = \frac{1}{C\omega}}$$: upor kondenzatorja

Moč, ki se troši na kondenzatorju:

$$P = u\cdot I = u_0 I_0 \sin\omega t \cos\omega t$$

$$P = \frac{u_0 I_0}{2} \sin 2\omega t$$

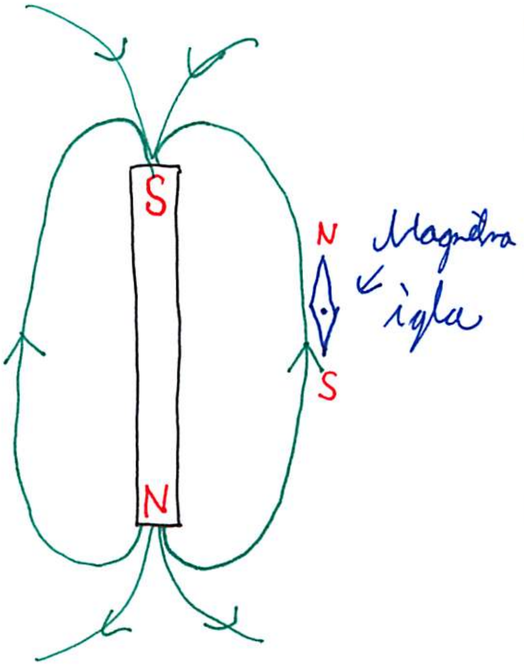
$$\overline{P} = \frac{1}{t_0}\int_0^{t_0} \frac{u_0 I_0}{2} \sin 2\omega t = 0 \,!$$

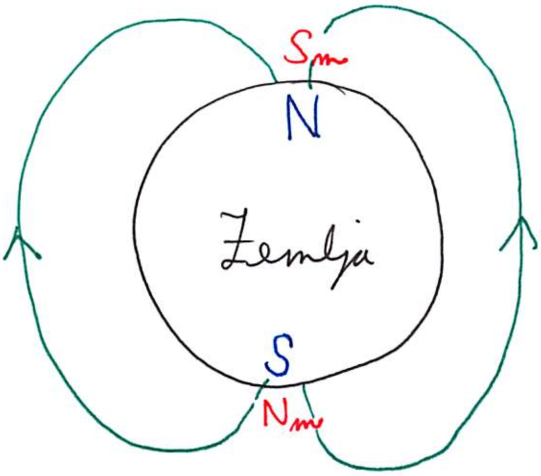


- Železni opilki
-

Magnetno polje

S južni magnetni pol }
N severni magnetni pol }

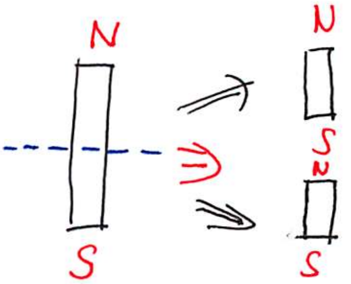




Silnice magnetnega polja lahko "otipamo" s pomočjo magnetne igle

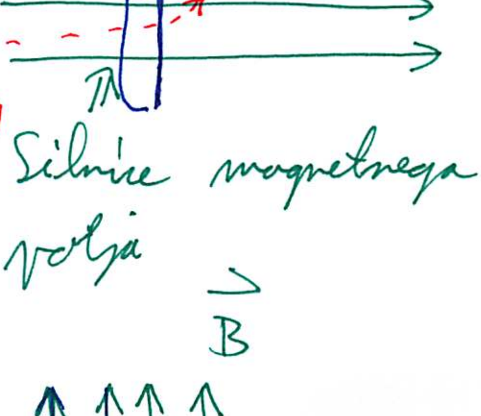
Magnetni monopoli ne obstajajo:

– Če presekamo magnet na dva dela, dobimo dva magneta



Sila na vodnik v $\vec{B}$

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



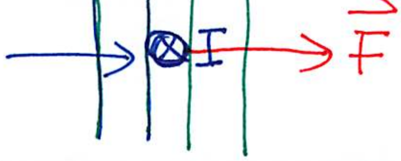
Sila kaže "gor"!

Silnice magnetnega polja

Enota?

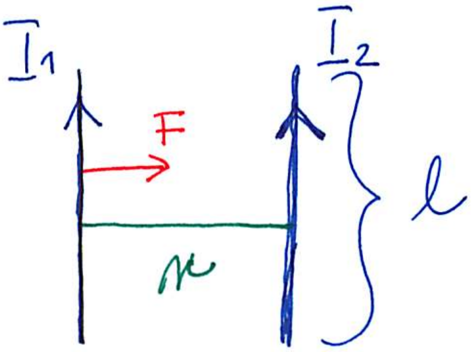
$$B = \frac{F}{Il} \left[\frac{N}{Am}\frac{m}{m} = \frac{\cancel{A}Vs}{\cancel{A}m^2} = \frac{Vs}{m^2} = 1T \right]$$

↑ gostota magnetnega polja se meri v Teslih!



vodnik s tokom!

Sila med vodnikoma s tokom



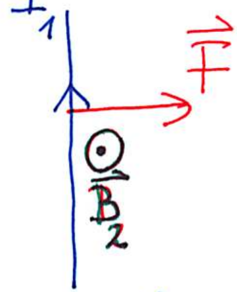
$$\boxed{F = \frac{\mu_0\, l\, I_1 I_2}{2\pi\, r}}$$

μ_0: magnetna permeabilnost vakuuma $\mu_0 = 4\pi \cdot 10^{-7}\,\frac{Vs}{Am}$

r: razdalja med paralelnima vodnikoma

I_1, I_2: tokova, ki tečeta v vodnikih

l: dolžina



Povezava z enačbo: $F = I\,l\,B$

Vzemimo, da drugi vodnik povzroči magnetno polje B_2 na mestu prvega vodnika $\Rightarrow F = I_1\, l\, B_2$

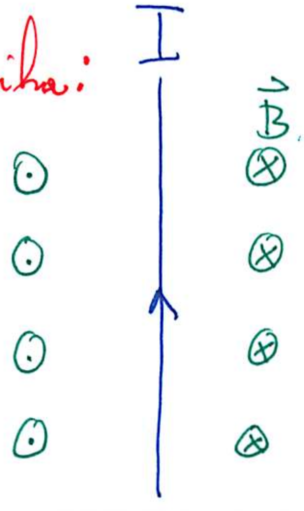
primerjajmo enačbi: $F = \mu_0 \frac{l\, I_1 I_2}{2\pi r}$

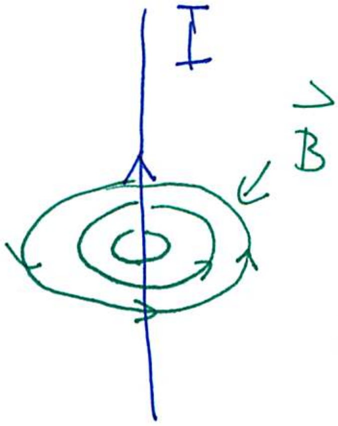
ter $F = I_1\, l\, B_2 \Rightarrow B_2 = \frac{\mu_0 I_2}{2\pi r}$

Ugotovitev posplošimo:

B v okolici neskončnega ravnega vodnika:

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

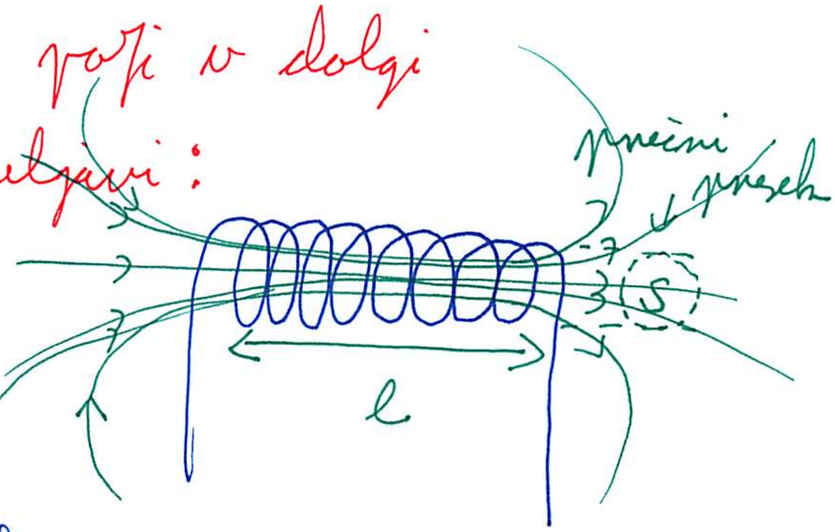




Risano v projekciji

Magnetno polje v dolgi tuljavi:

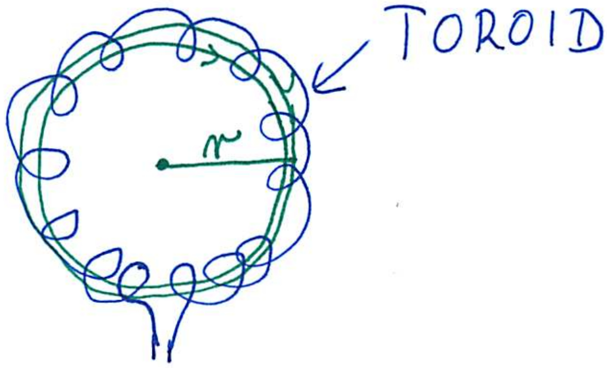
$$B = \frac{\mu_0 N I}{l}$$



Znotraj tuljave je $\vec{B}$ homogeno in usmerjeno vzdolž tuljave.

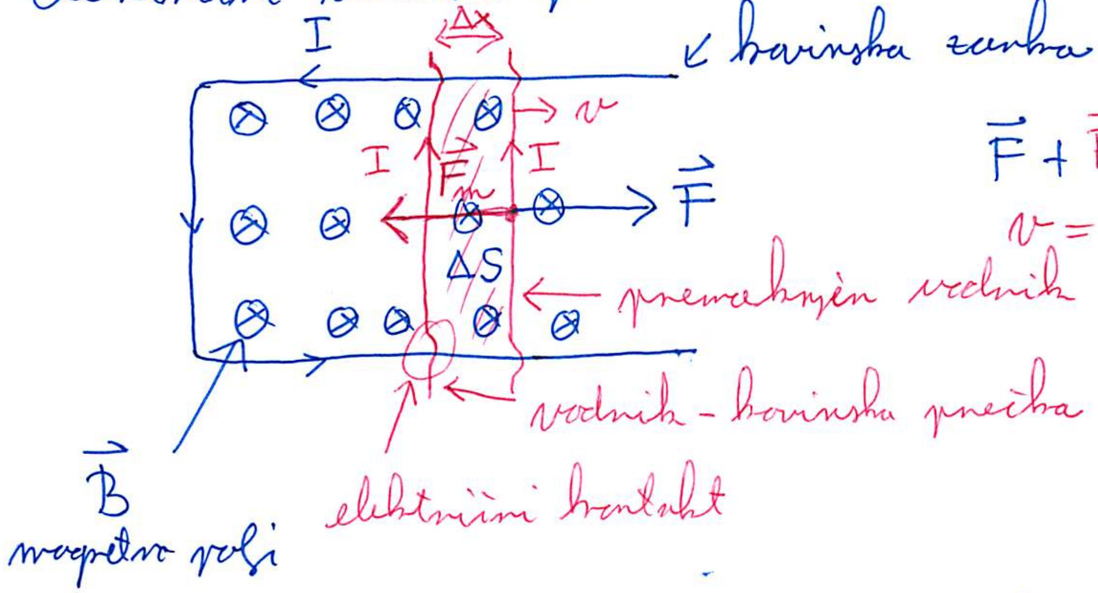
V toroidu:

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



Indukcija

Električni vodnik premikamo skozi magnetno polje



$$\vec{F} + \vec{F}_m = 0$$

v = konstantna

$$\Delta x = v \cdot \Delta t$$

Preko zanke ter prečke začne teči električni tok

$$\vec{F}_m = I \vec{l} \times \vec{B} \qquad F_m = F = I l B$$

Delo sile F v času Δt: $\Delta A = F \Delta x = F v \Delta t$

Električno delo: $\Delta A = P \cdot \Delta t = \boxed{U_i} I \Delta t$

U_i: Inducirana napetost (napetost, ki poganja el. tok na obroču)

Izenačimo električno delo z mehanskim delom sile F:

$$\underline{U_i I \Delta t} = F v \Delta t = \underline{I l B v \Delta t}$$

$$U_i = l v B = \frac{\overbrace{l \Delta x}^{\Delta S}}{\Delta t} B = \frac{\overbrace{\Delta S B}^{\Delta \Phi_m}}{\Delta t}$$

$$U_i = l v B \quad \text{ali} \quad U_i = \frac{\Delta \Phi_m}{\Delta t} \Big\}$$ sprememba magnetnega pretoka na časa.