FIZIKA II

1 UNI

Zapiski predavanj

Šolsko leto	2010/2011
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Skeniranje	Damjan Sirnik

STROMAR.SI

DRUŠTVO ELEKTROTEHNIKOV

UREJANJE DOKUMENTA	
VERZIJA	01.01
DATUM	23.5.2012

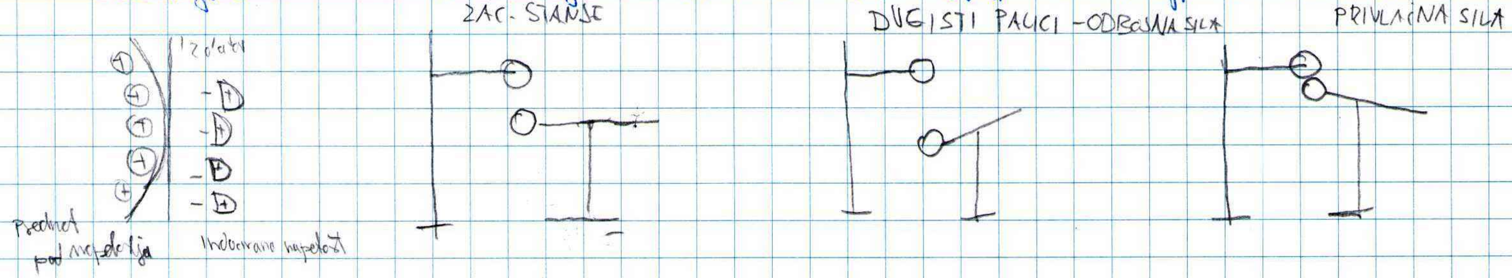
OPOMBE

21.2.11

ELEKTRON → JANTAR

Papir je izolator a se kljub tem nalepi na naelektreno palico zaradi influence.

Razlikujemo + in − el. naboj. Protoni in elektroni. Proton 2000 težji od elektrona



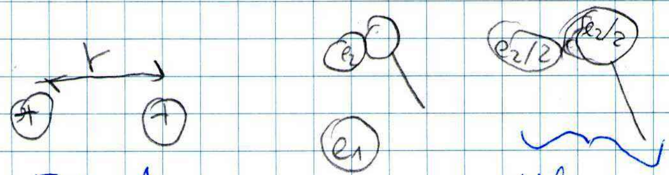
← ⊖ ⊖ → } Odbojna sila

← ⊕ ⊕ → }

⊖ → ← ⊕ } Privlačna sila

$e_0 = 1,6 \cdot 10^{-19}$ As

Sila el. pada s kvadratom razdalje.



$F \propto \frac{1}{r^2}$

$F \propto e_2$

$F \propto e_1$

$F \propto \frac{e_1 e_2}{r^2}$

Naboj se porazdeli če imate krogli enake r, pade naboj za polovico

Coulombov zakon

$$\boxed{F = K \cdot \frac{e_1 e_2}{r^2}}$$

K = Coulombova konstanta $= 9 \cdot 10^9 \; N \cdot m^2/(As)^2$

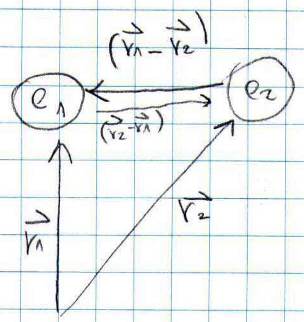
$K = \frac{1}{4\pi\varepsilon_0}$

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

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

Nima veze z dielektričnosti; nanaša se na lastnost praznega prostora.

$c_0 = \frac{1}{\sqrt{\varepsilon_0 \mu_0}} \approx 3 \cdot 10^8$ m/s

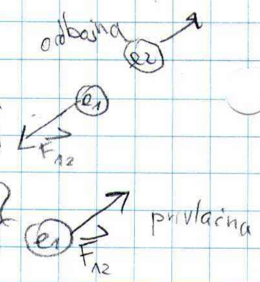


$$\vec{F}_{12} = \frac{e_1 e_2}{4\pi\varepsilon_0 r_{12}^2}\underbrace{\left(\frac{\vec{r}_{12}}{r_{12}}\right)}_{\text{enotni vektor}}$$

$$\left|\frac{\vec{r}_{12}}{r_{12}}\right| = 1$$

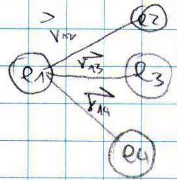
$$\vec{F}_{21} = \frac{e_1 e_2}{4\pi\varepsilon_0 r_{21}^2}\left(\frac{\vec{r}_{21}}{r_{21}}\right)$$

$e_1>0, e_2>0 : e_1e_2>0$
$e_1<0, e_2<0 : e_1e_2>0$
$e_1>0, e_2<0 : e_1e_2<0$
$e_1<0, e_2>0 : e_1e_2<0$



$$\boxed{\vec{F}_{21} = -\vec{F}_{12} \Rightarrow \vec{F}_{12} + \vec{F}_{21} = 0}$$

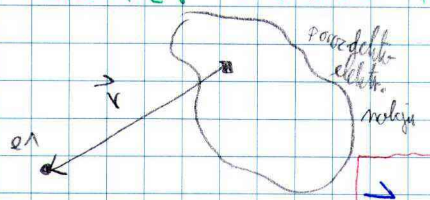
POSPLOŠITEV:



$$\vec{F}_1 = \sum_{j=2}^{n} \frac{e_1 e_j}{4\pi\varepsilon_0 r_{1j}^2}\left(\frac{\vec{r}_{1j}}{r_{1j}}\right)$$

n – št. nabojev v sistemu

POSPLOŠITEV V OKVIRU KONTINUUMSKEGA NABOJA



$$\sum_j \rightarrow \int \qquad r_{1j} \rightarrow r \qquad e_j \rightarrow de$$

$$\boxed{\vec{F}_1 = \int \frac{e_1 de}{4\pi\varepsilon_0 r^2}\left(\frac{\vec{r}}{r}\right)}$$

$\rho = \frac{de}{dV} \Rightarrow de = \rho dV$

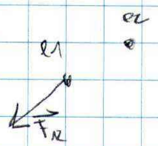
$\sigma = \frac{de}{dA} \Rightarrow de = \sigma dA$

$\varsigma = \frac{de}{dl} \Rightarrow de = \varsigma dl$

ELEKTRIČNO POLJE (JAKOST EL. POLJA $\vec{E}$)

$$\vec{F}_{12} = \frac{e_1 e_2}{4\pi\varepsilon_0 r_{12}^2}\left(\frac{\vec{r}_{12}}{r_{12}}\right)$$

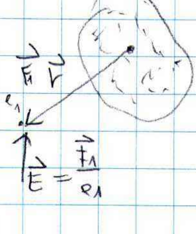
$$\vec{E}_2 = \frac{\vec{F}_{12}}{e_1} = \frac{e_2}{4\pi\varepsilon_0 r_{12}^2}\left(\frac{\vec{r}_{12}}{r_{12}}\right)$$



POSPLOŠITEV:

$$\vec{F}_1 = \int \frac{e_1 de}{4\pi\varepsilon_0 r^2}\left(\frac{\vec{r}}{r}\right)$$

$$\vec{E} = \frac{\vec{F}_1}{e_1} = \int \frac{de}{4\pi\varepsilon_0 r^2}\left(\frac{\vec{r}}{r}\right)$$



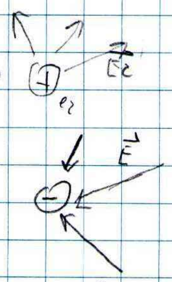
$e_1 \equiv$ testni naboj

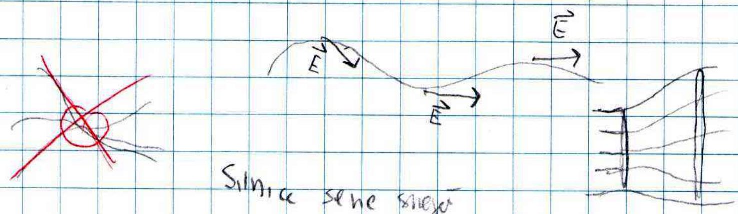
Testni naboj mora biti čim manjši, da ne zmoti porazdelitve. Velikost test naboja bi morala iti proti 0, ampak manjši kot e_0 ne more biti

Kvarki - delci z nabojem manjšim od e_0 ($1/3$, $2/3$ e_0 ipd.)

$$\boxed{\vec{F} = e\vec{E}}$$

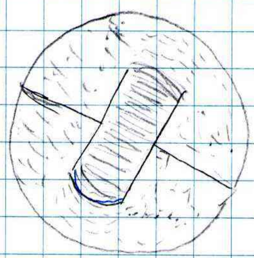
→ Sila na el. naboj v el. polju jakosti $\vec{E}$



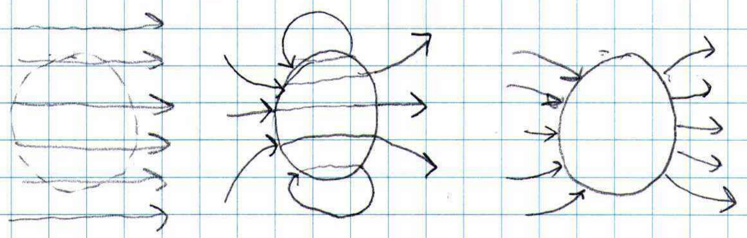


Silnice se ne sekajo
oz. ne morejo sekat ker bi polje
potem imela dve smeri

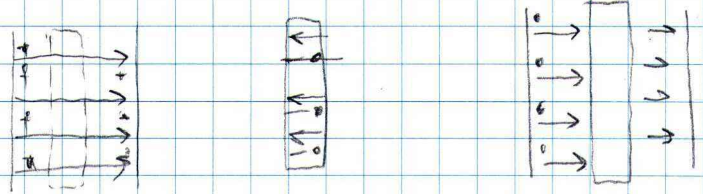
VAN DER GRAFOV GENERATOR



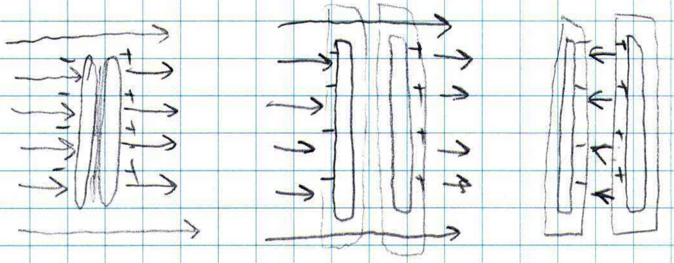
INFLUENCA



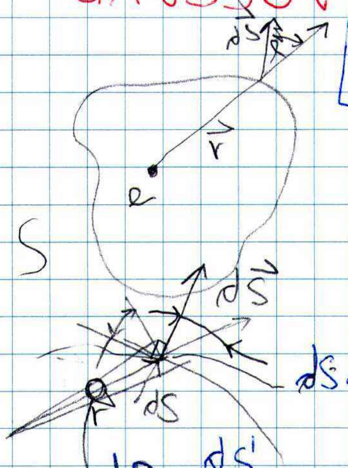
Površina prevodnika postane ekvipotencialna ploskev



NEPOSREDNA MERITEV GOSTOTE EL. POLJA



GAUSSOV ZAKON O ELEKTRIČNEM PRETOKU



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

$$\oint_A \vec E\cdot d\vec S = \oint \frac{e\vec r\cdot d\vec S}{4\pi\varepsilon_0 r^3} = \oint \frac{e\,\overbrace{dS\cos\varphi}}{4\pi\varepsilon_0 r^2} = \frac{e}{4\pi\varepsilon_0}\oint \frac{dS'}{r^2}$$

$$= \frac{e}{4\pi\varepsilon_0}\oint d\Omega = \frac{e}{4\pi\varepsilon_0}4\pi = \frac{e}{\varepsilon_0}$$

$\Omega = \frac{4\pi R^2}{R^2} = 4\pi$

$d\Omega = \frac{dS}{R^2}$

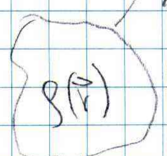
$dS\cos\varphi = dS'$

$$\boxed{\oint \vec E\cdot d\vec S = \frac{e}{\varepsilon_0}}$$

$d\Omega = \frac{dS'}{r^2}$

POSPLOŠITEV: $\boxed{\oint \vec E\cdot d\vec S = \frac{\sum_i e_i}{\varepsilon_0}}$

Druga oblika Coulombovega zakona, samo v drugi obliki



$\sum_i e_i \to \int \rho(\vec r)dV$

vol. gostota naboja

$$\boxed{\varepsilon_0 \oint_A \vec E\cdot d\vec S = \int_V \rho(\vec r)\,dV}$$

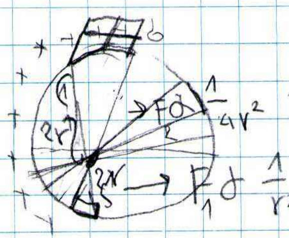
GAUSSOV ZAKON O EL. PRETOKU V INTEGRALNI OBLIKI

$\varepsilon_0 \vec\nabla\cdot\vec E = \rho(r)$ – v diferencialni obliki

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

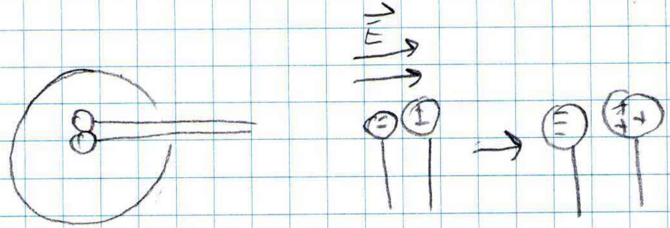
$\vec E = (E_x, E_y, E_z)$

Kjer velja Faradayeva kletka (če je tanek) potem velja Coulombov zakon



$F_2 \propto \frac{1}{4r^2} \, d\Omega (4r^2) \sigma \qquad R = 2r$

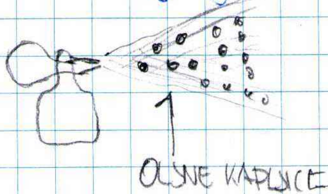
$F_1 \propto \frac{1}{r^2} \, d\Omega \, r^2 \sigma \qquad R = 4r$

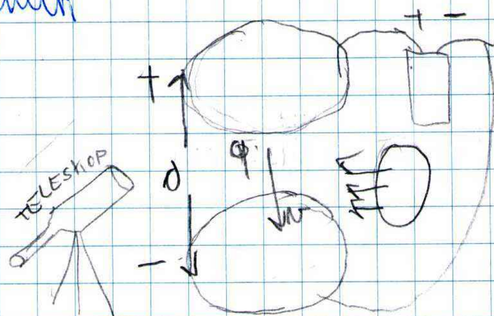


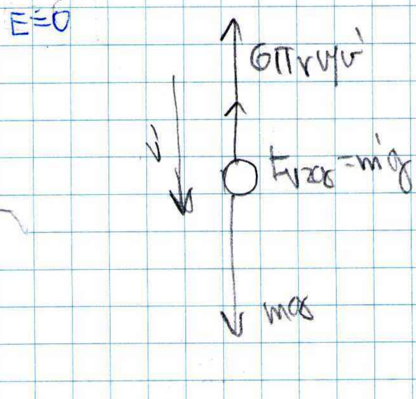
MILLIKANOV POSKUS

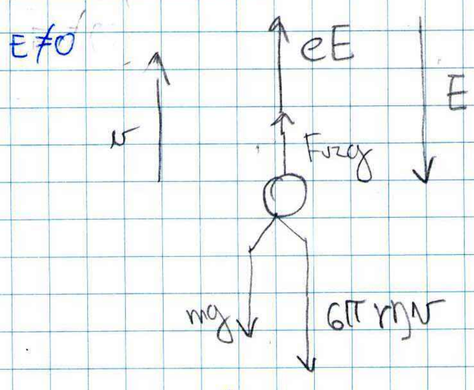
28.02.'11

- el. naboj je kvantiziran









ZA STACIONARNO STANJE: E=0

$$mg = m'g + 6\pi r \eta v'$$

ZA E≠0:

$$eE + m'g = mg + 6\pi r \eta v$$

$$m = \frac{4\pi r^3}{3} \rho_k$$

$$m' = \frac{4\pi r^3}{3} \rho_z$$

znano: $6\pi r \eta v' + \frac{4\pi r^3}{3} \rho_z g = \frac{4\pi r^3}{3} \rho_k g$

$$\Rightarrow 6\eta v' + \frac{4r^2}{3} \rho_z g = \frac{4r^2}{3} \rho_k g$$

$$6\eta v' = \frac{4gr^2}{2} (\rho_k - \rho_z)$$

$$\frac{9 v' \eta}{2g(\rho_k - \rho_z)} = r^2$$

$$\sqrt{\frac{9 v' \eta}{2g(\rho_k - \rho_z)}} = r$$

$$eE - 6\pi r \eta v' = 6\pi r \eta v$$

$$\Rightarrow eE = 6\pi r \eta (v + v')$$

$$\Rightarrow e = \frac{6\pi \eta r}{E} (v + v')$$

$e = n e_0$, $n = \pm 1, \pm 2, \pm 3$

$e_0 = 1{,}6 \cdot 10^{-19}\ As$

⇒ el. naboj ni zvezen, ampak

	(C)	(kg)
Elektron	$-1{,}602197\times10^{-19}$	$0{,}1005\times10^{-31}$
Proton	$+1{,}602197\times10^{-19}$	$1{,}67201\times10^{-27}$
Nevtron	0	$1{,}674192\times10^{-27}$

GIBANJE ELEKTRIČNIH NABOJEV V SNOVI (V EL. POLJU)

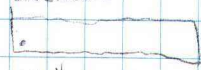
VAKUUM:
$\vec{E}\neq 0$

$$\underbrace{m\frac{d\vec{v}}{dt}}_{\vec{a}}=e\vec{E}\Rightarrow \vec{a}=\frac{e\vec{E}}{m}$$

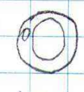
(VELJA ZA $\frac{v}{c_0}\lesssim 0{,}1$) c_0 … SVETL. HITROST

POSPEŠEVALNIKI

LINEAREN



KROŽEN

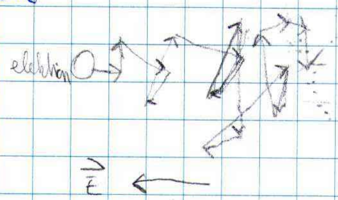


HITROST NE MORE BIT VEČJA OD SVETLOBNE HITROSTI

GIBANJE NABOJA V KOVINI:

V KOVINI PREVODNI ELEKTRONI, KI TRKAJO V ATOME

pot. hitrosti je zelo majhna



$$m\frac{d\vec{v}}{dt}=e\vec{E}$$

$$\vec{F}_{ny}=-k\vec{v}$$

NEWTON:

$$m\frac{d\vec{v}}{dt}=e\vec{E}-k\vec{v}\,/m$$

$$\frac{d\vec{v}}{dt}=\frac{e}{m}\vec{E}-\frac{k}{m}\vec{v}\Rightarrow \boxed{\frac{d\vec{v}}{dt}+\frac{\vec{v}}{\tau}=\frac{e}{m}\vec{E}}$$

$\boxed{\tau=\frac{m}{k}}$ } RELAKSACIJSKI ČAS

$$\vec{E}=0:\ \frac{d\vec{v}}{dt}+\frac{\vec{v}}{\tau}=0$$

$$\int_{\vec{v}_0}^{\vec{v}}\frac{d\vec{v}}{\vec{v}}=-\int_0^t\frac{dt}{\tau}\Rightarrow \ln\vec{v}\Big|_{v_0}^{v}=-\frac{t}{\tau}\Rightarrow \boxed{\vec{v}=\vec{v}_0\cdot e^{-t/\tau}}$$

⇒ $\langle\rangle$ $\quad$ E – konst.

$$\Rightarrow \underbrace{\left\langle\frac{d\vec{v}}{dt}\right\rangle}_{0}+\frac{\langle\vec{v}\rangle}{\tau}=\frac{e}{m}\vec{E}$$

$$\Rightarrow \frac{\langle\vec{v}\rangle}{\tau}=\frac{e}{m}\vec{E}$$

RELAKSACIJSKI ČASI

Snov	τ [s]
kovina	$\sim10^{-14}$
vezele kovine v plinu	$\sim10^{-9}$
sončna korona	$\sim10^{2}$
nezvezdni plin	$\sim10^{5}$

GIBLJIVOST:

$$\rightarrow \beta=\left|\frac{e\tau}{m}\right|$$

$$\Rightarrow \boxed{\langle\vec{v}\rangle=\frac{e\tau}{m}E}$$

Ohmov zakon

$$\boxed{\langle\vec{v}\rangle=\mp\beta\vec{E}}$$

$$\vec{v}=\frac{e\tau}{m}\vec{E}$$

$$I=\frac{de}{dt}\qquad j=\frac{I}{S}=\frac{1}{S}\frac{de}{dt}$$

$$=\frac{1}{S}\frac{d(e_0 n V)}{dt}=\frac{1}{S}e_0 n\frac{dV}{dt}=\frac{1}{S}e_0 n S\frac{dx}{dt}=e_0 n v$$

$$n=\frac{N}{V}\ [m^{-3}]$$

$$e=e_0 n V=e_0\left(\frac{N}{V}\right)V$$

$$j=ne_0v$$

$$\boxed{\vec{j}=ne_0\langle\vec{v}\rangle}$$

$\vec{j} = n e_0 \langle \vec{v} \rangle \quad \vec{v} = \frac{e_0 \tau}{m} \vec{E}$

$\vec{j} = n e_0 \frac{e_0 \tau}{m} \vec{E}$

SPECIFIČNA PREVODNOST / UPORNOST

Ohmov ZAKON $\boxed{\vec{j} = \underbrace{\frac{n e_0^2 \tau}{m}}_{\sigma} \vec{E}}$ SPLOŠNA OBLIKA $\quad \sigma = \frac{n e_0^2 \tau}{m}$

$\Downarrow \quad \frac{I}{S} = \sigma \frac{U}{l} \qquad \left(\frac{l}{\sigma S}\right) I = U \quad \Rightarrow R = \frac{l}{\sigma S} \qquad \boxed{RI = U}$

$\boxed{\rho_{el} = \frac{1}{\sigma}} \qquad \boxed{\rho_{el} = \rho_0 [1 + \alpha (T - T_0)]}$

Upornost je odvisna od temperature

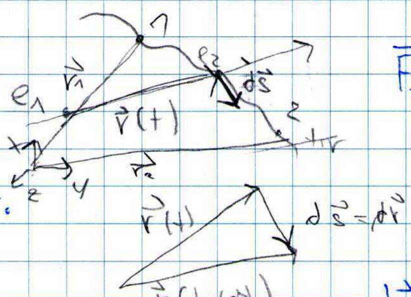
ELEKTROSTATSKA POTENCIALNA ENERGIJA

3.3.'11

$\boxed{A_{ost} = \Delta W_k + W_{gp}}$

Delo vseh ostalih sil razen gravitacijske

Delo vseh ostalih sil razen gravitacijske in električne:



$\vec{F}_e = \frac{e_1 e_2}{4\pi\varepsilon_0 r^2} \left(\frac{\vec{r}}{r}\right)$

$\vec{A}_{ost} + \int \vec{F_e} \cdot d\vec{s} = \Delta W_k + \Delta W_{gp}$

$d\vec{r} = \vec{r}(t+dt) - \vec{r}(t)$

Delo vseh $A_{ost} = \Delta W_k + \Delta W_{g,p} - \underbrace{\int \vec{F_e} \cdot d\vec{s}}$ → Negativno delo el. sile

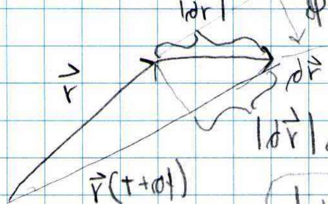
$$-\int \vec{F_e} d\vec{s} = -\int \vec{F_e} d\vec{r} = -\int \frac{e_1 e_2 \, \vec{r} \cdot d\vec{r}}{4\pi\varepsilon_0 r^2 r} = \int_{r_1}^{r_2} \frac{e_1 e_2 r dr}{4\pi\varepsilon_0 r^2 r} = \frac{e_1 e_2}{4\pi\varepsilon_0} \frac{1}{r}\Big|_{r_1}^{r_2} = \frac{e_1 e_2}{4\pi\varepsilon_0 r_2} - \frac{e_1 e_2}{4\pi\varepsilon_0 r_1}$$

$d(\vec{r} \cdot \vec{r}) = \vec{r} \cdot d\vec{r} + d\vec{r} \cdot \vec{r} = 2\vec{r}\, d\vec{r}$

$d(r^2) = 2r\,dr = 2\vec{r} \cdot d\vec{r} \qquad r = |\vec{r}|$

$r\,dr = \vec{r} \cdot d\vec{r} \qquad \vec{r} \cdot \vec{r} = r^2$

⇒ Ni odvisno po kateri poti gremo, ampak samo od r_1 in r_2



$\underline{\vec{r} \cdot d\vec{r}} = |\vec{r}||d\vec{r}| \cos\varphi = \underline{\underline{r\,dr}}$

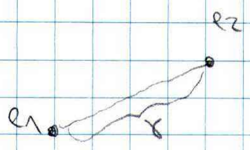
$|d\vec{r}| \cos\varphi = d|\vec{r}| = dr$

$|d\vec{r}| \neq d|\vec{r}|$

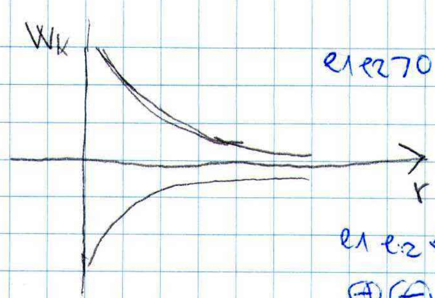
$W_{e2} - W_{e1} = \Delta W_e$

$\boxed{W_e = \frac{e_1 e_2}{4\pi\varepsilon_0 r}}$

Com Sol → Program



$W_e = \frac{e_1 e_2}{4\pi\varepsilon_0 r}$



$e_1 e_2 > 0$ ⊕⊕ / ⊖⊖

$e_1 e_2 < 0$ ⊕⊖

$A_{ost} = \Delta W_k + \Delta W_{p,p} - \underbrace{\int \vec F_e d\vec s}_{\Delta W_e}$

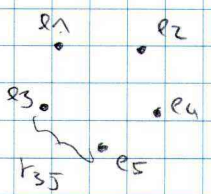
$\boxed{A_{ost} = \Delta W_k + \Delta W_{g,p} + \Delta W_e}$ POSPLOŠENO

$A_{ost} = 0 \Rightarrow \Delta W_k + \Delta W_{gp} + \Delta W_e = 0$

$\Delta(W_k + W_{gp} + W_e) = 0$

$\boxed{W_k + W_{gp} + W_e = konst}$

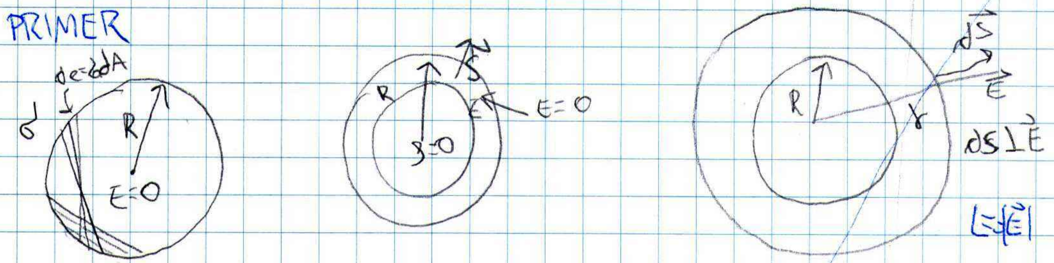
POSPLOŠITEV



$\boxed{W_e = \frac{1}{2}\sum_{i,j} \frac{e_i e_j}{4\pi\varepsilon_0 r_{ij}} \cdot \frac{1}{2}} \Longrightarrow W_e = \int_V \underbrace{\frac{1}{2}\varepsilon_0 E^2}_{\frac{1}{2}\varepsilon_0 E^2} dV = \int_R^\infty \frac{1}{2}\varepsilon_0 \frac{\sigma^2 R^4}{\varepsilon_0^2 r^4} \overbrace{4\pi r^2 dr}^{dV}$

$= \int_R^\infty \frac{2\sigma^2 R^4 \pi}{\varepsilon_0} \frac{1}{r^2} dr$

PRIMER



σ = konst.

GAUSSOV ZAKON

$\varepsilon_0 \oint \underbrace{\vec E \cdot d\vec S}_{E\,dS} = e\int \rho\, dV$

$E = |\vec E|$ $\quad \varepsilon_0 \int E\, dS = \sigma 4\pi R^2$

$\varepsilon_0 E(r) \int dS = \sigma 4\pi R^2$

$\varepsilon_0 E(r)\, 4\pi r^2 = \sigma 4\pi R^2$

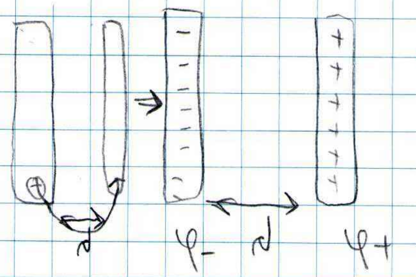
$\Rightarrow \boxed{E(r) = \frac{\sigma R^2}{\varepsilon_0 r^2}}$ $\left(\frac{\vec r}{r}\right)$ za smer

$\frac{2\sigma^2 R^4 \pi}{\varepsilon_0}\left(-\frac{1}{r}\right)\Big|_R^\infty = \frac{2\sigma^2 R^4 \pi}{\varepsilon_0 R}$

$W_e = \int \frac{1}{2}\varepsilon_0 E^2 dV = \frac{2\sigma^2 R \pi^2 8 R^3}{8\varepsilon_0 \pi R^4} = \boxed{\frac{e^2}{8\pi\varepsilon_0 R}}$

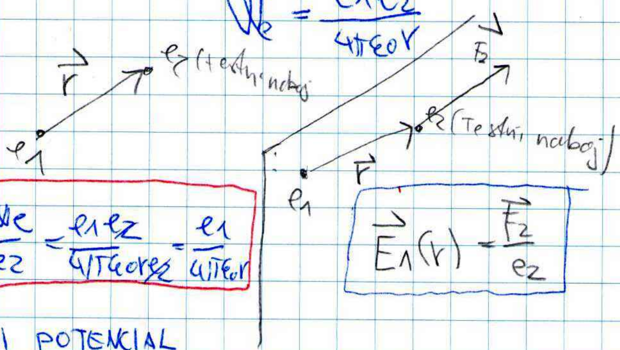
$e = \sigma 4\pi R^2$

$e^2 = 16\pi^2 \sigma^2 R^4$



ELEKTRIČNI POTENCIAL

$$W_e = \frac{e_1 e_2}{4\pi\varepsilon_0 r}$$

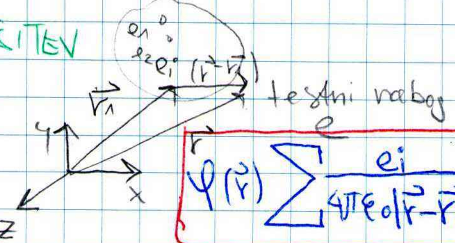


$$\boxed{\varphi_1(r) = \frac{W_e}{e_2} = \frac{e_1 e_2}{4\pi\varepsilon_0 r e_2} = \frac{e_1}{4\pi\varepsilon_0 r}}$$

ELEKTRIČNI POTENCIAL

$$\boxed{\vec{E}_1(r) = \frac{\vec{F}_2}{e_2}}$$

POSPLOŠITEV



$$\boxed{\varphi(\vec{r}) \sum \frac{e_i}{4\pi\varepsilon_0 |\vec{r} - \vec{r}_i|}}$$

ZVEZA MED φ IN $\vec{E}$

$$\varphi(\vec{r}) = \varphi(x, y, z)$$
$$\vec{r} = (x, y, z)$$

$$y(x)$$
$$dy = \left(\frac{dy}{dx}\right) dx$$

$$d\varphi = \frac{\partial \varphi}{\partial x} dx + \frac{\partial \varphi}{\partial y} dy + \frac{\partial \varphi}{\partial z} dz$$
$$= \underbrace{\left(\frac{\partial \varphi}{\partial x}, \frac{\partial \varphi}{\partial y}, \frac{\partial \varphi}{\partial z}\right)}_{\nabla\varphi} \cdot \underbrace{(dx, dy, dz)}_{d\vec{r}}$$

$$dW_e = -\int \underbrace{\vec{F}_e}_{\vec{F}_e = e\vec{E}} \cdot d\vec{r} = -e\int \vec{E} \cdot d\vec{r}$$

2 $\boxed{d\varphi = \nabla\varphi \cdot d\vec{r} = \text{grad}\,\varphi \cdot d\vec{r}}$

Nabla operator

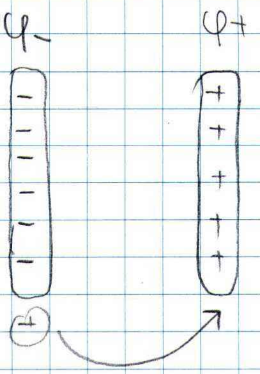
$$\boxed{W_e = e_2 \varphi_1(r)}$$

$$\downarrow$$

$$d(\cancel{e}\varphi) = -\cancel{e}\vec{E} \cdot d\vec{r}$$

1 $\boxed{d\varphi = -\vec{E} \cdot d\vec{r}}$

$$\left.\begin{aligned} d\varphi &= d\varphi \\ -\vec{E}\,d\vec{r} &= \text{grad}\,\varphi \cdot d\vec{r} \end{aligned}\right\} \boxed{E = -\text{grad}\,\varphi}$$

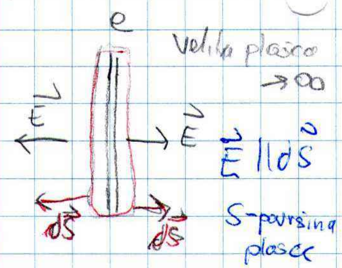


$A = \Delta W_k + \cancel{\Delta W_{gp}} + \Delta W_e$

$dA = de\varphi_+ - de\varphi_- = de(\varphi_+ - \varphi_-) = U\,de$

$\boxed{dA = U\,de}$

$dA = \int U\,de$



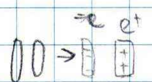
$\vec{E} \parallel d\vec{S}$

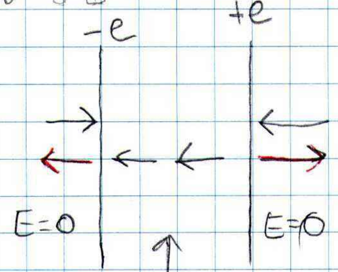
$\varepsilon_0 \oint \vec{E} \cdot d\vec{S} = \varepsilon_0 \int E\,dS$

$= \varepsilon_0 E \int dS = \varepsilon_0 E\, 2S$

$= \sigma S$

$\varepsilon_0 E_1 2S = \sigma S \Rightarrow \boxed{E_1 = \frac{\sigma}{2\varepsilon_0}}$





$E = 2E_1 = \frac{\sigma}{\varepsilon_0}$

$E = -\frac{d\varphi}{dx}$

$\int_0^l d\varphi = -\int_l^0 E\,dx = El$

$U = El \Rightarrow E = \frac{U}{l}$

$U = \frac{\sigma}{\varepsilon_0} l$

$U = \frac{e\,l}{\varepsilon_0 S}$ $\quad C = \varepsilon_0 \frac{S}{l}$

$\boxed{e = \varepsilon_0 \frac{S}{l} U}$

$\boxed{e = CU} \Rightarrow \boxed{U = \frac{e}{C}}$

$A = dA = \int U\,de = \int_0^e \frac{e}{C}\,de = \frac{e^2}{2C} = \frac{C^{\cancel{2}}U^2}{2\cancel{C}} = \boxed{\frac{1}{2} CU^2}$ ENERGIJA NAELEKTRENEGA KONDENZATORJA

$W = \frac{1}{2} \sum_{i,j} \frac{e_i e_j}{4\pi\varepsilon_0 r_{ij}} = \ldots = \boxed{\int \frac{1}{2} \varepsilon_0 E^2\,dV}$

$\boxed{w_e = \frac{1}{2} \varepsilon_0 E^2}$ Gostota energije el. polja kondenzatorja

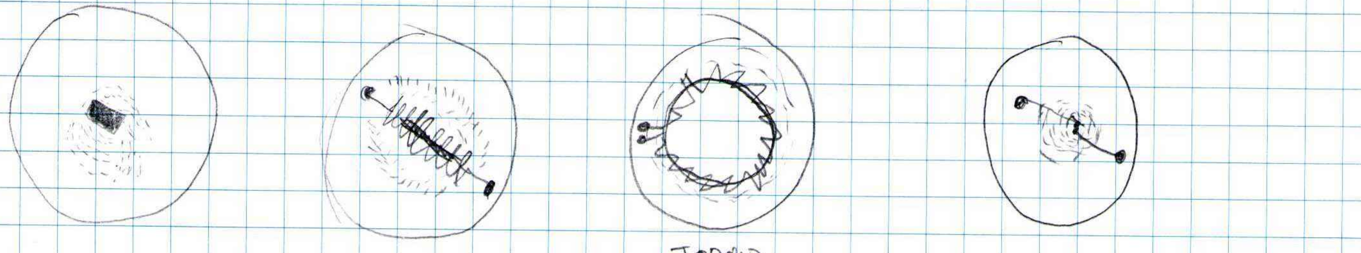
E=0 | E≠0 | E=0 $\Big\} \; W_c = \frac{1}{2} CU^2 = \frac{1}{2} C E^2 l^2 = \frac{1}{2} \varepsilon_0 \frac{S}{l} E^2 l^2 = \frac{1}{2} \varepsilon_0 E^2 \underbrace{S l}_{V = Sl} = \frac{1}{2} \varepsilon_0 E^2 V$

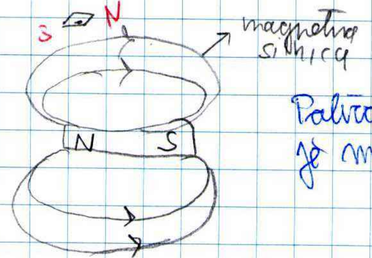
TO NI SPLOŠNA IZPELJAVA, TO IZPELJAVA NA POSEBNEM PRIMERU

$\Rightarrow w_E = \frac{1}{2} \varepsilon_0 E^2$

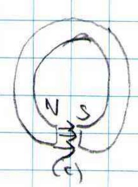
MAGNETNO POLJE

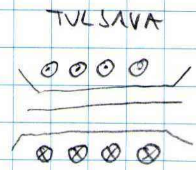
7.3.2011

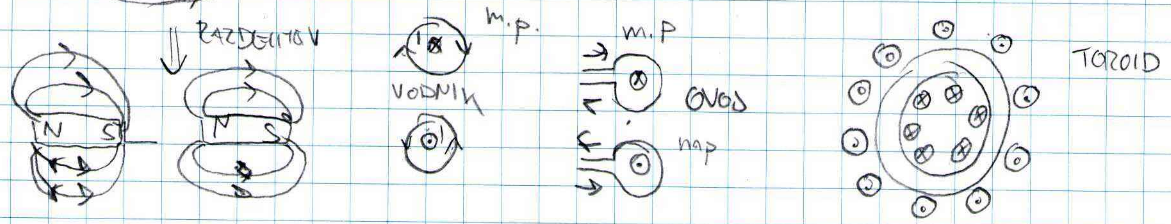




Palični magnet je magnetni dipol

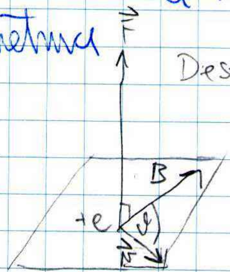






N → severni pol
S → južni pol

V vsaki točki mag. polja je njegova smer določena s smerjo v katero kaže v ravnovesni legi severni (N) pol vrtljive magnetnice



Desno sučni vijak

ENOTA ZA B: $B \doteq \frac{F}{ev} = \frac{Ns}{Asm} = \frac{N}{Am} = \frac{Nm}{Am^2} = \frac{J}{Am^2} = \frac{VAs}{Am^2} = \frac{Vs}{m^2} = 1T$

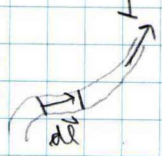
DEF $\vec{B}$: $\boxed{\vec{F} = e\vec{v} \times B}$

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

V ŽICI

$d\vec{F} = de\vec{v} \times \vec{B}$

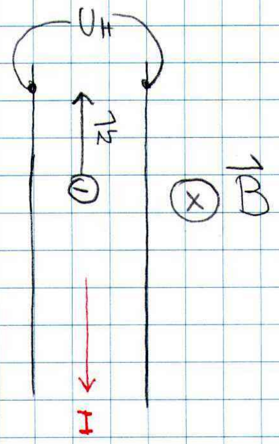
$d\vec{F} = I \underbrace{dt\vec{v}}_{d\vec{l}} \times \vec{B}$



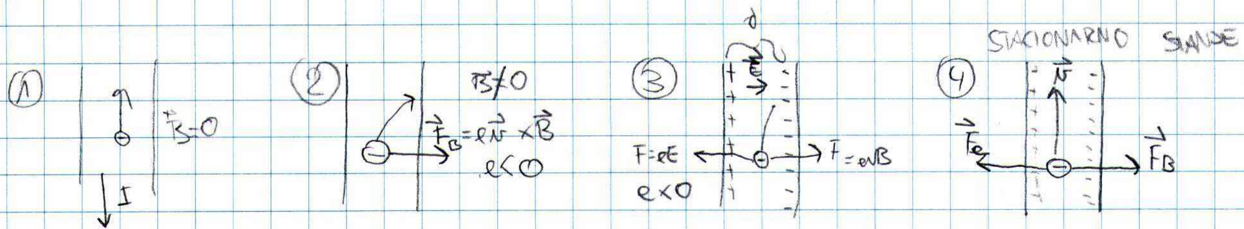
$\boxed{\vec{F}_e = I\vec{l} \times \vec{B}}$ RAVEN VODNIK

$d\vec{F} = I\, d\vec{l} \times \vec{B} \Rightarrow \boxed{\vec{F}_e = \int I\, d\vec{l} \times \vec{B}}$ SILA NA VODNIK PO KATEREM TEČE TOK I

HALL-OV POJAV



$U_H \equiv$ Hallova napetost



V STACIONARNEM STANJU

$$F_E = F_B$$

$$\cancel{e}E = \cancel{e}vB$$

$$\boxed{\frac{U_H}{d} = \langle v\rangle B}$$

Povpr. hitrost

$E = \frac{U_H}{d}$ - Hallova napetost

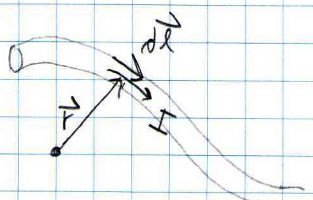
$$j = ne\langle v\rangle \Rightarrow \langle v\rangle = \frac{j}{ne} = \frac{I}{neS}$$

$$\boxed{\frac{U_H}{d} = \frac{IB}{ne_0 S}} \Rightarrow B$$

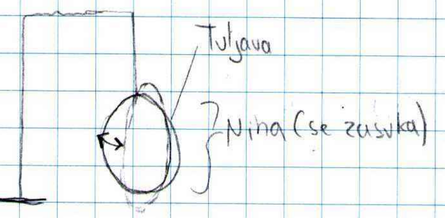
BIOT - SAVARTOV ZAKON

10.3.11

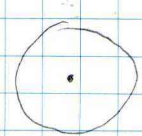
$$\boxed{B = \frac{\mu_0 I}{4\pi} \oint \frac{\vec{r} \times d\vec{l}}{r^3}}$$

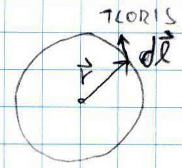


Magnetno polje deluje z navorom



1. PRIMER - OKROGLA TOKOVNA ZANKA



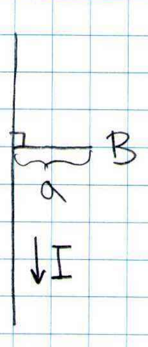


$\vec{F} \perp d\vec{l}$ $\quad |\vec{r}| = r = \text{konst}$

$$\Rightarrow B = \frac{\mu_0 I}{4\pi} \int \frac{r\,dl}{r^{\cancel{3}2}} = \frac{\mu_0 I}{4\pi r^2} \int dl$$

$$= \frac{\mu_0 I\, 2\pi r}{4\pi r^2} = \underline{\underline{\frac{\mu_0 I}{2r}}}$$

2. PRIMER - DOLG RAVEN VODNIK

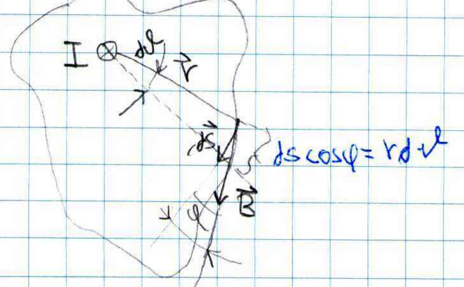


$$\vec{B} = \frac{\mu_0 I}{2\pi a}$$

AMPEROV ZAKON

Integriramo mag. polje po zaključeni krivulji

PRIMER:



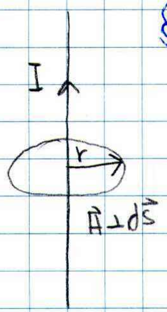
$$\oint \vec{B} \cdot d\vec{s} = \oint B \underbrace{ds\cos\varphi}_{r\,d\vartheta} = \oint \frac{\mu_0 I\, r\,d\vartheta}{2\pi r} = \frac{\mu_0 I}{2\pi} \underbrace{\oint d\vartheta}_{2\pi} = \mu_0 I$$

$$\Rightarrow \oint \vec{B}\, d\vec{s} = \cancel{I}\mu_0 \int \vec{j_e}\, d\vec{S}$$

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

$$\boxed{\oint \vec{H}\, d\vec{s} = \int \vec{j_e}\, d\vec{S}}$$

1. PRIMER:



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

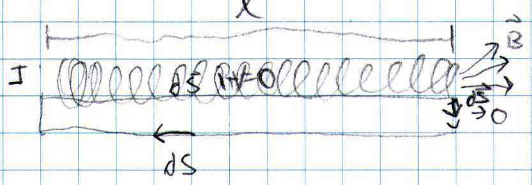
$$H \oint ds = I$$

$$H\, 2\pi r = I$$

$\vec{H} \perp d\vec{s}$

$$H = \frac{I}{2\pi r}$$

2. PRIMER – DOLGA TULJAVA

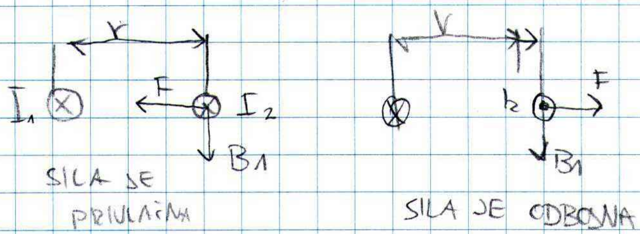


$H \cong 0$

$$\oint \vec{H} \cdot d\vec{s} = H l = \underset{\substack{\uparrow \\ \text{ŠT. OVOJEV}}}{N I} \Rightarrow H = \frac{NI}{l}$$

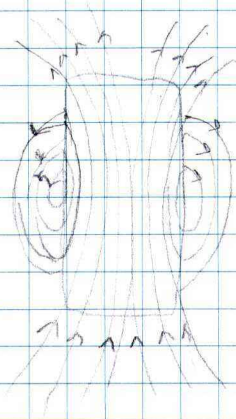
$$\boxed{B = \mu_0 \frac{NI}{l}}$$

SILA MED VZPOREDNIMA VODNIKOMA



Če tečeta toka v isto smer žici polegne skupaj – privlačna sila, če pa v nasprotna smer pa je polegne narazen – odbojna sila

~~Velikost gostote mag. polja v preseku vodnika s tokom I_1~~



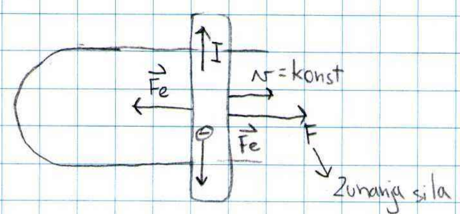
$$\vec{F}_e = I \int d\vec{l} \times \vec{B}$$

INDUKCIJA

$\vec{F}_e = I\int d\vec{l}\times\vec{B}$ $\quad \oint \vec{E}\cdot d\vec{s} = 0$

$\vec{E} = \mathrm{grad}\,\varphi$

$U = \Delta\varphi - \int\vec{E}\cdot d\vec{s}$



$\otimes\,\vec{B}$

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

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

$$\boxed{\vec{F} + \vec{F}_e = 0} \Leftrightarrow v = \text{konst}$$

$$\vec{F}_{zun} = -\vec{F}_e = -I(\vec{l}\times\vec{B})$$

$$-I(\vec{l}\times\vec{B})\,\vec{v} = UI$$

DELO: $dA = \vec{F}\cdot\underbrace{\vec{v}\,dt}_{d\vec{s}} = \underbrace{UI}_{P}\,dt$

$$U_i\,dt = \vec{v}\cdot(\vec{B}\times\vec{l})\,dt = -\vec{v}\,dt(\vec{l}\times\vec{B})$$

$$= -d\vec{s}(\vec{l}\times\vec{B}) = -\vec{B}(d\vec{s}\times\vec{l})$$

$$= \vec{B}\cdot d\vec{s} \Rightarrow U_i = \frac{-\vec{B}\,d\vec{s}}{dt} = \frac{-d\Phi_m}{dt}$$

$$\boxed{(\vec{B}\times\vec{l})\,\vec{v} = U_i}$$

$$\boxed{U_i = \vec{v}(\vec{B}\times\vec{l})}$$

INDUKCIJSKI ZAKON (POSEBNA OBLIKA)

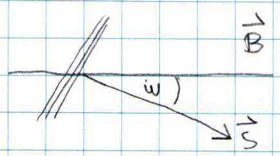
$U_i\,dt = -\vec{B}\,d\vec{s}/dt$

$$U_i = -\frac{\vec{B}\cdot d\vec{s}}{dt} = \frac{d(\vec{B}\cdot\vec{s})}{dt} = -\frac{d\Phi_m}{dt}$$

POSPLOŠITEV:

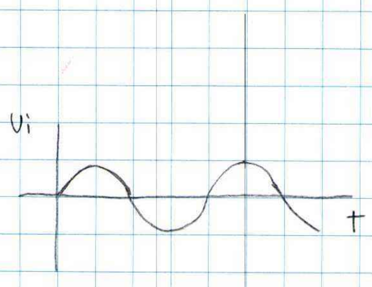
$$\boxed{U_i = -\frac{d\Phi_m}{dt}} \qquad \boxed{\Phi_m = \int\vec{B}\cdot d\vec{s}}$$

PRIMER:



$\Phi_m = \vec{B}\cdot\vec{S} = BS\cos(\omega t)$

$|U_i| = \left|\frac{d\Phi_m}{dt}\right| = BS\omega\sin(\omega t)$

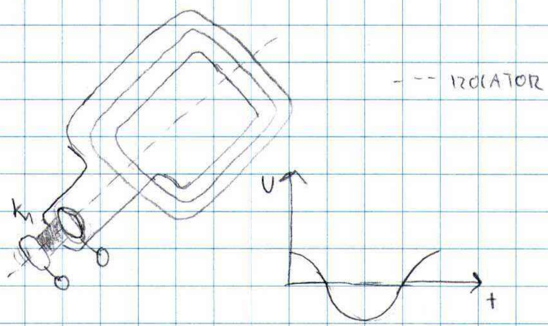


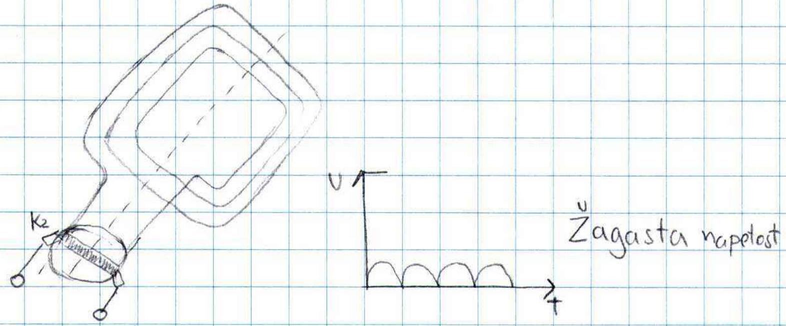
LENZOVO PRAVILO

Inducirana napetost požene tok, ki se upira spremembi, ki je inducirana napetost sprožila

14.3.11

GENERATORJI ELEKTRIČNEGA TOKA





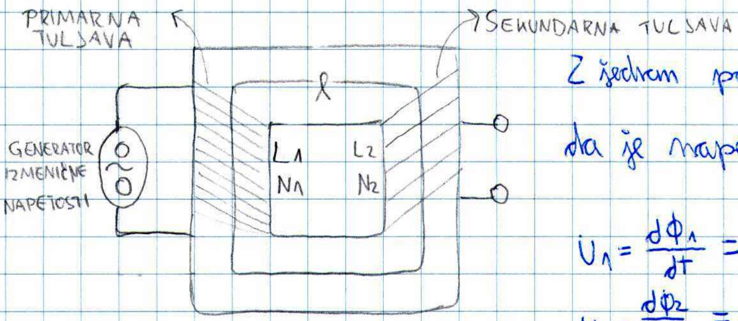
DINAMOSTATOR S KOLEKTORJEM ZA IZMENIČNO NAPETOST

DINAMOSTATOR S KOMUTATORJEM ZA ENOSMERNO NAPETOST

$$U_i = -\frac{d\Phi_m}{dt} \;/\, dt \Rightarrow \underbrace{\int U_i\, dt}_{\text{SUNEK NAPETOSTI}} = -\int d\Phi_m = -\Phi_m \Big|_{\Phi_{m\,zač}}^{\Phi_{m\,konč}} = \Phi_{m\,zač} - \Phi_{m\,konč} = \Delta \Phi_m$$

Izmeničen tok je pomemben zaradi prenosa energije na velike razdalje

TRANSFORMATOR



l - SREDNJI OBSEG JEDRA

Z jedrom povežamo napetostni pretok in dosežemo, da je napetostni pretok skozi tuljavo sklenjen

$$\left.\begin{aligned} U_1 &= \frac{d\Phi_1}{dt} = -N_1 \frac{d(BS)}{dt} \\ U_2 &= \frac{d\Phi_2}{dt} = -N_2 \frac{d(BS)}{dt} \end{aligned}\right\} \% \Rightarrow \frac{U_{1,0}}{U_{2,0}} = \frac{N_1}{N_2}$$

$\Phi_1 = N_1 BS \qquad \Phi_2 = N_2 BS$

IDEALNI TRANSFORMATOR: 1.) Magnetna pretoka skozi tuljavi sta enaka
2.) Upor obeh tuljav za enosmerno napetost je zanemarljiv

Zaradi spremembe magnetnega pretoka se inducira napetost na primarni in sekundarni tuljavi:

$$\boxed{\frac{(U_1)_0}{(U_2)_0} = \frac{N_1}{N_2}}$$

Tokokrog na sekundarni tuljavi sklenemo skozi Ohmski upor:

$$\boxed{\frac{(I_1)_0}{(I_2)_0} = \frac{N_2}{N_1}}$$

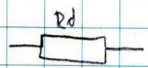
EFEKTIVNA MOČ:

$$\bar{P} = I_g U_g \qquad \boxed{P_1 = P_2}$$

$$\boxed{I_1 U_{g2} = I_2 U_{g1} \Rightarrow \frac{I_{g1}}{I_{g2}} = \frac{U_{g2}}{U_{g1}} = \frac{U_{02}}{U_{01}} = \frac{N_2}{N_1}}$$

DALJNOVOD

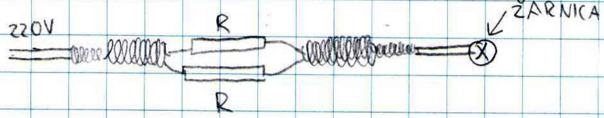
$P = IU$



IZGUBA NA DALJNOVODU:

$P_d = I^2 R_d$

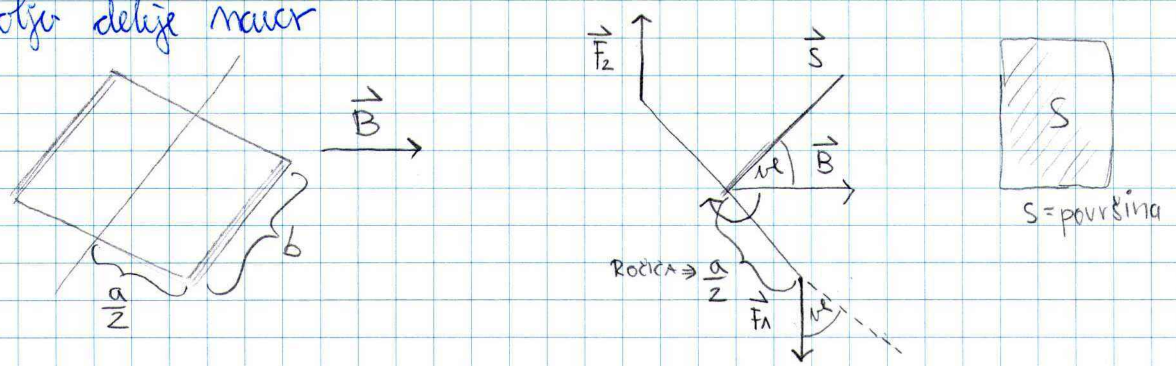
MODEL:



Na principu transformatorja deluje tudi varilni aparat

NAVOR NA TOKOVNO ZANKO

Na tokovno zanko, ki ima magnetni dipolni moment v magnetnem polju deluje navor



Ker po žici teče tok dobimo na obeh straneh sile

SILA NA RAVNI VODNIK V $\vec{B}$

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

$$M = \frac{a}{2} I b B \sin\vartheta + \frac{a}{2} I b B \sin\vartheta$$
$$= I a b B \sin\vartheta = I S B \sin\vartheta$$

$$\boxed{M = I S B \sin\vartheta}$$

$p_m = IS$ → magnetni dipolni moment tokovne zanke

$\boxed{p_m = IS}$

Če ima zanka več ovojev:

$\boxed{p_m = NIS}$

$$\boxed{\vec{M} = \vec{p_m} \times \vec{B}}$$

NAVOR NA TOKOVNO ZANKO ALI MAGNETNI DIPOLNI MOMENT V VEKTORSKI OBLIKI

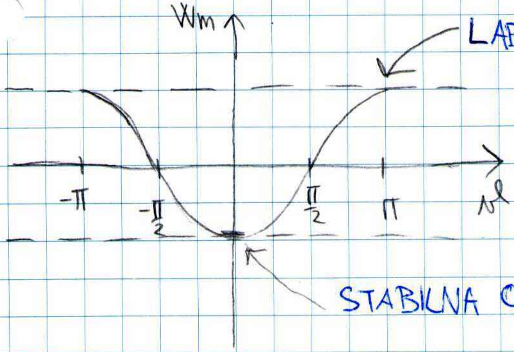
17.3.11

$$A = \int M \, d\vartheta = \int p_m B \sin\vartheta \, d\vartheta = -p_m B \cos\vartheta \Big|_{\vartheta_{zač}}^{\vartheta_{konč}}$$

$$\boxed{W_m = -p_m B \cos\vartheta}$$

ENERGIJA MAGNETNEGA DIPOLA $\vec{p_m}$ V ZUNANJEM MAGNETNEM POLJU $\vec{B}$

EVA START:

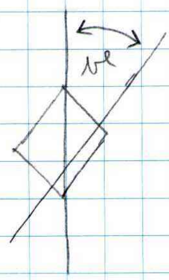


$\vartheta = 0$: $W_m = -p_m B$ (min) $\vec{p}_m \uparrow\uparrow \vec{B}$

$\vartheta = \pi$: $W_m = +p_m B$ (max) $\vec{p}_m \downarrow\uparrow \vec{B}$

NIHAJNI ČAS MAGNETNICE

$M = J\alpha$ $\qquad \alpha = \frac{d^2\vartheta}{dt^2} \doteq \ddot{\vartheta}$



$-p_m B \sin\vartheta = J\ddot{\vartheta}$

$\sin\vartheta = \vartheta$

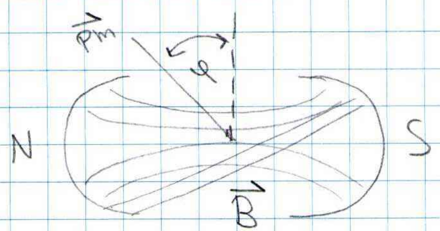
$-p_m B \vartheta = J\ddot{\vartheta}$

REŠITEV: $\vartheta = \vartheta_0 \sin\left(\left[\frac{2\pi}{t_0}\right]t + \delta\right)$

$\ddot{\vartheta} = -\vartheta_0 \left(\frac{2\pi}{t_0}\right) \sin\left(\left(\frac{2\pi}{t_0}\right) + \delta\right)$

$\left(\frac{p_m B}{J}\right)\cancel{\vartheta} = \left(\frac{2\pi}{t_0}\right)^2 \cancel{\vartheta} \Rightarrow \boxed{t_0 = 2\pi\sqrt{\frac{J}{p_m B}}}$

MAGNETNI MOMENT TULJAVE



$\vec{p}_m$ je nekako vedno pravokoten na $\vec{B}$

$\boxed{M = p_m B \sin\vartheta = p_m B}$

RAVNOVESNO STANJE

$M_B = M_D$

$p_m B = D\varphi$

$NISB = D\varphi$

$I = \frac{D}{NSB}\varphi$ → konstanta prožnostne vzmeti

$I \propto \varphi$ TOK JE SORAZMEREN ZASUKU

Iglič: Voda je najbolj pomembna tekočina poleg VINA!

MERJENJE TOKOVNEGA SUNKA

$\int I dt$

$\int M dt = \delta F = J\omega_0$

$\int pm B dt \Rightarrow \int INSB dt = J\omega$

$$\boxed{\int I dt = \frac{J\omega_0}{NSB}}$$

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

$\omega = \frac{d\varphi}{dt}\ \varphi_0 \left(\frac{e\pi}{b}\right) \cos\left(\frac{4\pi}{t_0} t\right)$

EVA END

MAXWELLOVE ENAČBE

(OSNOVNI ZAKONI ELEKTROTEHNIKE)

$$\boxed{\oint \vec{D} \cdot d\vec{S} = \int \rho_e \, dV}$$

ZAKON O ELEKTRIČNEM PRETOKU (GAUSSOV ZAKON)

$$\boxed{\oint \vec{B} \cdot d\vec{S} = 0}$$

ZAKON O MAGNETNEM PRETOKU

$$\boxed{\oint \vec{H} \cdot d\vec{S} = \int \left(\vec{\gamma}_e + \frac{\partial \vec{D}}{\partial t}\right) d\vec{S}}$$

ZAKON O NEGATIVNI NAPETOSTI (AMPEROV ZAKON)

$$\boxed{\oint \vec{E} \cdot d\vec{S} = -\int \left(\frac{\partial \rho_e}{\partial t}\right) d\vec{S}}$$

INDUKCIJSKI ZAKON (FARADAYEV ZAKON)

Dodatno mora veljati še zakon o ohranitvi naboja

$$\boxed{\oint \gamma_e \, d\vec{S} = -\int \frac{\partial \rho_e}{\partial t} \, dV}$$

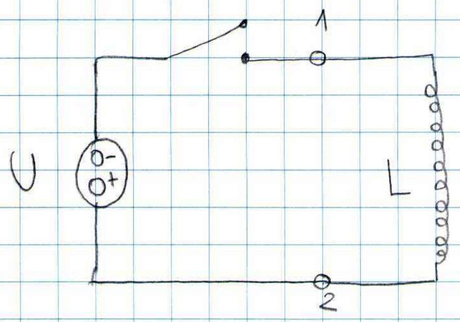
Ko poznamo prostorske odvisnosti $\vec{E}$ in $\vec{B}$:

$$\boxed{\vec{F} = e\vec{E} + e\vec{v} \times \vec{B}}$$

LORENTZOVA SILA

Voda ima dielektričnost okoli 80

LASTNA INDUKCIJA



$\boxed{U + U_L = 0}$

Generator s konstantno gonilno napetostjo priključimo (izključimo) na idealno tuljavo:

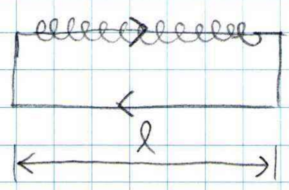
a) Ob času $t \approx 0$ po priključitvi teče po tuljavi spremenljiv NARAŠČAJOČ el. tok. Ker je $dI/dt > 0$ se v tuljavi inducira napetost, ki bi po LENZOVEM pravilu el. tok v nasprotni smeri ⇒ TULJAVA DELUJE KRATEK ČAS KOT UPOR

$$\frac{dI}{dt} > 0 \Rightarrow U_L = -L\frac{dI}{dt} < 0 \Rightarrow U > 0$$

b) Ob času $t \approx$ PO IZKLJUČITVI teče po tuljavi spremenljiv PADAJOČ el. tok. Ker je $dI/dt < 0$ se v tuljavi inducira napetost, ki bi po LENZOVEM pravilu el. tok v smeri začetnega toka ⇒ TULJAVA DELUJE KRATEK ČAS KOT GENERATOR

$$\frac{dI}{dt} < 0 \Rightarrow U_L = -L\frac{dI}{dt} > 0 \Rightarrow U < 0$$

IZPELJAVA



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

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

$$\phi_m = NBS = N\frac{N I \mu_0 S}{l} = \left(\mu_0 \frac{N^2 S}{l}\right) I \ ; \quad L = \mu_0 \frac{N^2 S}{l}$$

$$U_i = \frac{d\phi_m}{dt} \qquad \phi_m = LI$$

$$U_i = \frac{dLI}{dt} \Rightarrow \boxed{U_i = -L\frac{dI}{dt}}$$

IZMENIČNI TOK PO TULJAVI

Gonilna napetost $U_0 \sin(\omega t)$

$$\boxed{U_0 \sin(\omega t) + U_L = 0}$$

$$U_0 \sin(\omega t) - L\frac{dI}{dt} = 0$$

$$U_0 \sin(\omega t) = L\frac{dI}{dt}$$

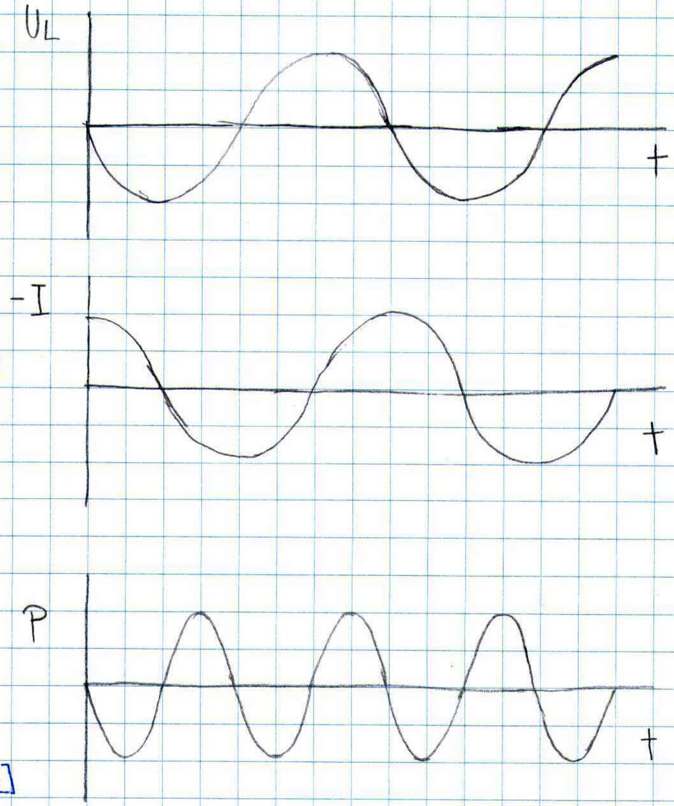
$$dI = \frac{U_0}{L}\sin(\omega t)\, d(\omega t)$$

$$I = \frac{U_0}{L}\int \sin(\omega t)\, d(\omega t) = \underbrace{-\frac{U_0}{\omega L}\cos(\omega t)}_{} = \frac{U_0}{L}\sin\left(\omega t - \frac{\pi}{2}\right)$$

$$\boxed{I(t) = I_0 \sin\left(\omega t - \frac{\pi}{2}\right)} \;;\; I_0 = \frac{U_0}{\omega L}$$

$$\Downarrow$$

$$U_L = -U_0 \sin(\omega t) = U_0 \sin(\omega t - \pi)$$

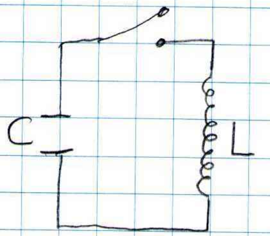


$$\left.\begin{array}{l} I = I_0 \cos(\omega t) \\ U = U_0 \cos(\omega t + \delta) \end{array}\right\} P = IU = I_0 U_0 \underbrace{\cos(\omega t + \delta)}_{[\cos\omega t \cos\delta - \sin\omega t \sin\delta]}$$

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

$$\boxed{P = I_0 U_0 \frac{1}{2}\cos\delta = \frac{1}{2} I_0 U_0 \cos\delta}$$

IDEALNI NIHAJNI KROG



$U_L + U_C = 0$

$U_C(t=0) = U_0$

$e = CU$

$-L\frac{dI}{dt} - \frac{e}{C} = 0 \quad / \frac{d}{dt}$

$-L\frac{d^2I}{dt} - \frac{\left(\frac{de}{dt}\right)}{C} = 0$

$$\boxed{I(t) = \; -L\frac{d^2I}{dt^2} - \frac{I}{C} = 0 \Rightarrow \frac{d^2I}{dt^2} = -\frac{1}{LC} I}$$

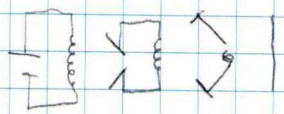
$w_0^2 I = -\frac{1}{LC} I$

$\boxed{w_0^2 = \frac{1}{LC}}$ LASTNA FREKVENCA IDEALNEGA NIHAJNEGA KROGA

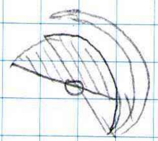
Rešitev:

$I = I_0 \sin(w_0 t)$

$\frac{d^2I}{dt^2} = -I_0 w_0^2 \sin(w_0 t) = -w_0^2 I$



DIPOLNA ANTENA
(EM Valovanje)



VRTLJIVI KONDENZATOR
(Z ZASUKOM SPREMINJAMO KAPACITETO)

NAPETOST NA TULJAVI

$U_L = -L\frac{dI}{dt} = -LI_0 w_0 \cos(w_0 t) \rightarrow$ Največja napetost na tuljavi

NAPETOST NA KONDENZATORJU

$U_L + U_C = 0 \Rightarrow U_C = -U_L = \underbrace{LI_0 w_0}\cos(w_0 t)$ Največja napetost na kondenzatorju

$\boxed{U_0 = LI_0 w_0}$

$\boxed{W_C = \frac{1}{2} C U_C^2}$

$$\boxed{\int U_L I \, dt = \int_0^{I_0} L \frac{dI}{dt} I \, dt = \frac{1}{2} L I^2}$$ ENERGIJA TULJAVE

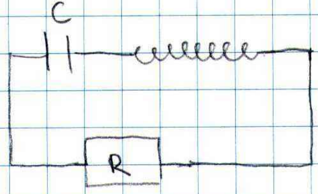
Energija nedelemega nih kroga: $\boxed{W = \frac{1}{2} C U_0^2 = \frac{1}{2} L I_0^2}$

V splošnem:

$W = \frac{1}{2} C U_C^2 + \frac{1}{2} L I^2 = \frac{1}{2} C L^2 I_0^2 w_0^2 \cos^2(w_0 t) + \frac{1}{2} L I_0^2 \sin^2(w_0 t) = \frac{1}{2}$

$= \frac{1}{2} L I_0^2 [\cos^2(w_0 t) + \sin^2(w_0 t)] = \frac{1}{2} L I_0^2 = \frac{1}{2} C U_0^2$

DUŠENI ELEKTRIČNI NIHAJNI KROG



$$U_C + U_L + U_R = 0$$

$$-\frac{e}{C} = -L\frac{dI}{dt} - RI = 0 \quad / \frac{d}{dt}$$

$$-\frac{I}{C} - L\frac{d^2I}{dt^2} = -R\frac{dI}{dt} = 0$$

$$-\frac{I}{LC} - \frac{d^2I}{dt^2} - \frac{R}{L}\frac{dI}{dt} = 0$$

$$\boxed{\frac{d^2}{dt^2} + \frac{R}{L}\frac{dI}{dt} + I\omega_0^2 = 0} \Rightarrow I(t)$$

NASTAVEK ZA REŠITEV $I = I_0 e^{-\beta t}\cos(\omega_0' t)$ $\quad\beta$ - koeficient dušenja

$$e^{i\omega_0' t} = \cos(\omega_0' t) + i\sin(\omega_0' t)$$

$$I = I_0 e^{-\beta t} e^{i\omega_0' t} = I_0 e^{(i\omega_0' - \beta)t}$$

$$\frac{dI}{dt} = I_0(i\omega_0' - \beta)e^{(i\omega_0' - \beta)t} = I_0(-\omega_0'^2 - 2\omega_0'\beta i + \beta^2)e^{(i\omega_0' - \beta)t}$$

$$I_0 e^{(i\omega_0' - \beta)t}\underbrace{\left[-\omega_0'^2 - 2\omega_0'\beta i + \beta^2 + \frac{R}{L}(i\omega_0') - \frac{R}{L}\beta + \omega_0^2\right]}_{=0} = 0$$

$$\underbrace{\left(-\omega_0'^2 + \beta^2 - \frac{R}{L}\beta + \omega_0^2\right)}_{=0} + i\underbrace{\left(\frac{R}{L} - 2\omega_0'\beta\right)}_{=0} = 0$$

$$-\omega_0'^2 + \beta^2 - 2\beta^2 + \omega_0^2 = 0$$

$$-\omega_0'^2 - \beta^2 + \omega_0^2 = 0$$

$$\Rightarrow \boxed{\omega_0' = \sqrt{\omega_0^2 - \beta^2}}$$

$$\frac{R}{L} = 2\beta \Rightarrow \boxed{\beta = \frac{1}{2}\frac{R}{L}}$$

Če $R = 0$:

$\beta = 0$

$\omega_0' = \omega_0$

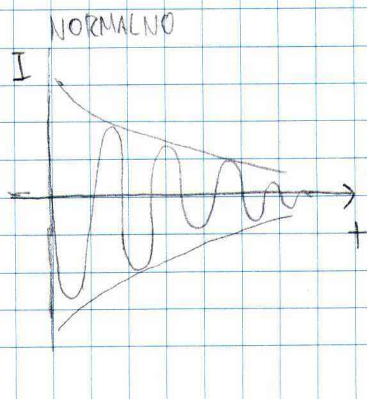
$I = I_0\cos(\omega t)$

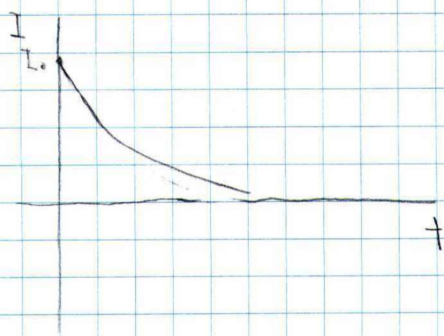
$\beta > \omega_0$: $\omega_0' = \sqrt{\omega_0^2 - \beta^2} = i\underbrace{\sqrt{\beta^2 - \omega_0^2}}_{\sigma} = i\sigma$

$I = I_0 e^{-\beta t} e^{i\omega_0' t} = I_0 e^{-\beta t} e^{-\sqrt{\beta^2 - \omega_0^2}\, t}$

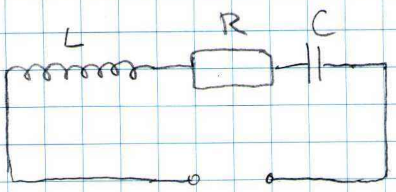
$$\boxed{\beta < \omega_0: \; I = I_0 e^{-\beta t}\cos(\omega_0' t + \delta)}$$

$$\boxed{\beta > \omega_0: \; I = I_0 e^{-(\beta + \sqrt{\beta^2 - \omega_0^2})t}}$$





VSILJENO NIHANJE EL. NIHAJNEGA KROGA



$U_g = U_0 \cos(\omega t)$ $\qquad I = I_0 e^{i\omega t}$

$U_g = U_0 e^{i\omega t}$ $\qquad I_0 \in \mathbb{R}e$

$U_0 \in \mathbb{C}$

$U_g + U_L + U_R + U_C = 0$

$U_g - L\frac{dI}{dt} - IR - \frac{e}{C} = 0 \; / \frac{d}{dt}$

$\frac{dU_g}{dt} - L\frac{d^2I}{dt^2} - R\frac{dI}{dt} - \frac{I}{C} = 0$

$e^{i\omega t}\underbrace{\left[U_0 i\omega + LI\omega^2 - I_0 R i\omega - \frac{I_0}{C}\right]}_{=0} = 0$

$i\omega U_0 + LI_0\omega^2 - I_0 R i\omega - I_0/C = 0 \; / i\omega$

$U_0 = -\frac{LI_0\omega^2}{i\omega} + I_0 R + \frac{I_0 i}{\omega C i}$

$U_0 = I_0 \overbrace{\left[\underbrace{+L\omega i}_{Z_L} + \underbrace{R}_{Z_R} - \underbrace{\frac{i}{\omega C}}_{Z_C}\right]}^{Z \;\to\; \text{IMPENDANCA}} = I_0\left[R + i\left(L\omega - \frac{1}{\omega C}\right)\right]$

$U_0 = \underbrace{I_0 L\omega i}_{U_L} - \underbrace{I_0 \frac{i}{\omega C}}_{U_C} + \underbrace{I_0 R}_{U_R}$

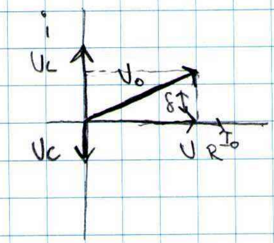
$Z_R = R$

$Z_L = L\omega i$

$Z_C = \frac{1}{\omega C}$

$\boxed{U_0 = I_0 Z}$ $\qquad \boxed{Z = Z_R + Z_L + Z_C}$

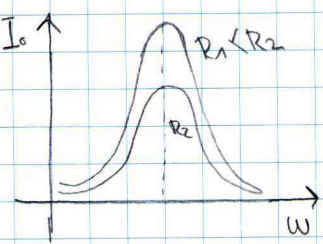
KAZALČNI DIAGRAM



$U_0^2 = U_0 U_0^* = \left[R^2 + \left(L\omega - \frac{1}{\omega C}\right)^2\right] I_0^2 \Rightarrow I_0 = \frac{|U_0|}{\sqrt{R^2 + \left(L\omega - \frac{1}{\omega C}\right)^2}}$

FAZNI ZAMIK:

$\mathrm{tg}\,\delta = \frac{L\omega - \frac{1}{\omega C}}{R}$; $I_0 = \frac{|U_0|}{\sqrt{R^2 + \left(L\omega - \frac{1}{\omega C}\right)^2}}$

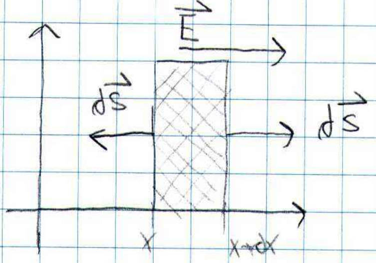


MAX: $L\omega_{RES} - \frac{1}{\omega_{RES} C} = 0 \Rightarrow \omega_{RES}^2 = \frac{1}{LC} = \omega_0^2$

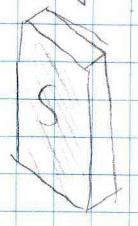
$\overline{P} = \frac{1}{2} I_0 \underbrace{|U_0|\cos\delta}_{U_R = I_0 R}$

24.3. [illegible]

POISSONOVA ENAČBA



$\rho(x)$ = volumska porazdelitev naboja



$$\varepsilon_0 \oint \vec{E} \cdot d\vec{S} = \int \rho\, dV$$

$$\varepsilon_0 \left[E(x+dx)\cancel{S} - E(x)\cancel{S} \right] = \rho(x)\, dx\, \cancel{S}$$

$$\varepsilon_0 [\overbrace{E(x+dx) - E(x)}^{dE}] = \rho(x)\, dx \quad /:dx$$

$$\boxed{\varepsilon_0 \frac{dE}{dx} = \rho(x)} \qquad \boxed{E = -\frac{d\varphi}{dx}}$$

$$\varepsilon_0 \frac{d}{dx}\left(\frac{d\varphi}{dx}\right) = \rho(x) \rightarrow \boxed{\frac{d^2\varphi}{dx^2} = -\frac{\rho(x)}{\varepsilon_0}}$$

POISSONOVA ENAČBA V 1-DIMENZIJI

V SPLOŠNEM

$$\boxed{\vec{E} = -\operatorname{grad}\varphi}$$

$$\varepsilon_0 \oint_S \vec{E} \cdot d\vec{S} = \int_V \rho\, dV \Rightarrow \varepsilon_0 \operatorname{div}\vec{E} = \rho(\vec{r})$$

$$\boxed{\varepsilon_0 \vec{\nabla} \cdot \vec{E} = \rho(\vec{r})}$$

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

$$\vec{E} = (E_x, E_z, E_y)$$

$$\varepsilon_0 \left[\frac{\partial E_x}{\partial x} + \frac{\partial E_y}{\partial y} + \frac{\partial E_z}{\partial z}\right] = \rho(\vec{r})$$

V 3D:

NABLA

$$\varepsilon_0 \vec{\nabla} \cdot \vec{E} = \rho(\vec{r})$$

$$\varepsilon_0 \vec{\nabla} \cdot (-\nabla\varphi) = \rho(\vec{r})$$

$$-\varepsilon_0 \nabla^2 \varphi = \rho(\vec{r}) \Rightarrow \nabla^2 \varphi(\vec{r}) = -\frac{\rho(\vec{r})}{\varepsilon_0} \Rightarrow \boxed{\Delta\varphi = \frac{\rho}{\varepsilon_0}}$$

POISSONOVA ENAČBA V 3-DIMENZIJAH

$$\Delta = \nabla^2 \quad \Delta \equiv \text{Laplace}$$

$$\Delta\varphi(\vec{r}) = -\frac{\rho(\vec{r})}{\varepsilon_0}, \quad \Delta = \vec{\nabla} \cdot \vec{\nabla} = \left(\frac{\partial}{\partial x}, \frac{\partial}{\partial y}, \frac{\partial}{\partial z}\right)\left(\frac{\partial}{\partial x}, \frac{\partial}{\partial y}, \frac{\partial}{\partial z}\right) = \frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2} + \frac{\partial^2}{\partial z^2}$$

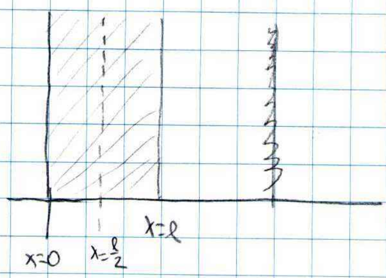
$$\frac{\partial^2 \varphi(\vec{r})}{\partial x^2} + \frac{\partial^2 \varphi(\vec{r})}{\partial y^2} + \frac{\partial^2 \varphi(\vec{r})}{\partial z^2} = -\frac{\rho(\vec{r})}{\varepsilon_0}$$

DIELEKTRIČNA „KONSTANTA" $\varepsilon_r(\vec{r})$

$$\boxed{\vec{\nabla} \cdot [\varepsilon_0 \varepsilon_r(\vec{r}) \nabla\varphi] = -\rho(\vec{r})}$$

Reševanje FEM – Comsol

PP – FIKSIRAN NABOJ



$$\frac{d^2\varphi}{dx^2} = -\frac{\rho_0}{\varepsilon_0}, \quad \rho = \text{konst}$$

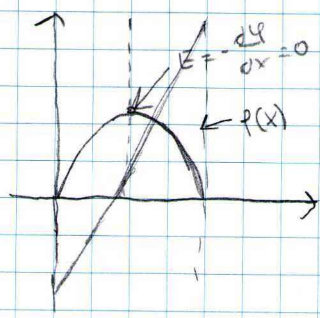
$$\frac{d\varphi}{dx} = -\frac{\rho_0}{\varepsilon_0} x + B$$

$$\boxed{\varphi(x) = -\frac{\rho_0 x^2}{\varepsilon_0 2} + Bx + C}$$

$$F\left(x=\frac{l}{2}\right) = 0 \Rightarrow E\left(x=\frac{l}{2}\right) = 0$$

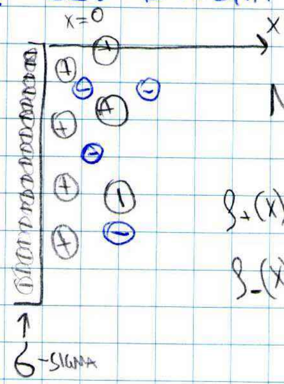
$$E(x) = -\frac{d\varphi}{dx} = \frac{\rho_0}{\varepsilon_0} x - B$$

$$E\left(x=\frac{l}{2}\right) = \frac{\rho_0 l}{\varepsilon_0 2} - B = 0 \Rightarrow \boxed{B = \frac{\rho_0 l}{2\varepsilon_0}}$$



$$\varphi(x) = -\frac{\rho_0 x^2}{\varepsilon_0 2} + \frac{\rho_0 l}{2\varepsilon_0} x \qquad \varphi(x=0), \varphi(x=l) = 0$$

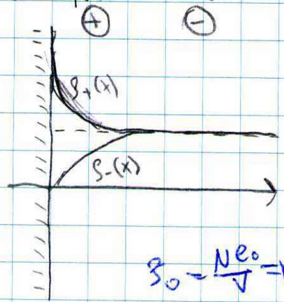
PP2: – EL. DVOSNA PLAST



$$NaCl \rightarrow Na^+ + Cl^-$$

$\rho_+(x)$

$\rho_-(x)$



$$\rho_0 = \frac{Ne_0}{V} = ne_0$$

$$n = \frac{N_0}{V}$$

IDEALNI PLIN MAXWELLOVA PORAZDELITEV

$$e^{-\frac{mv^2}{2kT}}$$ BOLTZMANNOV FAKTOR

$$+\; W_+ = e_0 \varphi(x) \Rightarrow \rho_+(x) = \rho_0 e^{-\frac{W_+}{kT}} = \rho_0 e^{-\frac{e_0\varphi}{kT}}$$

$$-\; W_- = -e_0 \varphi(x) \Rightarrow \rho_-(x) = \rho_0 e^{-\frac{W_-}{kT}} = \rho_0 e^{+\frac{e_0\varphi}{kT}}$$

$$\Rightarrow \boxed{\rho(x) = \rho_+(x) + \rho_-(x) = \rho_0 e^{-\frac{e_0\varphi}{kT}} - \rho_0 e^{+\frac{e_0\varphi}{kT}}}$$

$$\frac{d^2\varphi}{dx^2} = \frac{\rho_0}{\varepsilon_0}\frac{\left(e^{+\frac{e_0\varphi}{kT}} - e^{-\frac{e_0\varphi}{kT}}\right)2}{2}$$

$$\boxed{\frac{d^2\varphi}{dx^2} = \frac{2\rho_0}{\varepsilon_0} sh\left(\frac{e_0\varphi}{kT}\right) = \frac{2n_0 e_0}{\varepsilon_0} sh\left(\frac{e_0\varphi}{kT}\right)}$$

$$\varepsilon_0 \rightarrow \varepsilon_r \varepsilon_0$$

od $H_2O \approx 78{,}5$

$$\boxed{\frac{d^2\varphi}{dx^2} = \frac{2n_0 e_0}{\varepsilon_r \varepsilon_0} sh\left(\frac{e_0\varphi}{kT}\right)}$$

$$\frac{d^2\varphi}{dx^2} = \frac{2 n_0 e_0}{\varepsilon_r \varepsilon_0}\, sh\left(\frac{e_0 \varphi}{kT}\right) \pm \frac{e_0\varphi}{kT}$$

$$\frac{d^2\varphi}{dx^2} = \frac{2 n_0 e_0}{\varepsilon_r \varepsilon_0} \cdot \frac{e_0 \varphi}{kT}$$

REŠITEV ZA MAJHNE $\frac{e_0 \varphi}{kT} < 1$

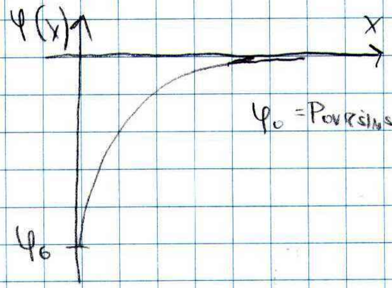
$kT = \frac{1}{40}\, e_0 V$

$$\frac{d^2\varphi}{dx^2} = \underbrace{\frac{2 n_0 e_0^2}{\varepsilon_r \varepsilon_0 k T}}_{K^2} \varphi$$

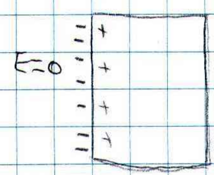
$\Rightarrow K^2 = \frac{2 n_0 e_0}{\varepsilon_r \varepsilon_0 k T}$

$$\boxed{\frac{d^2\varphi}{dx^2} = K^2 \varphi}$$

LINEARIZIRANA PB ENAČBA



φ_0 = POVRŠINSKI EL POTENCIAL

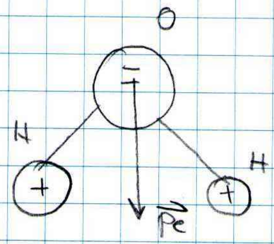


DIELEKTRIČNE LASTNOSTI SNOVI

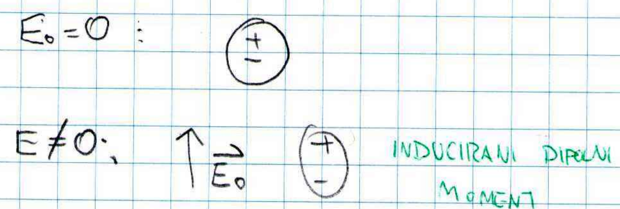
POLARNE – Molekule imajo permanentni dipolni moment

NEPOLARNE – Imajo polarni dipolni moment enak 0. Če jih damo v el. polje pa dobijo induciran dipolni moment - izgubijo ko ni permanenten.

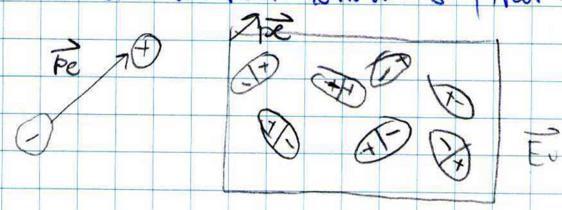
POLARNA MOLEKULA

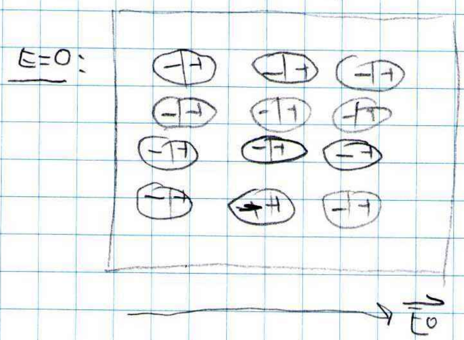


NEPOLARNA MOLEKULA

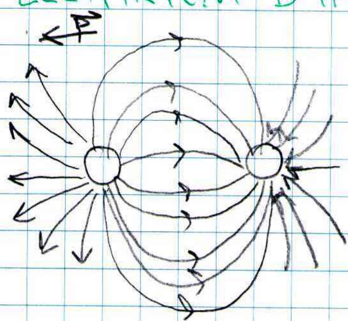


⇒ Voda dielektričnost okoli 80, ker ima permanentni dipolni moment.

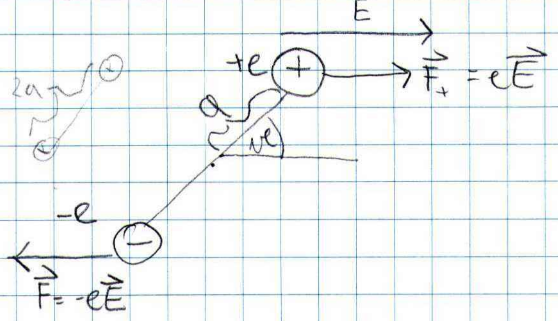




ELEKTRIČNI DIPOL



SILA IN NAVOR V ZUNANJEM POLJU DIPOLA



$$M = M_+ + M_- = a e E + (-a)(-e)E = \underbrace{2a}_{d}\, eE \sin\vartheta$$

$$\boxed{M = \underbrace{ed}_{p_e d}E\sin\vartheta = p_e E \sin\vartheta}$$

$$\boxed{\vec M = \vec p_e \times \vec E}$$

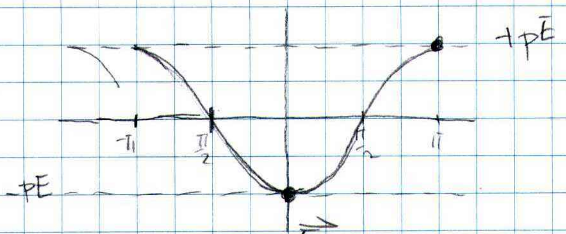
$$W_e = \int M\,d\vartheta = \int_{\vartheta_{zač}}^{\vartheta_{kon}} p_e E \sin\vartheta\, d\vartheta = -p_e E \cos\vartheta \Big|_{\vartheta_{zač}}^{\vartheta_{kon}} = -\vec p_e \vec E$$

$$\boxed{W_e = -\vec p_e \cdot \vec E}$$

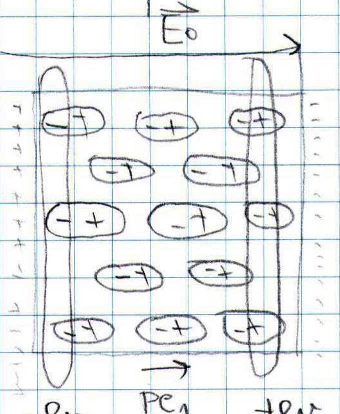
$\vartheta = 0 \quad \uparrow \vec p_e \ \uparrow \vec E \ : \ W_e = -p_e E$ — Najmanjša energija

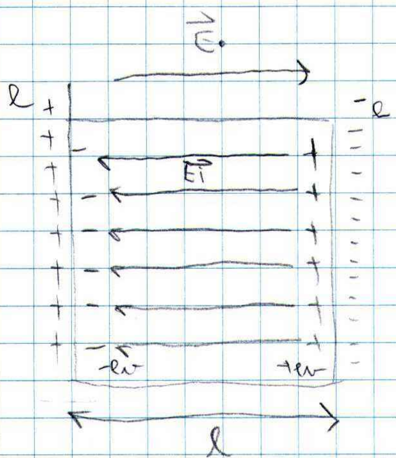
$\vartheta = \pi \quad \uparrow \vec p_e \ \downarrow \vec E \ : \ W_e = +p_e E$ — Največja energija

Večja temp manj orientirana; manjša bolj orientirana



Zunaj kond ni polja





Vezani naboji

$\langle \rho(x)\rangle = \rho(x) - \frac{dP}{dx}$

$\langle \rho(x)\rangle = \rho(x) - \nabla\cdot\vec P$

$\varepsilon_0 \nabla\vec E = \langle\rho(x)\rangle$

$-\nabla(\varepsilon_0\nabla\varphi) = \langle\rho(x)\rangle$ Polarizacija

CELOTNO POLJE:

$E = E_0 - E_i$

$E = E_0 - \frac{e_v}{S\varepsilon_0}$

POLARIZACIJA:

$\vec P = n\langle\vec p_e\rangle, \quad n = \frac{N}{V}$

DIPOLNI MOMENT VEZ. NABOJA: $e_v l = p$

$N\langle\vec p_e\rangle = e_v l$

OD ENE MOL.:

$PV = n\langle\vec p\rangle V = \frac{N}{V}\langle p_e\rangle V = N\langle\vec p\rangle$

$N\langle \vec{p}_e\rangle = e_v l$

$PS l = e_v l \Rightarrow \boxed{e_v = PS}$

$\Rightarrow E = E_0 - \frac{PS}{S\varepsilon_0} \,/\, \varepsilon_0 \Rightarrow \varepsilon_0 E = \varepsilon_0 E_0 - P \Rightarrow \boxed{\varepsilon_0 E_0 = \varepsilon_0 E + P}$

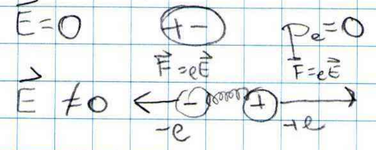
$\boxed{D = \varepsilon_0 E + P}$

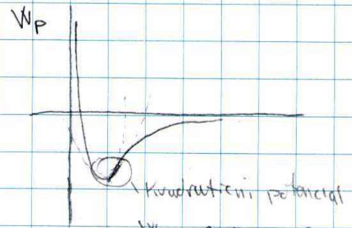
$P = \varepsilon_0 \chi E$ ← SUSCEPTIBILNOST

$D = \varepsilon_0 E + \varepsilon_0 \chi E$

$D = \varepsilon_0 \underbrace{(1+\chi)}_{\varepsilon = 1+\chi} E$ ε - dielektričnost

NEPOLARNE MOLEKULE





$W_p \simeq k(x-x_0)^2 - C$ vzmet

$F = -\frac{\partial W_p}{\partial x} = -k(x-x_0) \leftarrow -kx + kx_0$

$eE = kd$

INDUCIRANI DIPOLNI MOMENT

$d = \frac{eE}{k} \Rightarrow p_e = de = \frac{e^2 E}{k}$

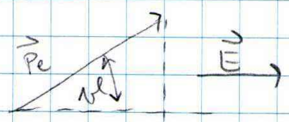
$p_e \propto E$ $\boxed{p_e = \frac{e^2 E}{k}}$

$P = n p_e = \frac{ne^2 E}{k}$ $\leftarrow \varepsilon_0 \chi$

$\varepsilon_0 \chi = \frac{ne^2}{k}$

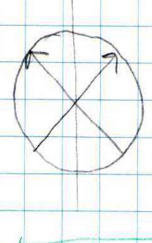
$\boxed{\chi = \frac{ne^2}{\varepsilon_0 k}} \Rightarrow \varepsilon_0 = 1+\chi = 1 + \frac{ne^2}{\varepsilon_0 k}$ $\lim_{k\to\infty} \varepsilon \to 1$

POLARNE MOLEKULE $P = \varepsilon_0 \chi E$

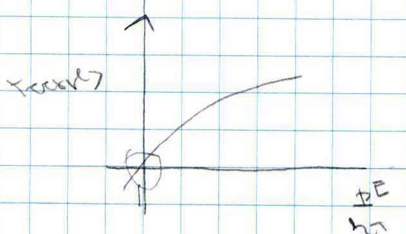


$|\vec{p}_e| = p_e$

$P = n\langle \vec{p}_e\rangle = n\langle p_e \cos\vartheta\rangle = n p_e \langle \cos\vartheta\rangle$



$\boxed{\langle \cos\vartheta\rangle = \frac{\int \cos\vartheta \, d\Omega}{\int d\Omega}}$ ZA $E=0$



$\boxed{W_d = -p_e E \cos\vartheta}$

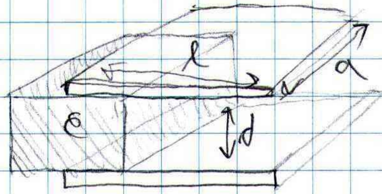
ZA $\frac{p_e E}{kT} \ll 1$: $\langle \cos\vartheta\rangle \simeq \frac{p_e E}{3kT}$

$P = n p_e \langle \cos\vartheta\rangle = \frac{n p_e^2 E}{3kT}$ $\varepsilon_0 \chi$

$\Rightarrow \varepsilon_0 \chi = \frac{n p_e^2}{3kT} \Rightarrow \chi = \frac{n p_e^2}{3\varepsilon_0 kT}$

$\boxed{\varepsilon = 1 + \chi = 1 + \frac{n p_e^2}{3\varepsilon_0 kT}}$

Sila na dielektrik



Ko vstavimo dielektrik med plošči kondenzatorja (do globine x) se naboj na ploščah spremeni

$$e = C_0 U_0 = \varepsilon_0 \frac{S}{d} U_0 \Rightarrow \text{konstanta za vse } x$$

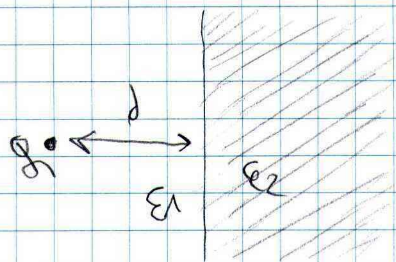
Kjer $C_0 = \varepsilon_0 \frac{S}{d}$ = kapaciteta pri $x=0$ in U_0 napetost med ploščama;

Pri $x \neq 0$: Sistem obravnavamo kot dva vzporedno vezana kondenzatorja

$$W(x) = \frac{1}{2}\frac{e^2}{C} = \frac{1}{2}\frac{C_0^2 U_0^2}{\varepsilon_0 \varepsilon \frac{ax}{d} + \varepsilon_0 \frac{a(l-x)}{d}} = \frac{1}{2}\frac{C_0^2 U_0^2}{\varepsilon_0 \frac{ax}{d}(\varepsilon-1) + \varepsilon_0 \frac{al}{d}}$$

SILA NA DIELEKTRIK = sila med nabojema na ploščah in dipol v dielektriku

$$\boxed{F = -\frac{dW(x)}{dx} = \frac{1}{2} U_0^2 \frac{\varepsilon_0 a l}{d} \frac{(\varepsilon-1)}{[(\varepsilon-1)x + l]^2}}$$

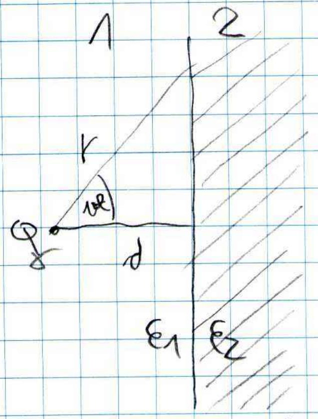


Če: $\varepsilon_1 > \varepsilon_2 \Rightarrow F > 0$ odbojna sila stran od mejne ploskve

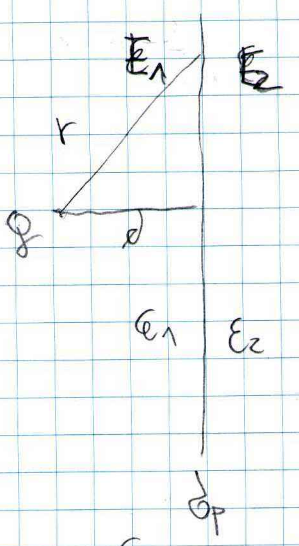
Če: $\varepsilon_1 < \varepsilon_2 \Rightarrow F < 0$ privlačna sila proti mejni ploskvi

$$\boxed{F = \frac{1}{4\pi\varepsilon_0 \varepsilon_1} \frac{(\varepsilon_1 - \varepsilon_2)}{(\varepsilon_1 + \varepsilon_2)} \frac{q^2}{4d^2}}$$

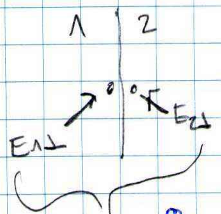
SILA NA TOČKASTI NABOJ V BLIŽINI MEJE DVEH DIELEKTRIKOV

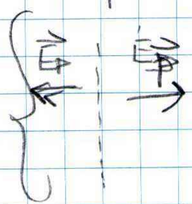


MODEL:
Predpostaviš, da na desni tudi $\varepsilon = \varepsilon_1$, razliko v ε-ih pa upoštevaš s površinskim nabojem na mejnem področju



$\cos\vartheta = \frac{d}{r}$





$E_p = \pm\frac{\sigma_p}{2\varepsilon_1\varepsilon_0}$

$$E_{1\perp} = \frac{q}{4\pi\varepsilon_0\varepsilon_1}\frac{1}{r^2}\frac{d}{r} - \frac{\sigma_p}{2\varepsilon_0\varepsilon_1}$$

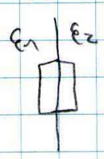
$$E_{2\perp} = \frac{q}{4\pi\varepsilon_0\varepsilon_1}\frac{1}{r^2}\frac{d}{r} + \frac{\sigma_p}{2\varepsilon_0\varepsilon_1}$$

Vr. polja samo stični ploskvi

ROBNI POGOJ $\Rightarrow -\varepsilon_1 E_{1\perp} + \varepsilon_2 E_{2\perp} = 0 \Rightarrow \sigma_p \Rightarrow E_p = -\frac{\sigma_p}{2\varepsilon_0\varepsilon_1} = -\frac{\varepsilon_1-\varepsilon_2}{\varepsilon_1+\varepsilon_2}\frac{1}{4\pi\varepsilon_0\varepsilon_1}\frac{q}{r^2}\frac{d}{r}$

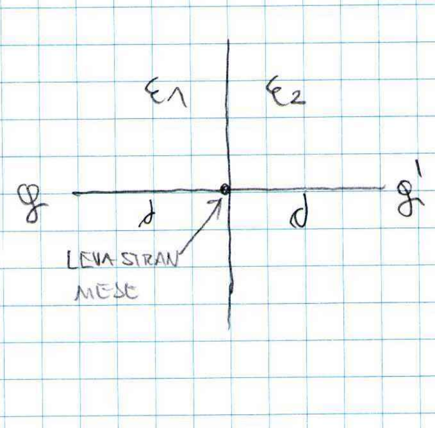
PRISPEVEK k električnem polju na levi strani meje zaradi $\varepsilon_1 \neq \varepsilon_2$ izgleda kot polje točkastega naboja q'

ROBNI POGOJ



$-\varepsilon_1 E_{1\perp}\,dA + \varepsilon_2 E_{2\perp}\,dA = 0$

$$q' = \frac{\varepsilon_1-\varepsilon_2}{\varepsilon_1+\varepsilon_2}\,q \quad \text{v mediju } \varepsilon = \varepsilon_1$$



31.3.

SNOV V MAGNETNEM POLJU

$\boxed{W_p = -\vec{p}_m \vec{B}}$ → $\vartheta = 0$: $W_p = -p_m B$ $\quad \vec{p}_m \uparrow\uparrow \vec{B}$

$\vartheta = \pi$: $W_p = +p_m B$ $\quad \vec{p}_m \downarrow\uparrow \vec{B}$

$p_m \uparrow\uparrow \vec{B}$

V zunanjem mag. polju se preferenčni magneti vrtijo v smer zunanjega polja, ki pa v skladu z Lenzovim pravilom

$\boxed{B = B_0 + B_m}$ → Notr. mag. polje

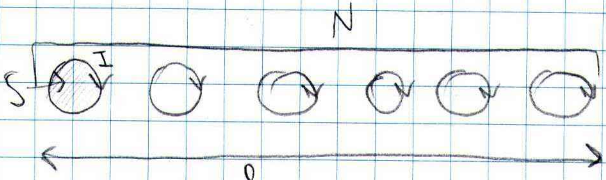
Paramagneti – permanentni dipolni moment

Diamagneti – Nimajo permanentnega dipolnega momenta

Vsak paramagnet je tudi diamagnet

1-DIMENZIONALNI PRIMER

MAGNETIZACIJA: $\vec{M} = n\langle \vec{p}_m \rangle$, $n = \frac{N}{V}$



$B_m = \mu_0 \frac{NI}{l}\frac{S}{S} = \mu_0 \frac{N}{V} p_m = \mu_0 \underbrace{n p_m}_{M}$

$\boxed{V = lS}$ VOLUMEN

$\boxed{IS = p_m}$ MAGNETNI MOMENT

$\boxed{B_m = \mu_0 \vec{M}}$

Magnetizacija je odvisna od magnetnega polja

$M = \chi H$

↖ SUSCEPTIBILNOST

$$B = B_0 + B_m = B_0 + \mu_0 \overset{\nearrow M = \chi H}{M} =$$

$$B = \mu_0 H + \mu_0 \chi H = \mu_0 (1 + \chi) H$$

$$1 + \chi = \mu \Rightarrow \text{PERMEABILNOST}$$

$$\boxed{\vec{B} = \mu_0 \mu \vec{H}}$$

PARAMAGNETI → Susceptibilnost > 0 , Permeabilnost > 1

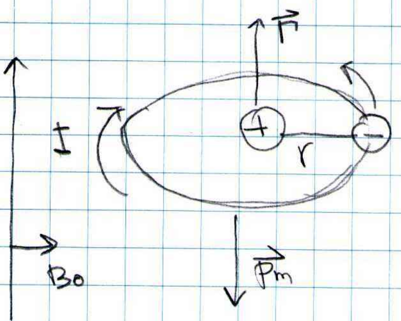
DIAMAGNETI → Susceptibilnost < 0 , Permeabilnost < 1

^{x} zelo velike $\Rightarrow \mu(H) \gg 1$

B in H nista sorazmerna } FEROMAGNETI

ISINGOV MODEL

KLASIČNI MODEL DIAMAGNETIZMA



$\vec{\Gamma}$ VRTILNA KOLIČINA

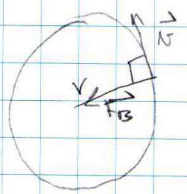
$\vec{\Gamma} = m\vec{r} \times \vec{v}$

$$p_m = IS = \frac{e_0 v \pi r^2}{2\pi r} = \frac{e_0}{2m_e} \underbrace{m_e r v}_{\Gamma}$$

$S = \pi r^2$

$I = \frac{e_0}{t_0} = \frac{e_0}{2\pi r}$

$t_0 = \frac{2\pi r}{v}$



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

Newtonov zakon:

$m_e a_r = F_B$

$m_e \frac{v^2}{r} = e_0 v B \quad / r$

$m_e v = e_0 r B$

$\Gamma = m_e r v = e_0 r^2 B$

$$\boxed{\vec{p}_m = -\frac{e_0}{2m_e} \vec{\Gamma}}$$

$$p_m = \frac{e_0}{2m_e} e_0 r^2 \mu_0 H$$

$$M = n p_m = -\frac{n e_0^2 \langle r^2 \rangle}{2m_e} H$$

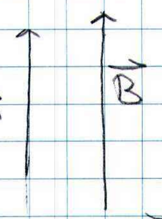
$$M = -\frac{\mu_0 n e_0^2 \langle r^2 \rangle Z}{2m_e} H \Rightarrow \boxed{\chi = -\frac{\mu_0 n e_0^2 \langle r^2 \rangle}{2m_e}}$$

χ SUSCEPTIBILNOST

$\chi \approx 10^{-5}$

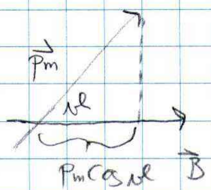
4.4.TM

PARAMAGNETI



$T \to 0$ $\vec{p_m}$ $\vec{B}$ $\left.\right\}$ $\vartheta = 0$, $W_p = -p_m B$

$W_m = -\vec{p_m} \cdot \vec{B}$



magnetizacija: $\vec{M} = n \langle \vec{p_m} \rangle$

Termična energija $\sim kT$

$n = \frac{N}{V}$ $\langle \cos\vartheta \rangle = \frac{\int \cos\vartheta \, e^{-\frac{W_m}{kT}} d\Omega}{\int e^{-\frac{W_m}{kT}} d\Omega}$ $\to$ Prostorski kot

$\mathcal{L}(x)$ = LANGEVIN OVA funkcija

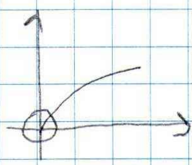
$\Rightarrow \frac{p_m B}{kT} < 1: \cong \frac{p_m B}{3kT}$

$M = n p_m \langle \cos\vartheta \rangle = \frac{n p_m^2 B_0}{3kT} \Rightarrow B_0 = \mu_0 H$ $= \boxed{\frac{n \mu_0 p_m^2}{3kT} H}$

$\boxed{M = \chi H}$ χ - SUSCEPTIBILNOST

Če je $\frac{p_m B_0}{kT} \ll 1$: $\boxed{\chi = \frac{n \mu_0 p_m^2}{3kT}}$

$\boxed{\mu = 1 + \chi = 1 + \frac{n \mu_0 p_m^2}{3kT}}$

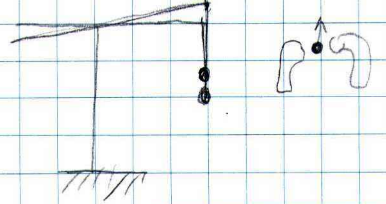


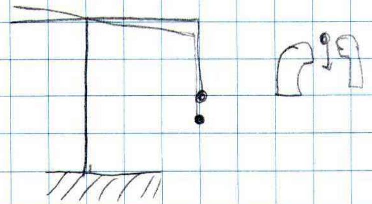
$$\boxed{M = C \frac{B_0}{T}, \quad C = \frac{n p_m^2}{3k}}$$

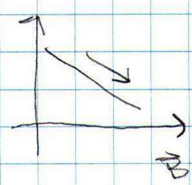
Curieov zakon

Poskus

DIAMAGNET PARAMAGNET



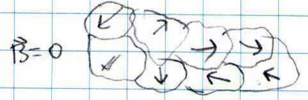




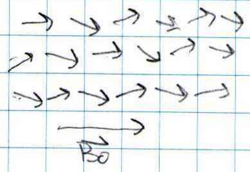
FEROMAGNETI

Isingov model

MAGNETNO STANJE SNOVI - s pomočjo domen razložimo



Vsak feromagnet je tudi paramagnet če temperatura dovolj poveča zaradi faznega prehoda

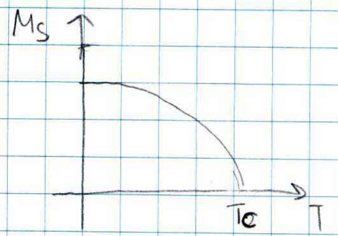


Usmerjene domene v zunanjem mag. polju $\vec{B_0}$

μ ni konstanta

$\bar{\mu} \Rightarrow$ povpr. permeabilnost

$$\boxed{\mu(H) = \frac{1}{\mu_0} \frac{\partial B}{H}}$$



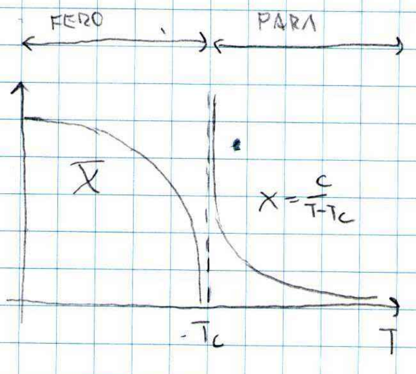
$T_C \rightarrow$ Curijeva temp.

Spontana magnetizacija znotraj domen

Če je $T \geq T_C$ feromagnetne snovi izgubijo spontano magnetizacijo in postanejo paramagneti.

Za $T \geq T_C$ za feromagnete velja Curie-Weissov zakon

$$\boxed{\chi = \frac{C}{T - T_C}}$$



$\chi > 0 \Rightarrow \mu > 1$: PARAMAGNETI

$\chi < 0 \Rightarrow \mu < 1$: DIAMAGNETI

χ zelo velik $\Rightarrow \mu(H) \gg 1$: feromagnetne snovi

B in H nista sorazmerna

BERKHANSEN-OV POSKUS

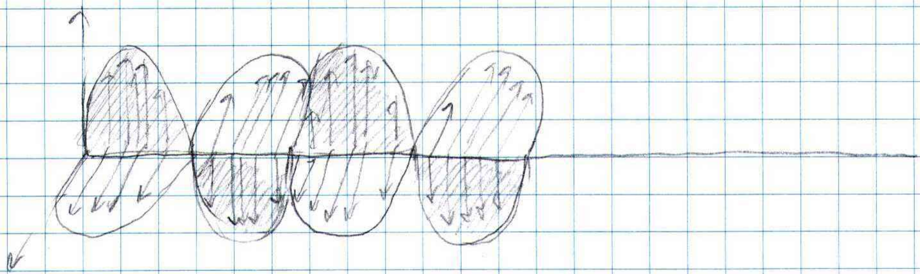
Snov v tuljavo damo pol pa se v magnet

Inducira se napetost. Dipolni momenti se začnejo vrteti

$$U_i = -\frac{d\Phi_m}{dt}$$

Slišimo zvok obračanja domen

ELEKTRO-MAGNETNO VALOVANJE



MAXWELLOVE ENAČBE:

$$\boxed{\begin{aligned}\oint \vec{E}\cdot d\vec{s} &= -\frac{\partial}{\partial t}\int_S \vec{B}\, d\vec{S}\\ \oint \vec{H}\, d\vec{s} &= \frac{\partial}{\partial t}\int_S \vec{D}\cdot d\vec{S}\end{aligned}}$$

$$\frac{\partial^2 E}{\partial t^2} = \frac{1}{\varepsilon_0\mu_0}\frac{\partial^2 E}{\partial x^2}$$
$$\frac{\partial^2 H}{\partial t^2} = \frac{1}{\varepsilon_0\mu_0}\frac{\partial^2 H}{\partial x^2}$$
VALOVNI ENAČBI

Rešitev: Potujoče valovanje:

$$E = E_0\cos(\omega t - kx)$$

$$\left.\begin{aligned}\frac{\partial^2 E}{\partial x^2} &= -E_0 k^2\cos(\omega t - kx)\\ \frac{\partial^2 E}{\partial t^2} &= -E_0\omega^2\cos(\omega t - kx)\end{aligned}\right\} \div$$

$$\frac{\partial^2 E}{\partial t^2} = \frac{1}{\varepsilon_0\mu_0}\frac{\partial^2 E}{\partial x^2}$$

$$\Rightarrow k = \frac{\omega}{c_0} \qquad \frac{\frac{\partial^2 E}{\partial x^2}}{\frac{\partial^2 E}{\partial t^2}} = \frac{k^2}{\omega^2} = \frac{\omega^2}{\omega^2 c_0^2} = \frac{1}{c_0^2} \Rightarrow \boxed{\frac{\partial^2 E}{\partial t^2} = c_0^2\frac{\partial^2 E}{\partial x^2}}$$

Hitrost širjenja motnje

$$c_0^2 = \frac{1}{\varepsilon_0\mu_0}$$

$$\boxed{c_0 = \frac{1}{\sqrt{\varepsilon_0\mu_0}}}$$

$$\Downarrow$$

$$c_0 \approx 3\cdot 10^8\ \mathrm{m/s}$$

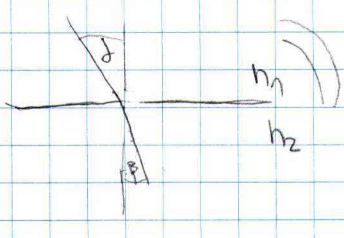
Če $\varepsilon \neq 1$ $\quad \varepsilon_0 \rightarrow \varepsilon\varepsilon_0$

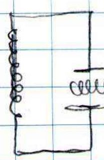
$\mu \neq 1$ $\quad \mu_0 \rightarrow \mu\mu_0$

ZA PROZORNE SNOVI

$$\mu = 1 \qquad c = \frac{1}{\sqrt{\varepsilon\varepsilon_0\mu_0}} = \frac{c_0}{\sqrt{\varepsilon}}$$

$\boxed{n = \sqrt{\varepsilon}}$ $\Rightarrow$ LOMNI KOLIČNIK

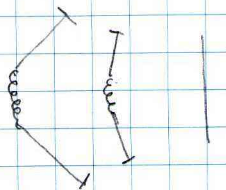




$\omega_0 = \frac{1}{\sqrt{LC}}$

$L \propto N^2$

$C \propto \frac{S}{d}$



DIPOLNA ANTENA

GOSTOTA ENERGIJSKEGA TOKA V EM VALOVANJU 7.4.11

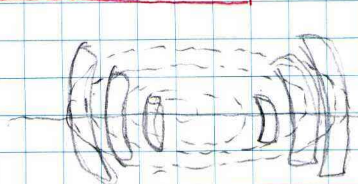
$\bar{j} = \bar{w} c_0 \qquad c_0 = \frac{1}{\sqrt{\varepsilon_0 \mu_0}} \qquad \vec{E} = \vec{B} \times \vec{c_0} \Rightarrow E = B c_0$

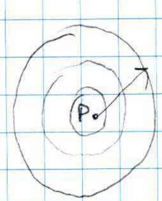
$w = w_E + w_B = \frac{1}{2}\varepsilon_0 E^2 + \frac{1}{2}\mu_0 H^2 = \frac{1}{2}\varepsilon_0 E^2 + \frac{1}{2}\mu_0 \frac{B^2}{\mu_0} = \frac{1}{2}E^2\varepsilon_0 + \frac{1}{2}\frac{B^2}{\mu_0}$

$= \frac{1}{2}\varepsilon_0 E^2 + \frac{1}{2}\frac{E^2}{\mu_0 c_0^2} = \frac{1}{2}\varepsilon_0 E^2 + \frac{1}{2}\frac{E^2 \varepsilon_0 \mu_0}{\mu_0} = \boxed{\varepsilon_0 E^2} \Leftarrow \boxed{E = E_0 \cos(\omega t - kx)}$

$\varepsilon_0 E_0^2 \overline{\cos^2(\omega t - kx)} = \frac{1}{2}\varepsilon_0 E_0^2$

$$\boxed{\bar{j} = \bar{w} c_0 = \frac{1}{2}\varepsilon_0 E_0^2}$$





$S = 4\pi r^2$

$j = \frac{P}{4\pi r^2} \propto \frac{1}{r^2}$

Gostota energijskega toka pada s kvadratom razdalje

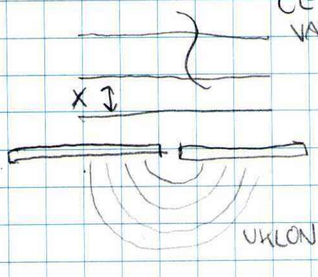
Poskus:

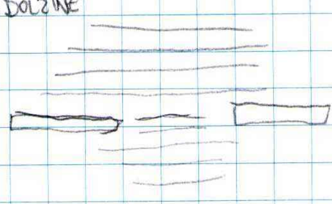
$c_0 = \frac{18{,}2\,m}{60\,ns} = \frac{18{,}2 \cdot 10^{-9}}{60} \simeq 3 \cdot 10^8\,m/s$

Dolgi elm-valovi → So radijski, se uklanjajo na ovirah

ČE REŽA REDA VALOVNE DOLŽINE

ČE REŽA VEČJA



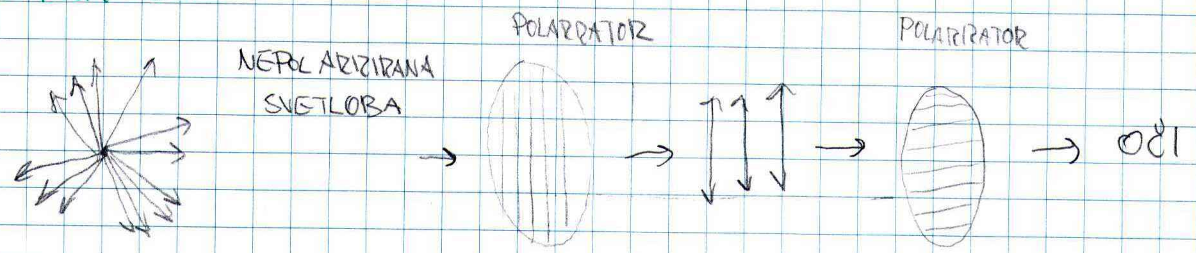


Pri TV in mobilnih ~~oddajnikih~~ se že ovira valovi ne širijo

Radijski se širijo zaradi uklona

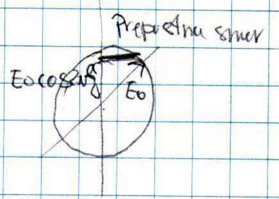
POLARIZACIJA

Polarizacija



Rabimo dva, ker energija nič ne pride

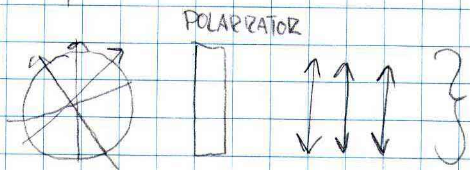
$\overline{j} = \overline{w} c_0 \to \frac{1}{2} \varepsilon_0 E_0^2$



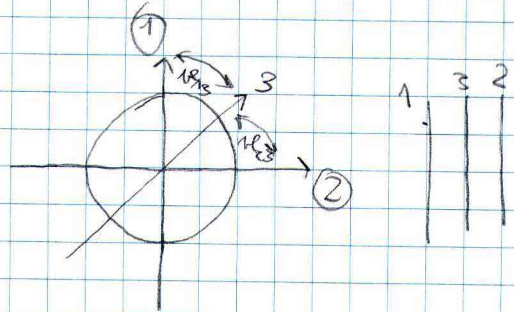
$\overline{j}_{vpadna} = \frac{1}{2} \varepsilon_0 E_0^2 c_0$

$\overline{j}_{prep} = \frac{1}{2} \varepsilon_0 (E_0 \cos\vartheta)^2 c_0$

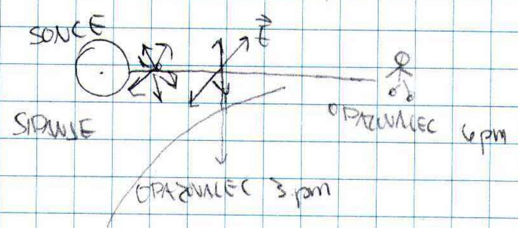
Prepustnost $= \frac{\overline{j}_{prep}}{\overline{j}_{vp}} = \frac{\frac{1}{2}\varepsilon_0 (E_0 \cos\vartheta)^2 c_0}{\frac{1}{2}\varepsilon_0 E_0^2 c_0} = \boxed{\cos^2\vartheta}$



$\overline{\cos^2\vartheta} = \frac{1}{2}$

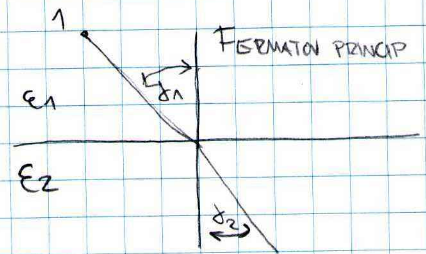


To je zmanjšanje zaradi polarizacije, to ni absorbcija



LOMNI ZAKON

7.4.11



$c_1 = \frac{c_0}{\sqrt{\varepsilon_1}} = \frac{c_0}{n_1}$, $n_1 = \sqrt{\varepsilon_1}$

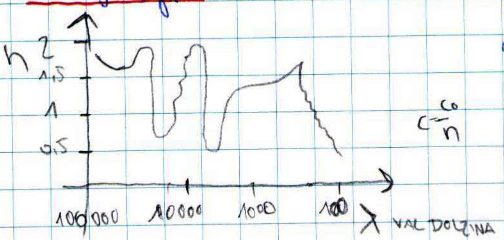
$c_2 = \frac{c_0}{\sqrt{\varepsilon_2}} = \frac{c_0}{n_2}$, $n_2 = \sqrt{\varepsilon_2}$

$$\boxed{\frac{\sin\alpha}{\sin\beta} = \frac{c_1}{c_2}}$$ LOMNI ZAKON

$$\boxed{\frac{\sin\alpha}{\sin\beta} = \frac{n_2}{n_1}}$$

TOTALNI ODBOJ ↑

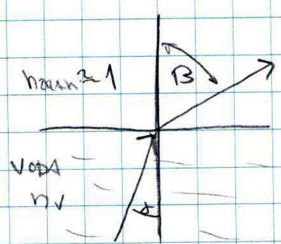
Disperzija - odvisnost lomnega količnika od valovne dolžine



$c = \frac{c_0}{n}$

Odvisen zaradi tega, ker imajo molekule v snovi neke lastne nihajne čase.

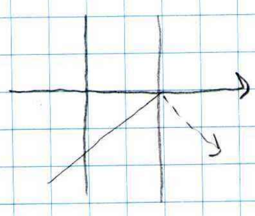
TOTALNI ODBOJ



$$\boxed{\begin{aligned}\alpha &= \alpha_c \\ \beta &= \frac{\pi}{2}\end{aligned}}$$

$$\boxed{\frac{\sin\alpha}{\sin\beta} = \frac{n_v}{1}}$$

$\frac{\sin\alpha_c}{1} = n_v$

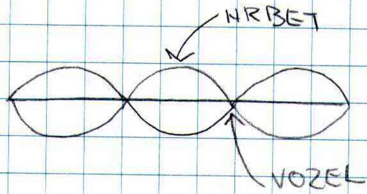


$$\boxed{\alpha_c = \arcsin(n_v)}$$

→ α kritični

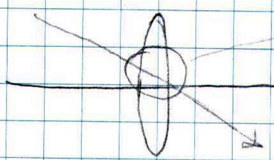
11.4.11

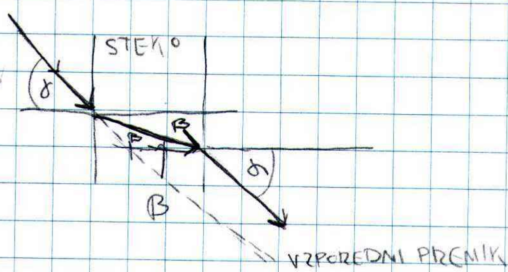
STOJNO EM VALOVANJE



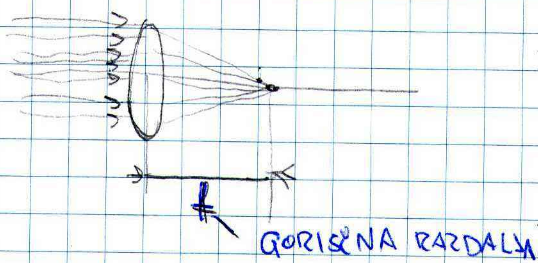
OPTIČNI APARATI

TANKE LEČE



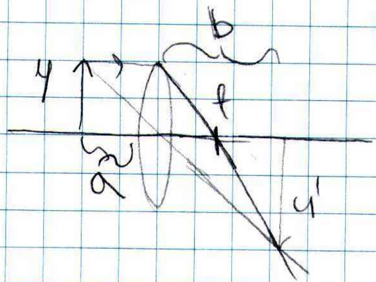


GORIŠČE



Razpršilna in zbiralna leča

KONVEKSNA LEČA



ENAČBA

$$\boxed{\frac{1}{a} + \frac{1}{b} = \frac{1}{f}}$$

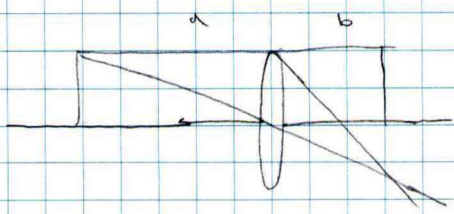
$$\frac{b}{y} = \frac{fa}{a(a-f)} = \frac{f}{a-f}$$

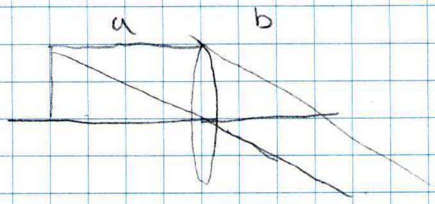
POVEČAVA

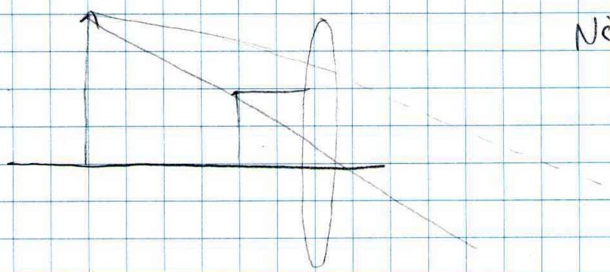
$$M = \frac{y'}{y} \qquad \frac{y}{a} = \frac{y'}{b} \Rightarrow \frac{y'}{y} = \frac{b}{a}$$

$$\boxed{M = \frac{y'}{y} = \frac{b}{a} =} \quad \boxed{M = \frac{f}{a-f}}$$

BIKONVEKSNA LEČA







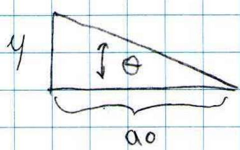
NIČ NE VIDMO NA ZASLONU

LUPA

a_0 = NORMALNA ZORNA RAZDALJA

$$\boxed{M = \frac{\operatorname{tg}\theta'}{\operatorname{tg}\theta}} = \frac{y a_0}{f y} = \frac{a_0}{f}$$

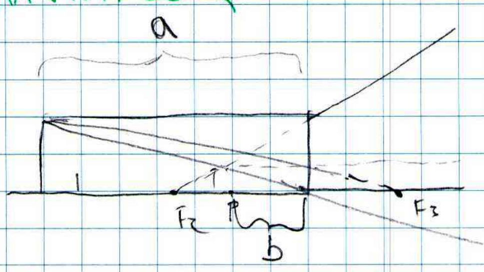
$$\boxed{M = \frac{a_0}{f}}$$

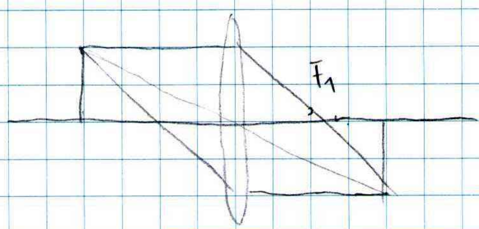


$$\boxed{\operatorname{tg}\theta = \frac{y}{a_0}}$$

BIKONKAVNA LEČA

$f<0$
$a>0$
$b>0$





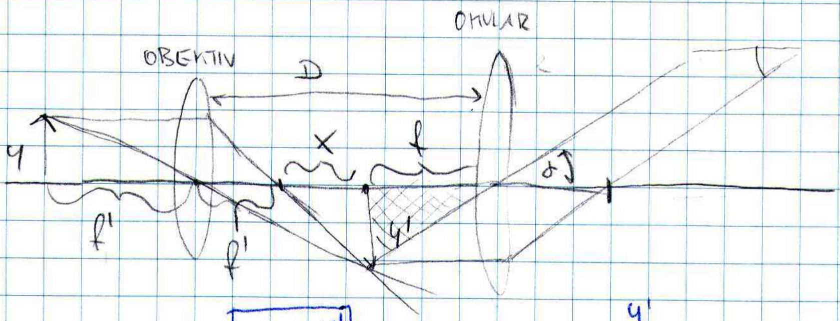
SISTEM DVEH LEČ

$$\boxed{\frac{1}{f} = \frac{1}{f_1} + \frac{1}{f_2} - \frac{s}{f_1 f_2}}$$

NADOMESTNA GORIŠČNA RAZDALJA

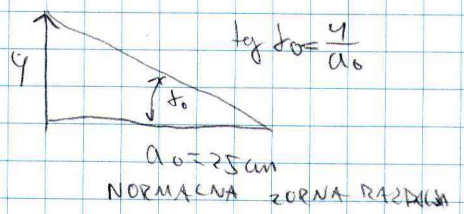
s = razdalja med lečama

MIKROSKOP



$$\boxed{\frac{y}{f'} = \frac{y'}{f}}$$

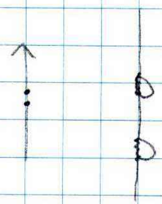
$$\tan\gamma = \frac{y'}{f}$$



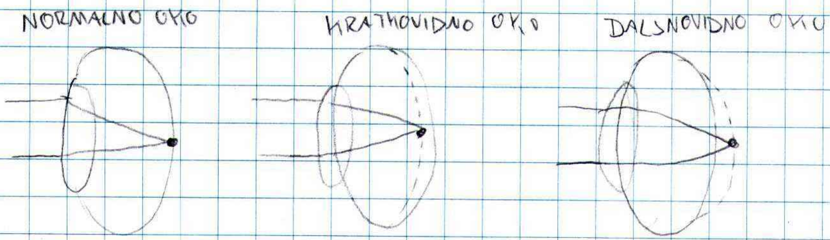
$$\tan\gamma_0 = \frac{y}{a_0}$$

POVEČAVA

$$M = \frac{\tan\gamma}{\tan\gamma_0} = \frac{y' a_0}{f y} = \frac{x a_0}{f f'} = \boxed{\frac{(D-f-f')a_0}{f f'}}$$

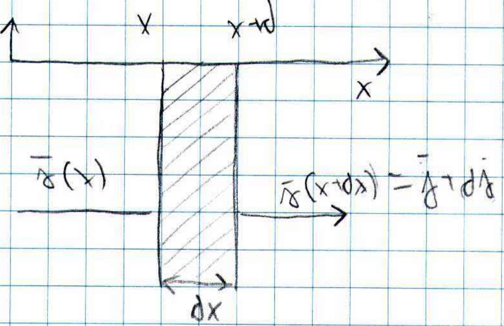


LOČLJIVOST
(valovna dolžina)



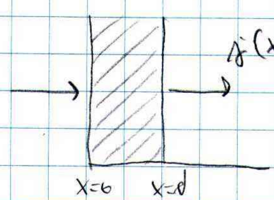
DIOPTRIJA: $\frac{1}{f_1}$

ABSORPCIJA



$$\boxed{dj \propto -dx\, j}$$

$$\boxed{dj = -\mu j\, dx}$$ ABSORPCIJSKI KOEFICIENT



$$dj = -\mu j\, dx \,/\, j$$

$$\int_{j_0}^{j(x=d)} \frac{dj}{j} = -\mu \int_0^d dx$$

$$\ln j \Big|_{j_0}^{j(x=d)} = -\mu d$$

$$\ln j(x=d) - \ln j_0 = -\mu d$$

$$\ln \frac{j(x=d)}{j_0} = -\mu d$$

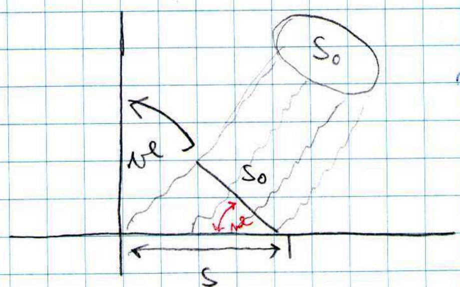
$$\boxed{j(x=d) = j_0 \exp(-\mu d)}$$

EKSPONENTNI ABSORPCIJSKI ZAKON

FOTOMETRIJA

14.4.11

OSVETLJENOST



$\cos\vartheta = \frac{S_0}{S}$

$\boxed{S = \frac{S_0}{\cos\vartheta}}$

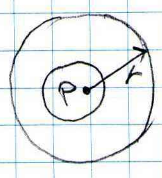
GOSTOTA ENERGIJSKEGA TOKA j

$E = \frac{P}{S}$ → Energijski tok [W]

$= \frac{P}{S_0}\cos\vartheta$ → Energijski tok v curku

SVETILNOST

1. TOČKASTO TELO



$j = \frac{P}{4\pi r^2} = \frac{I}{r^2}$

$\boxed{j = \frac{I}{r^2}}$

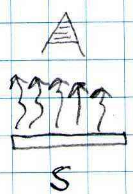
I - svetilnost [illegible]

$I = \frac{P}{4\pi}$

4π - poln prostorski kot

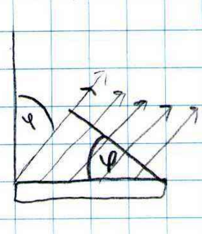
$\boxed{I = \frac{P}{4\pi}}$

2. PLOSKOVNO SVETILO



$I = B_0 S$

↑ SVETLOST



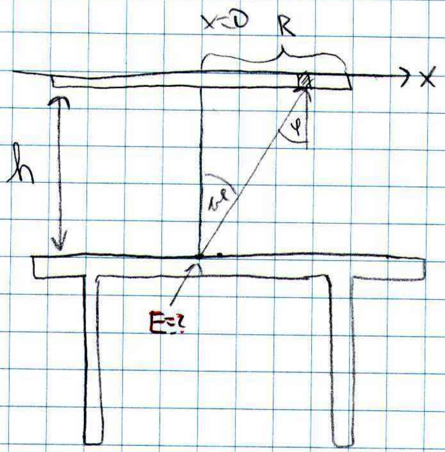
$\cos\varphi = \frac{\tilde{S}}{S}$

$\tilde{S} = S\cos\varphi$

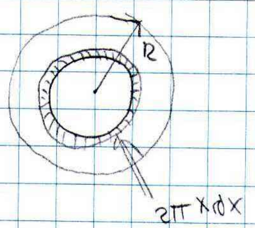
B_0 - svetlost

$\boxed{I = BS' = BS\cos\varphi}$

Svetlost odvisna od kota. Če ni odvisna od kota pravimo takemu svetilu LAMBERTOVO SVETILO



TLORIS



$$dE = \frac{dI}{r^2} \vartheta = \frac{B 2\pi\, x\, dx \cos 3\vartheta}{r^2}$$

$$dI = B 2\pi\, dx \cos\varphi$$

$$\varphi = \vartheta$$

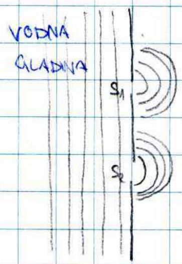
$$E = \int \frac{2\pi B \cos^3\vartheta\, x\, dx}{r^2} = \frac{\pi B}{2}\left(1 - \cos 2\beta\right)$$

Limita - zelo veliko svetilo $(R \to \infty \Rightarrow \beta_m \to \frac{\pi}{2}) \cdot \cos(2\frac{\pi}{2}) = 1$

$$E_\infty = \pi B$$

INTERFERENČNI POJAVI PRI EMV

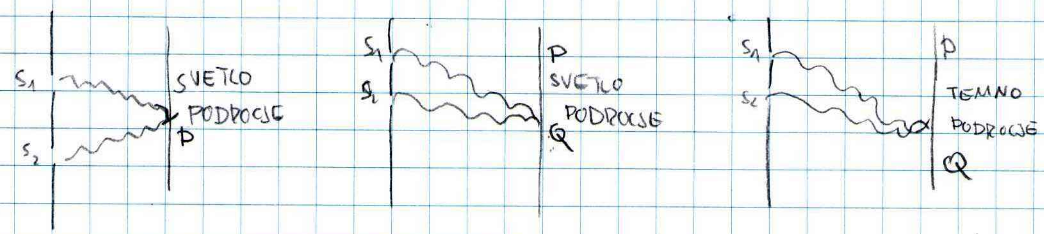
INTERFERENCA



HEYGENSOV PRINCIP.

Izvora KOHERENTNA - zavata v fazi. Sta iz istega izvora - zato sta koherentna

YOUNGOV POSKUS



Fazna razlika med enim in drugim ~~izvorom~~ mora biti konstantna

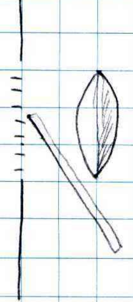
Če ni, niso svetlobe nikoli koherentne sem z zelo - vrh-na-vrh

Huygensovo načelo vsako točko valovne fronte obravnavamo kot nov krogelni val

OPTIČNA MREŽICA → več 100 rež - 600 rež na mm

⇒ Dobimo več pik . . . . . .

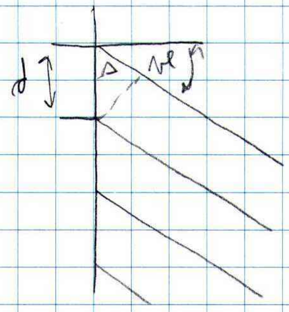
CENTRALNA



$$\boxed{j = j_0 \frac{\sin^2(\pi b \sin\theta/\lambda)}{(\pi b \sin\theta/\lambda)^2}}$$

$$j = j_0 \frac{\sin^2(\pi b \sin\theta/\lambda)}{(\pi b \sin\theta/\lambda)^2} \cdot \frac{\sin^2(N\pi d \sin\theta/\lambda)}{\sin^2(\pi d \sin\theta/\lambda)}$$

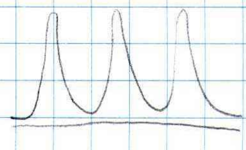
UKLONSKA MREŽICA



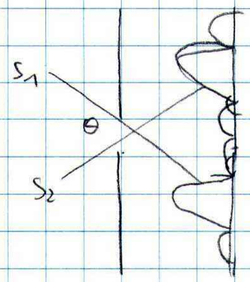
Pogoj za ojačitev:

$$\Delta = d \sin \vartheta = N\lambda$$

$$\sin \vartheta_{max} = N \frac{\lambda}{d} \quad ; N\ 1,2,3,4$$



LOČLJIVOST zaradi uklona



Pri optičnih mikroskopih omejitve kako zmanjšat valovna dolžina
⇒ Rabimo elektronski mikroskop – pri teh elektronov pa lahko dobimo veliko manjše valovne dolžine

FOŠNARIČ

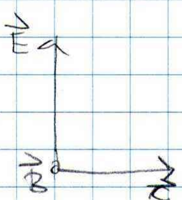
$$\vec{E} = \vec{B} \times \vec{c}$$

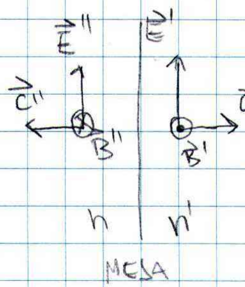
$$E = Bc$$

$$c_0 = \frac{1}{\sqrt{\varepsilon_0 \mu_0}}$$

$$c = \frac{1}{\sqrt{\varepsilon \varepsilon_0 \mu \mu_0}}$$

$$n = \frac{c_0}{c}$$





$$\boxed{E + E'' = E'}$$

$$B - B'' = B'$$

$$H - H'' = H'$$

$$B = \mu\mu_0 H \Rightarrow H = \frac{B}{\mu\mu_0}$$

$$\mu \approx \mu'$$

$$H' = \frac{B'}{\mu\mu_0}$$

$$H'' = \frac{B''}{\mu\mu_0}$$

$$\frac{E}{c} - \frac{E''}{c} = \frac{E'}{c'} \quad / \, c \quad \Rightarrow \quad \boxed{E - E'' = E' \frac{c}{c'} = E' \frac{n'}{n}}$$

$$2E = E' + E' \frac{n'}{n} = E'\left(1 + \frac{n'}{n}\right)$$

$$\boxed{E' = \frac{2E}{1 + \frac{n'}{n}}}$$

$$E - E'' = \frac{2E}{1 + \frac{n'}{n}} \frac{n'}{n} = \frac{2E}{\frac{n}{n'} + 1} = \frac{2n'}{n + n'} E$$

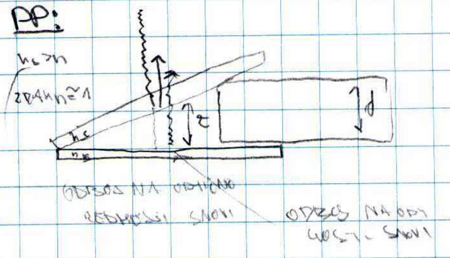
$$E'' = E\left(1 - \frac{2n'}{n + n'}\right) = \frac{(n - n')}{n + n'} E \Rightarrow \boxed{E'' = \frac{(n - n')}{(n + n')} E}$$

[illegible]

$n > n'$ – Odboj na optično redkejši snovi ... $\vec{E}$ se odbije z isto fazo

$n < n'$ – Odboj na optično gostejši snovi ... $\vec{E}$ se odbije z nasprotno fazo

PP:



$$\delta = 2z + \frac{\lambda_0}{2}$$

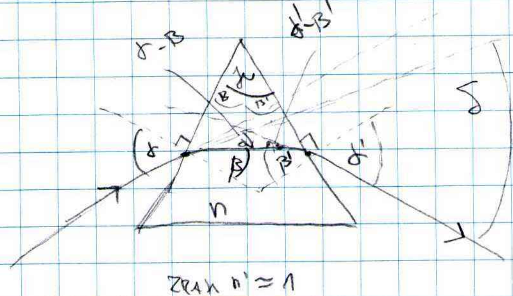
ZA OJAČITEV

$$2z + \frac{\lambda_0}{2} = N\lambda_0 \quad\Rightarrow\quad 2z = N\lambda_0 - \frac{\lambda_0}{2} \qquad \Delta z \simeq \frac{\lambda_0}{2} \simeq 200\,\mathrm{nm}$$

$N = 1, 2, 3, \ldots$

$$\boxed{z = \frac{1}{4}(2N-1)\lambda_0}$$

PRIZMA (LOM SVETLOB)



$$\frac{\sin\gamma}{\sin\beta} = \frac{n}{n'_{=1}} = n \qquad \frac{\sin\beta'}{\sin\gamma'} = \frac{1}{n}$$

$$\delta = (\gamma - \beta) + (\gamma' - \beta') = (n-1)\beta + (n-1)\beta' = (n-1)(\beta + \beta')$$

$$\boxed{\Rightarrow \delta = (n-1)\varphi}$$

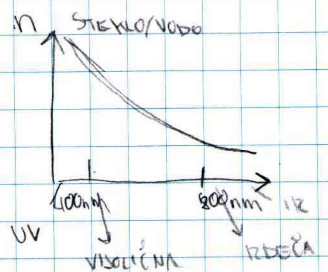
Majhni koti: $\frac{\gamma}{\beta} = n \Rightarrow \gamma = n\beta$

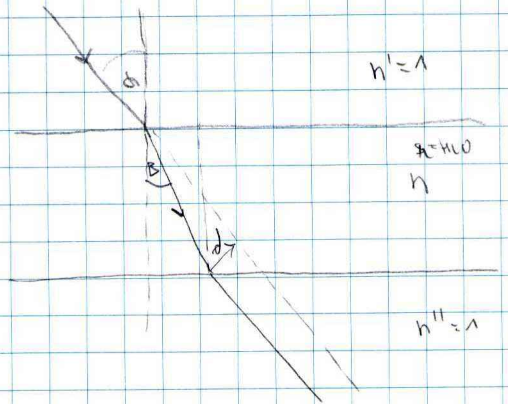
$$\frac{\beta'}{\gamma'} = \frac{1}{n} \Rightarrow \gamma' = n\beta'$$

DISPERZIJA: $c = c(\lambda)$

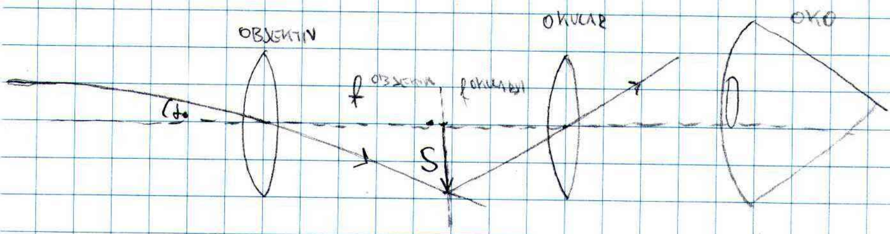
$n = n(\lambda)$

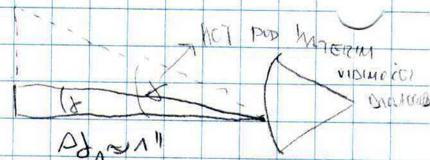
$\delta(\lambda) = (n(\lambda) - 1)\varphi$





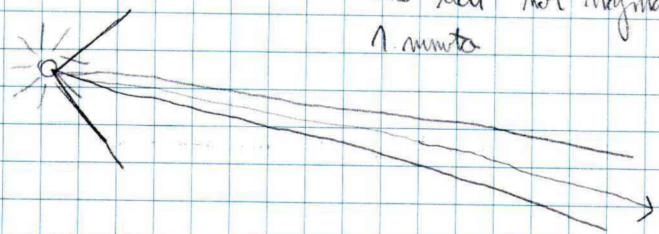
DALJNOGLED





$\Delta\delta_1 \approx 1''$

Oko vidi kot najmanj 1 minuto

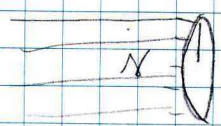


POVEČAVA

$$\boxed{M = \frac{\tan\delta}{\tan\delta_0} = \frac{\frac{h}{x}}{\frac{h_0}{x}} = \frac{h}{h_0}} = \frac{f_{objektiva}}{f_{okularja}}$$

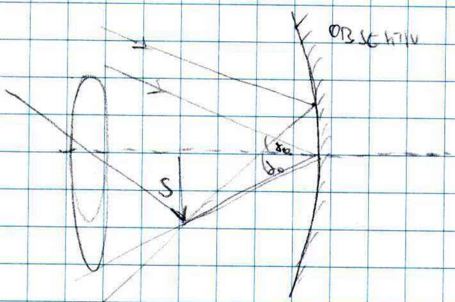
V [illegible] pomenu:

$$M = \frac{\frac{s}{f_{ok}}}{\frac{s}{f_{ob}}} = \frac{f_{ob}}{f_{ok}}$$



$P_{ob} = P_{OB} = \frac{P}{4\pi r^2}\pi r_{ob}^2$

OSVETLJENOST SLIKE $\boxed{j' \propto \frac{r_{ob}^2}{r^2}}$



V sredo ni Fošnarica na vajah :. No v sredo bo spet Šarka, no sej ni nč narobe če kdaj kakšno ženske vrže pred tablo

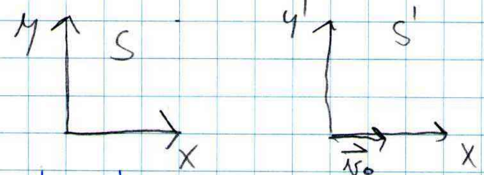
MODERNA FIZIKA

POSEBNA TEORIJA RELATIVNOSTI

9.5.11

(INERCIALNI - NEPOSPEŠENI OPAZOVALNI SIST.)

1. GALILEJEVA TRANSFORMACIJA



$x' = x - v_0 t \rightarrow \frac{dx'}{dt} = \frac{dx}{dt} - v_0 \frac{dt}{dt}$

$y' = y$

$z' = z$

$\boxed{v_x' = v_x - v_0}$

$x = x' + v_0 t$

$y = y'$

$z = z'$

$\boxed{t = t'}$ ABSOLUTNI ČAS

2.) MAXWELL

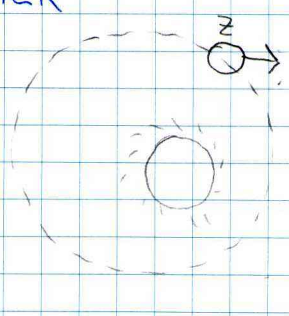
? Neki ni štimal ⇒ uvedejo ETER

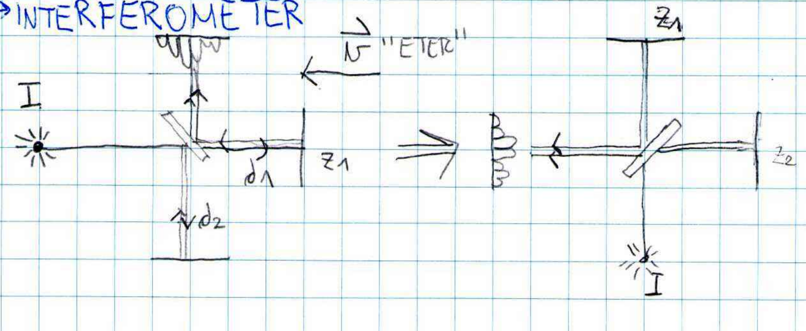
EMV: $\boxed{c_0 = \frac{1}{\sqrt{\varepsilon_0 \mu_0}} = konst}$

EKSPERIMENT MICHELSONA IN MORLEY

↳ INTERFEROMETER

„ETER"





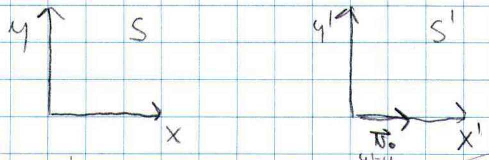
ALBERT EINSTEIN (1905):

DVE GLAVNI NAČELI:

1) Hitrost svetlobe $c_0 = konst$

2.) Načelo relativnosti - „vsi nepospešeni" opazovalni sistemi so enakovredni

LORENTZOVE TRANSFORMACIJE



$y=y'$ $z=z'$ $\quad$ $y'=y$ $z'=z$

$x=\gamma(x'+v_0 t')$ $\qquad$ $x'=\gamma(x-v_0 t) \longrightarrow \dfrac{dx'}{dt'}=\dfrac{\gamma(dx-v_0dt)}{\gamma\left(dt-\frac{dx}{v_0}\left(1-\frac{1}{\gamma^2}\right)\right)}=\dfrac{\frac{dx}{dt}-v_0}{1-\frac{dx}{dt}\cdot\frac{1}{v_0}\left(1-\frac{1}{\gamma^2}\right)}=\dfrac{v_x-v_0}{1-\frac{v_x}{v_0}\left(1-\frac{1}{\gamma^2}\right)}$

PRVIČ ČAS NI ABSOLUTEN

$\gamma=\gamma(v)$ → FUNKCIJA HITROSTI

$\frac{x}{\gamma}=x'+v_0t' \Rightarrow t'=\frac{1}{v_0}\left(\frac{x}{\gamma}-x'\right)=\frac{1}{v_0}\left(\frac{x}{\gamma}-\gamma x+v_0\gamma t\right)$

$=\gamma\left(t-\frac{x}{v_0}\left(1-\frac{1}{\gamma^2}\right)\right)$

$= dt'=\gamma\left(dt-\frac{dx}{v_0}\left(1-\frac{1}{\gamma^2}\right)\right)$

- Homogenost prostora in časa
- Izotropnost prostora

$v_x=c_0 \Rightarrow v_x'=c_0$

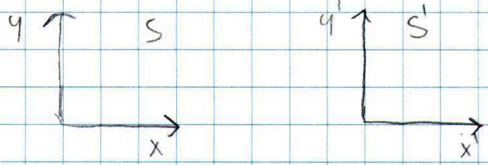
$$\boxed{c_0=\frac{c_0-v_0}{1-\frac{c_0}{v_0}\left(1-\frac{1}{\gamma^2}\right)}} \Rightarrow 1-\frac{c_0}{v_0}\left(1-\frac{1}{\gamma^2}\right)=1-\frac{v_0}{c_0}$$

$$1-\frac{1}{\gamma^2}=\frac{v_0^2}{c_0^2}$$

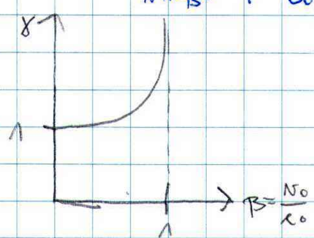
$$\frac{1}{\gamma^2}=1-\frac{v_0^2}{c_0^2}$$

$$\boxed{\gamma=\frac{1}{\sqrt{1-\frac{v_0^2}{c_0^2}}}} \qquad \boxed{t'=\gamma\left(t-\frac{v_0}{c_0^2}x\right)} \qquad \boxed{v_x'=\frac{v_x-v_0}{1-\frac{v_xv_0}{c_0^2}}}$$

DOGODKA SE ZGODITA NA ISTEM MESTU ($\tau=t_2-t_1$)



$\gamma=\frac{1}{\sqrt{1-\beta^2}}$ $\quad$ $\beta=\frac{v_0}{c_0}$



$$\boxed{\begin{aligned}x&=\gamma(x'+v_0t')\\ y&=y'\\ z&=z'\\ t&=\gamma\left(t'+\frac{v_0}{c_0^2}x'\right)\end{aligned}} \qquad \boxed{\begin{aligned}x'&=\gamma(x-v_0t)\\ y'&=y\\ z'&=z\\ t'&=\gamma\left(t-\frac{v_0}{c_0^2}x\right)\end{aligned}}$$

$$v_x=\frac{v_x'+v_0}{1+\frac{v_x'v_0}{c_0^2}} \qquad v_x'=\frac{v_x-v_0}{1-\frac{v_xv_0}{c_0^2}}$$

$$\boxed{\begin{aligned}v_y&=\frac{dy}{dt}=\frac{dy'}{\gamma\left(dt'-\frac{v_0}{c_0^2}dx'\right)}=\frac{\frac{dy'}{dt'}}{\gamma\left(1-\frac{v_0\frac{dx'}{dt'}}{c_0^2}\right)}=\frac{v_y'}{\gamma\left(1-\frac{v_0v_x'}{c_0^2}\right)}\\ v_z&=\frac{dz}{dt}=\frac{v_z'}{\gamma\left(1-\frac{v_0v_x'}{c_0^2}\right)}\end{aligned}}$$

Čas in krajevne koordinate niso neodvisni → Dogodek

SOČASNOST JE RELATIVNA

9.5.XI

	S	S'
1. DOGODEK :	$t_1 \quad x_1$	$t_1' = \gamma\left(t_1 - \frac{v_0}{c_0^2} x_1\right)$
2. DOGODEK :	$t_2 = t_1 \quad x_2 \neq x_1$	$t_2' = \gamma\left(t_1 - \frac{v_0}{c_0^2} x_2\right)$
	$\Delta t = t_2 - t_1 = 0$ SOČASNA	$\Delta t' = \gamma \frac{v_0}{c_0^2}(x_2 - x_1) \neq 0$ NISTA SOČASNA

PODALJŠANJE (DILATACIJA) ČASA

	S		S'
1. DOGODEK	t_1	x_1	$t_1' = \gamma\left(t_1 - \frac{v_0}{c_0^2} x_1\right)$
2. DOGODEK	t_2	$x_2 = x_1$	$t_2' = \gamma\left(t_2 - \frac{v_0}{c_0^2} x_2\right)$

$\Delta t = t_2 - t_1 = \tau$ — LASTNI ČAS (URA MIRUJE)

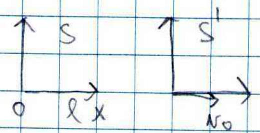
$$\Delta t' = t_2' - t_1' = \gamma t_2 - \gamma t_1 = \gamma \overbrace{(t_2 - t_1)}^{\Delta t}$$

$$\boxed{\Delta t' = \gamma \cdot \Delta t = \gamma \tau}$$

Čas med dogodkoma najkrajši v lastnem sistemu. Drugod daljši

SKRČENJE DOLŽINE

	S		S'	
1. DOGODEK	$x_1 = 0$	$t_1 \ldots$	$t_1' = t$	$x_1' =$
2. DOGODEK	$x_2 = l$	$t_2 \ldots$	$t_2' = t$	$x_2' =$



$\Delta x = x_2 - x_1 = l \qquad t_2' - t_1' = 0$

$\Delta x = \gamma(\Delta x' + v_0 \Delta t')$

$\Delta x = \gamma \Delta x'$

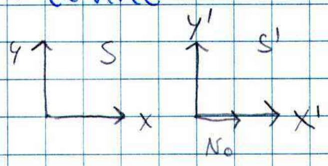
$l = \gamma \cdot l'$

$$\boxed{l' = \frac{l}{\gamma}}$$

ŠTIRIRAZSEŽNI PROSTOR ≡ PROSTOR-ČAS (PROSTOR MINKOWSKEGA)

Dogodek popiše "Svetovni četverec"

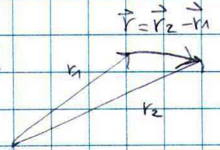
$$^4X = (\underbrace{c_0 t}_{\text{ČASOVNI DEL}}, \underbrace{x, y, z}_{\text{KRAJEVNI DEL}})$$



$\beta = \frac{v_0}{c_0}$

$$c_0 t = \gamma (c_0 t' - \beta x')$$
$$x = \gamma (x' - \beta c_0 t')$$
$$y = y' \quad z = z'$$

"KLASIČNO" 3D:



$|\vec r| = \sqrt{\vec r \cdot \vec r} =$ invarianta

Dolžina oz. absolutni prikaz tega vekt. je invarianta

"ŠTIRIRAZSEŽNI PROSTOR":

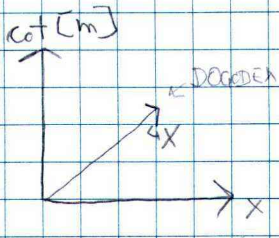
$$^4X \cdot {}^4X = \underset{\substack{\downarrow \\ \text{PREDZNAK DRUGAČEN}}}{-} c_0^2 t^2 + x^2 + y^2 + z^2$$

SVETOVNI ČETVEREC

$^4X \equiv X^\mu \rightarrow$ STANOVNIK TAKO NAPIŠE

3D: $|\vec r| = \sqrt{\vec r \cdot \vec r} =$ invarianta

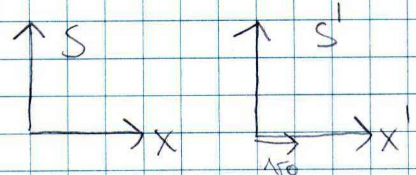
$$\boxed{^4X = (c_0 t, x, y, z) = (c_0 t, \vec r)}$$



$$\left.\begin{aligned} ^4X \cdot {}^4X &= -c_0^2 t^2 + x^2 + y^2 + z^2 \\ \text{ali} &= \underbrace{c_0^2 t^2 - x^2 - y^2 - z^2}_{\text{STANOVNIK}} \end{aligned}\right\} \text{DVE RAZLIČNI SIGNATURI}$$

$$^4v = (\underbrace{v_0}_{\text{ČASOVNI DEL}}, \underbrace{v_1, v_2, v_3}_{\text{KRAJEVNI DEL}})$$

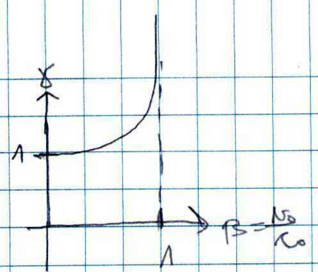
LORENTZOVE TRANSFORMACIJE



S, S' nepospešena - INERCIALNA

Če bi bila pospešena bi meli sistemske sile

$$v_0 = \gamma (v_0 - \beta v_1), \quad \beta = \frac{v_0}{c_0} \qquad \gamma = \frac{1}{\sqrt{1-\beta^2}}$$



$v_0' = \gamma(v_0 - \beta v_1)$

$v_1' = \gamma(v_1 - \beta v_0)$

$v_2' = v_2$

$v_3' = v_3$

ČETVEREC HITROSTI

$^4v = \frac{d^4x}{d\tau} = \boxed{\frac{d^4x}{dt}\cdot\gamma}$ τ - LASTNI ČAS   "Moving clocks run slow"

$t = \gamma \cdot \tau$ $\gamma = \frac{1}{\sqrt{1-\frac{v^2}{c_0^2}}}$

$\boxed{^4v = \gamma\left(c_0\frac{dt}{dt}, \frac{dx}{dt}, \frac{dy}{dt}, \frac{dz}{dt}\right) = \gamma(c_0, v_x, v_y, v_z)}$

$= \gamma(c_0, v)$

ČETVEREC GIBALNE KOLIČINE

$\vec{G} = m\vec{v}$ V klasični fiz G, v moderni P

$$\boxed{^4P = m_0\,{}^4v = (m_0\gamma c_0, \underbrace{m_0\gamma\vec{v}}_{P}) = \left(\frac{E}{c_0}, \vec{P}\right)}$$

$\vec{P} = m_0\gamma\vec{v}$ RELATIVISTIČNA GIBALNA KOLIČINA

$m_r = m_0\gamma$ RELATIVISTIČNA MASA

$\frac{E}{c_0} = m_0\gamma c_0 \Rightarrow E = m_0\gamma c_0^2$ POLNA ENERGIJA

$E = W$

$W_k = T$

$\boxed{E_0 = m_0 c_0^2}$ MIROVNA ENERGIJA

$W_k = E - E_0 = m_0\gamma c_0^2 - m_0 c_0^2 = m_0 c_0^2(\gamma-1)$

$W_k = m_0 c_0^2\left(\frac{1}{\sqrt{1-\frac{v^2}{c_0^2}}} - 1\right) = m_0 c_0^2\left(1 + \frac{1}{2}\frac{v^2}{c_0^2} + O\left(\frac{v_0^4}{c_0^4}\right) - 1\right)$ TAYLORJEVA VRSTA

$W_k = \frac{1}{2} m_0 v^2 + O\left(\frac{v^4}{c_0^4}\right)$

Pri $v \ll c_0$: $W_k \simeq \frac{1}{2} m_0 v^2$

${}^4v\,{}^4v$ = invarianta

LASTNI SISTEM ($v = 0$)

$^4P = \left(\frac{E}{c_0}, \vec{P}\right)$ $\vec{P} = m_0\gamma\vec{v}$

$^4P \cdot {}^4P = -\frac{E^2}{c_0^2} + p^2 = -\frac{E_0^2}{c_0^2}$

$\boxed{E^2 = E_0^2 + c_0^2 p^2}$

$$\vec{P} = m_0 \gamma \vec{N} \qquad \frac{E}{P} = \frac{m_0 \gamma c_0^2}{m_0 \gamma N} = \frac{c_0^2}{N}$$

$$\vec{E} = m_0 \gamma c_0^2$$

DELEC $N = c_0$ (Skrajni primer)

$$\frac{E}{P} = \frac{c_0^2}{c_0} = c_0 \Rightarrow \boxed{E = c_0 P} \rightarrow E_0 = 0 \Rightarrow \overset{\text{FOTON}}{\boxed{m_0 = 0}}$$

Da se delec lahko giblje s svetlobno energijo mora imet $m_0 = 0$

NEWTONOV ZAKON V ŠTIRIRAZSEŽNI OBLIKI

KLASIČNO

$$\vec{F} = \frac{dG}{dt} \qquad \vec{G} = m\vec{N}$$

RELATIVISTIČNO

$$^4P = \left(\frac{E}{c_0}, \vec{P}\right), \quad \vec{P} = m_0 \gamma \vec{N}$$

$$^4F = \frac{d(^4P)}{d\tau} = \gamma \frac{d(^4P)}{dt} = \gamma \left(\frac{1}{c_0} \frac{\overset{\text{POLNA ENERGIJA}}{dE}}{dt}, \frac{d\vec{P}}{dt}\right)$$

$t = \gamma \tau \quad , \quad dt = \gamma d\tau$

Četverec sile na naelektren delec:

$$^4F = \left(\frac{e \gamma \overset{\text{JAKOST EL. POLJA}}{\vec{E}} \cdot \vec{N}}{c_0}, e\gamma(\vec{E} + \vec{N} \times \vec{B})\right)$$

KRAJEVNI DEL:

$$\boxed{\frac{d\vec{P}}{dt} = e(\vec{E} + \vec{N} \times \vec{B})} \qquad \boxed{\vec{P} = m_0 \gamma \vec{N}}$$

ČASOVNI DEL:

$N = -\int \vec{E} \cdot d\vec{r} = V_2 - V_1$

$V \equiv \varphi$

$$\frac{\gamma}{\cancel{c_0}} \frac{dE}{dt}^{=W} = \frac{e\gamma \, \vec{E} \cdot \vec{N}}{\cancel{c_0}} \Rightarrow \Delta E = e \int \vec{E} \cdot \overbrace{\vec{N} \, dt}^{d\vec{r}} = -e\Delta\varphi$$

$$\Delta(E + e\varphi) = 0$$

$$E + e\varphi = \text{konst}$$

OHRANITVENI ZAKONI

$$^4F = \frac{d(^4p)}{d\tau} \Rightarrow \Delta\, ^4p = \int {}^4F\, d\tau$$

$$\int {}^4F\, d\tau = 0 \rightarrow \Delta\, ^4p \Rightarrow \boxed{\begin{matrix}\Delta E = 0 \\ \Delta p = 0\end{matrix}}$$

MAXWELLOVE ENAČBE

Vektor četverec potenciala $^4A = \left(\frac{\varphi}{c_0}, \vec{A}\right)$ $\qquad \varphi \equiv V$

(Jakost električnega polja) $\vec{E} = -\vec{\nabla}\varphi - \frac{\partial \vec{A}}{\partial t}$

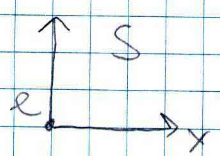
$\vec{B} = \vec{\nabla} \times \vec{A}$ $\qquad \vec{\nabla} = \left(\frac{\partial}{\partial x}, \frac{\partial}{\partial y}, \frac{\partial}{\partial z}\right)$

GOSTOTA NABOJA

$j = (\rho c_0, \vec{j})$

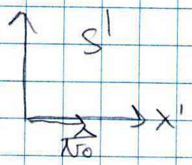
GOSTOTA EL. TOKA

PRIMER: Točkast naboj miruje v izhodišču sistema S



S: $\varphi = \frac{e}{4\pi\varepsilon_0 r}$ $\qquad \vec{A} = 0$

$v_0' = \gamma(v_0 - \beta v_1)$
$v_1 = \gamma(v_1 - \beta v_0)$



S': $\frac{\varphi'}{c_0} = \gamma\left(\frac{\varphi}{c_0} - \beta \cancelto{0}{A_x}\right) = \gamma\frac{\varphi}{c_0} = \gamma\frac{e}{4\pi\varepsilon_0 r c_0}$

$\varphi' = \gamma\frac{e}{4\pi\varepsilon_0 r}$

$$A_x' = \gamma\left(A_x - \beta\frac{\varphi}{c_0}\right) = \gamma\beta\frac{\varphi}{c_0} = \underline{\underline{\gamma\frac{v_0}{c_0^2}\frac{e}{4\pi\varepsilon_0 r}}} \neq 0$$

MAXWELLOVE ENAČBE S ČETVERCI

$\Box\, ^4A = \mu_0\, ^4j$

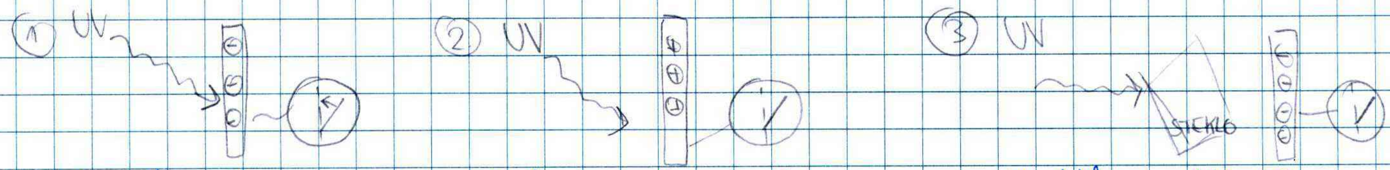
$$\Box = \frac{1}{c_0^2}\frac{\partial^2}{\partial t^2} - \frac{\partial^2}{\partial x^2} - \frac{\partial^2}{\partial y^2} - \frac{\partial^2}{\partial z^2}$$

FOTOEFEKT

18.5.11

Poskus

- Z UV svetimo na ploščico. Če naelektrimo negativno, naboj s časom pade
- Če pa pozitivno pa ne
- Če pa vmes damo steklo pa ne



UV žarek izbija elektrone iz ploščice

Pozitivni preostanek potegne izbite elektrone nazaj

V steklu se UV del spektra absorbira

Za izbijanje e^- mora biti dovolj veliko ν. Tega se ne da razložiti s klasično fiziko

$\bar{j} = c\varepsilon_0 \bar{w} \propto E_0^2$ ← ki opisuje svetlobo kot EMV

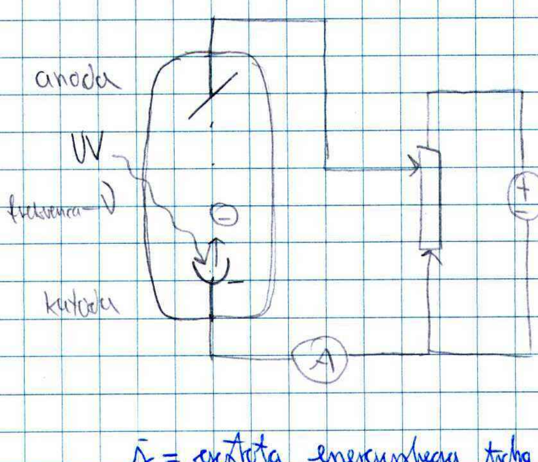
$E_{abs} \propto \bar{j} S t$ — površina ploščice

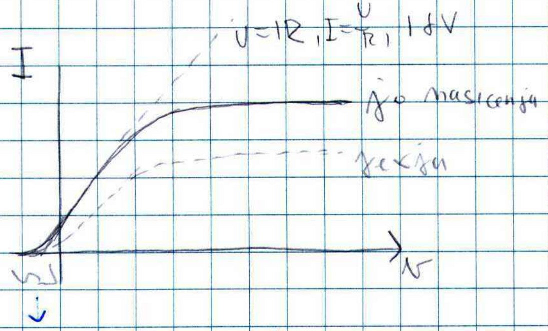
$E_{abs} = a\bar{j}St$ — a – albedo

$E_{abs} \propto t$ — bi morali dolgo ~~obsevati~~ obsevati, pa bo imel dovolj W za izbitje. Vendar W
~~Ampak~~ Ampak to ne gre

Einstein je ista leta objavil 3 ključne stvari

FOTOCELICA





U_0 = Zaporna napetost

$\bar{j}$ = gostota energijskega toka

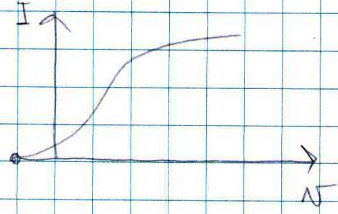
Plato nastane, ko vsi e^- sodelujejo

Zaporna napetost potrebna, ker sicer sami izletijo. Potrebna da vsaj tiste najhitrejše

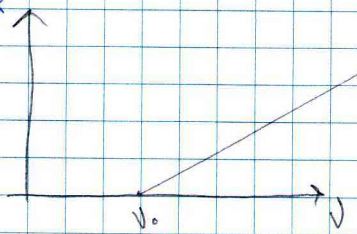
$\frac{m_e v_{max}^2}{2} = e_0 U_0 = A e$ $W_k \rightarrow W_{pe}$

||

W_{kmax} če poznamo U_0, lahko narišemo



$W_{kmax}(\nu) \rightarrow W_{kmax}$

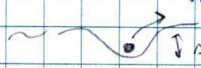


$W_k = h(\nu - \nu_0) = h\nu - h\nu_0 = h\nu - W_{izst}$

$\boxed{W_{kmax} = h\nu - W_{izstop}}$

absorbirana energija

vezavna energija elektronov



$\Delta W = mgh$

$\Delta W = mgh \rightarrow v = 0$

$\Delta W > mgh \rightarrow v > 0$

h - Planckova konstanta - h $\hbar = \frac{h}{2\pi}$

$h\nu$ [J]

Nimajo vsi enake energije, ker v različne smeri se razletijo, nekateri trčijo v atome

Ker je nenavadno: $W_{ass} \propto \nu$

Klasično je $j \propto E_0^2$, $E_{abs} \propto c_0 E_0^2 t$

Energija pride v paketkih → Energijski kvant

Fotoni imajo gibalno količino, mase pa nimajo

Pri trkih se ohranja polna energija

$W_{polna} = W_{0\,lastna} + T_{kinetična}$ $W_0 = m_0 c_0^2$

$\boxed{W^2 = W_0^2 + c_0^2 p^2}$ - relativnost

FOTON: $W_0 = 0$ - lastna energija

$W^2 = c_0^2 p^2$ - rel. gibalna količina

$W = h\nu$ - Polna energija

⇓

$c_0 p_\nu$ → Gibalna kol. fotona

$p_\nu = \frac{W_0}{c_0} = \frac{h\nu}{c_0}$ $c_0 = \nu\lambda$ ⇒ $\boxed{p_\nu = \frac{h}{\lambda}}$ rel. gibalna kol. fotona

Št. absorbiranih fotonov

$N_\nu = \frac{Pt}{h\nu} = \frac{jSt}{h\nu} = \frac{jSt}{h\nu}$

Kovina	λ [nm]
platina	230
volfram	280
srebro	290
Al, cink	340
kalij	560

Izstopno delo

$W_i = h\nu_0 = h\frac{c_0}{\lambda_0}$

Primer: Anihilacija (izničenje) ($\neq$ kreacija)

POZITRON ⊕
ELEKTRON ⊖ $W_0 = m_0 c_0^2 = 0{,}511\ MeV$

T - kin. en. $v=0$
⊕ ⟶ ⊖

Ko trčita, nesi razgleda

V relativni fiz. velja ohranitev sile gib. kol. in polna energija, če ni zunanjih sil

Nastaneta 2 - fotona

Ohranita se E in P

1.) Ohranitev polne energije

$$\boxed{W_0 + T_p + W_0 = h\nu + h\nu'}$$

2.) Ohranitev gibalne količine:

$$\boxed{P = \frac{h\nu}{c_0} - \frac{h\nu'}{c_0}} \Rightarrow c_0 P = h(\nu - \nu') = \sqrt{2W_0 T_p + T_p^2}$$

gib. kol. pozitrona

$\Rightarrow \nu, \nu'$

$c_0 p_\nu = W$

$p_\nu = \frac{h\nu}{c_0}$

$c_0 P = m_0 \gamma P$

$W^2 = W_0^2 + c_0^2 P^2$

$(W_0 + T_p)^2 = W_0^2 + c_0^2 P^2$

$\sqrt{2W_0 T_p + T_p^2} = c_0 p^2$

Interferenčni posk.: z curkom e^- svetimo na kristal grafita
Interferenca

Prej smo gledali: Svetloba lahko opazujemo kot valovanje ali kot delce
tudi z delci lahko kot z valovanjem delamo

de Broglie: Pripisal delcem valovne lastnosti - kot je to enica

$p_\nu = \frac{h}{\lambda}$, pripišemo delcem valovne dolžine!

$\lambda_B = \frac{h}{p} = \frac{h}{mv}$ $\lambda_B = \frac{h}{mv}$

$W = cp$

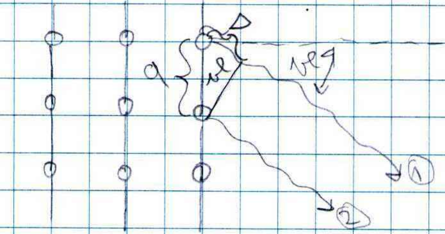
$p = \frac{W}{c} = \frac{h\nu}{c} = \frac{h}{\lambda}$ GIBALNA KOL. FOTONOV

$\boxed{\lambda_B = \frac{h}{mv}}$ de Broglie
$m_e = 9,1\cdot 10^{-31}$ kg

$\frac{m_e v^2}{2} = e_0 U_0 \Rightarrow v = \sqrt{\frac{2e_0U_0}{m_e}} \Rightarrow \lambda_B = \frac{h}{m_e v} = \frac{h}{m_e\sqrt{\frac{2e_0U_0}{m_e}}} = \frac{h}{\sqrt{2m_e e_0 U_0}}$

Večja napetost manjša valovna dolžina

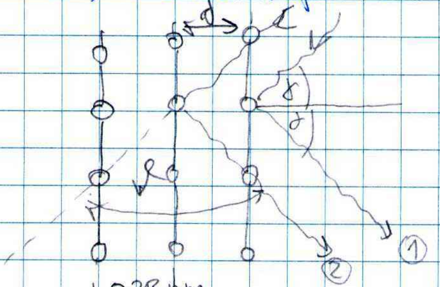
A.) Majhne $U_0 \Rightarrow$ majhne W_k, velike λ_B



$\Delta = a\sin\vartheta = N\lambda_B$

$U_0 = 100$ V, $\lambda_B = 0,123$ nm

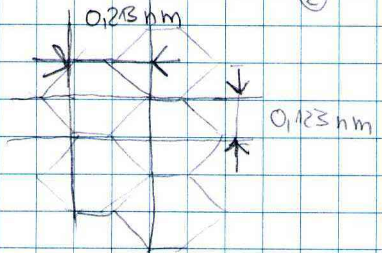
B.) Velike napetosti $U_0 \rightarrow$ večje W_k, manjše λ_B



Braggovo sipanje

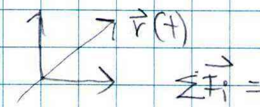
$U_0 = 1500$ V
$\lambda_B \cong 0,032$ nm

$\boxed{\lambda_B = \frac{h}{mv}}$ de Broglie



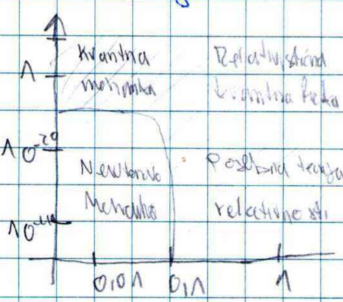
Newtonova mehanika

$\vec{r} = \vec{r}(t)$
$\vec{v}$
$\vec{a}$



$\sum \vec{F}_i = m\frac{d\vec{v}}{dt}$

Schrödinger E - nadomestilo Newtonova enačba.



$h = 6,6\cdot 10^{-34}$ Js.

Ne da se hkrati določit lege in hitrosti
Al eno al drugo

de Broglie zveza velja tudi z relativistično fiz

Rel. limita:

Nerelativna mehanika

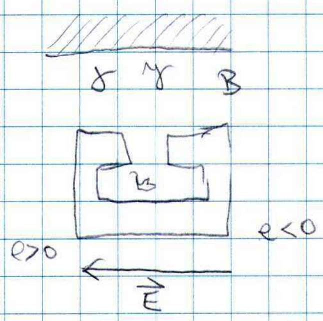
$\vec{p} = m_0 \gamma_e \vec{v} \rightarrow m_0 \vec{v}$

$T = m_0 c_0^2 (\gamma_e - 1) \rightarrow \frac{m_0 v^2}{2} \qquad \frac{v}{c_0} \rightarrow 0$

Tipične velikosti: Radij vodikovega atoma $5 \times 10^{-11}\,m \sim 10^{-10}\,m = \mathring{A}$
Radij protona $1{,}2 \cdot 10^{-15}\,m \sim 10^{-15}\,m$
} Delci reda med $10^{-10} - 10^{-15}\,m$

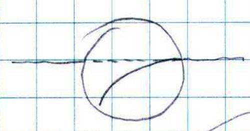
MEGLIČNA CELICA

Zrak z vodno paro sunkovito povečamo prostornino, da se ohladi
→ Z vodno paro nasičen zrak postane PRENASIČEN
→ Vodna para se usede na ionizirane ~~...~~ ionih in tvori vodne kapljice (kondenzacija)
→ Sledi nabitih delcev postanejo lahko vidni



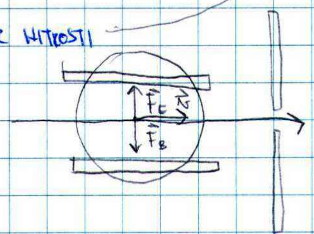
$\vec{F}_B = e\vec{v} \times \vec{B}$

$\vec{F}_E = e\vec{E}$



Lahko usmerimo žarek z magn. poljem
→ Curek delcev z enako hitrostjo

SELEKTOR HITROSTI

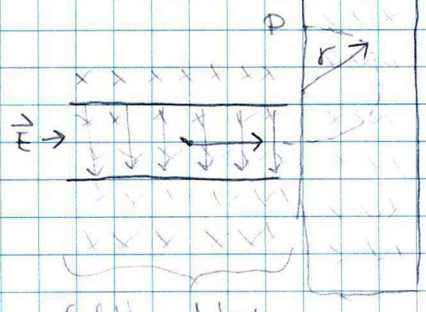


$\vec{F}_B = e\vec{v} \times \vec{B}$
$\vec{F}_E = e\vec{E}$

$\cancel{e} v B = \cancel{e} E$

$\boxed{v = \frac{E}{B}}$

MASNI SPEKTROMETER



$m a_r = e v B_0$

$m \frac{v^2}{r} = e v B_0$

$\boxed{r = \frac{m v}{e B_0}} \Rightarrow r = \frac{m E}{e B_0 B} \Rightarrow \boxed{\frac{m}{e} = \frac{r B_0 B}{E}}$

(1856–1940)

Thomsonov aparat za merjenje razmerja e/m → Specifični naboj

katodni žarki → elektroni

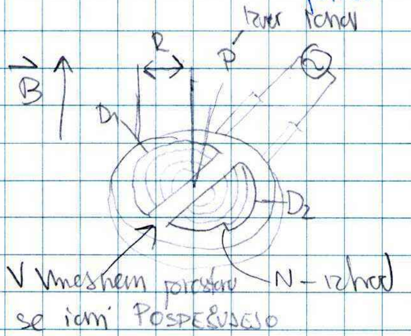
Thomson: $\frac{e}{m} \sim 0{,}77 \cdot 10^{11}\ \mathrm{As/kg}$

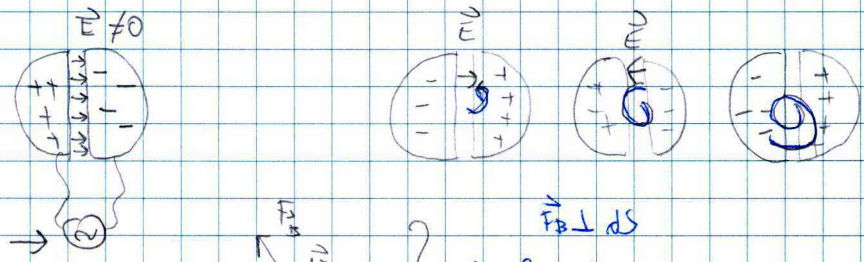
CIKLOTRON

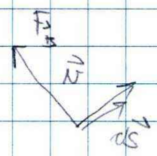
2 votli elektrodi → D_1, D_2

V evakuiranem prostoru

V elektrodah ni el. polja! (skalarni produkt)







$\vec{F}_B \perp d\vec{s}$

$A = \oint \vec{F} \cdot d\vec{s} = 0$

Obhodni čas delca: pri dani hitrosti v

$$t_0 = \frac{2\pi r}{v} = \frac{2\pi m v}{v e B} = \frac{2\pi m}{eB}$$

$$\boxed{\nu_c = \frac{1}{t_0} = \frac{eB}{2\pi m}}$$

CIKLOTRONSKA FREKVENCA

Frekvenca pri velikih hitrostih postane odvisna od hitrosti

SINHROCIKLOTRON

$\vec{p} = m_0 \gamma \vec{v}$

$$\frac{d\vec{p}}{dt} = e\vec{v} \times \vec{B}$$

$$\frac{d(m_0 \gamma \vec{v})}{dt} = e\vec{v} \times \vec{B}$$

$$\gamma m_0 \frac{d\vec{v}}{dt} = e\vec{v} \times \vec{B}$$

$$\boxed{\gamma m_0 \vec{a}_r = e\vec{v} \times \vec{B}}$$

Ker je kinetična energija konstantna → $|\vec{v}| = \text{konst} = v$

$$\gamma = \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}} = \text{konst}$$

V splošnem $\frac{d(m_0 \gamma \vec{v})}{dt} = m_0 \left[\frac{d\gamma}{dt} \vec{v} + \gamma \frac{d\vec{v}}{dt} \right]$

$$\gamma m_0 a_r = e v B$$

$$\gamma m_0 \frac{v^2}{r} = e v B$$

$$\gamma m_0 \frac{v}{r} = eB \Rightarrow \boxed{r = \frac{\gamma m_0 v}{eB}}$$

$$\tilde{t}_0 = \frac{2\pi r}{v} = \frac{2\pi}{v} \frac{\gamma m_0 v}{B} = \frac{2\pi \gamma m_0}{eB}$$

$$\boxed{\nu_{sc} = \frac{1}{\tilde{t}_0} = \frac{eB}{2\pi \gamma m_0} = \frac{1}{\gamma} \underbrace{\boxed{\frac{eB}{2\pi m_0}}}_{\nu_c}}$$

$$\frac{d\vec{p}}{dt} = eE$$

γ ne smemo dat ven ker ni konstanta

$$\frac{d(m_0\gamma\vec{v})}{dt} = e\vec{E}$$

$$\boxed{\frac{d(m_0\gamma v)}{dt} = eE} \quad / dt$$

$$\int d(m_0\gamma v) = \int eE\,dt$$

$E = \text{konst}$, $\vec{v} \parallel \vec{E}$

$$m_0\gamma v = eE\int dt = eEt \quad \rightarrow \quad m_0\gamma v = eEt$$

$$\boxed{\frac{m_0 v}{\sqrt{1-\frac{v^2}{c_0^2}}} = eEt}$$

$$\frac{\frac{v}{c_0}}{\sqrt{1-\left(\frac{v}{c_0}\right)^2}} = \underbrace{\left(\frac{eE}{m_0 c_0}\right)}_{\gamma} t = \gamma t \quad / (\,)^2$$

$$\left(\frac{v}{c_0}\right)^2 = \gamma^2 t^2 \left[1 - \left(\frac{v}{c_0}\right)^2\right]$$

$$\left(\frac{v}{c_0}\right)^2 \left[1 + \gamma^2 t^2\right] = \gamma^2 t^2$$

$$\Rightarrow \boxed{v = c_0 \left[\frac{\gamma t}{\sqrt{1+\gamma^2 t^2}}\right]}$$

$$\lim_{t\to\infty} v = c_0 \frac{\gamma t}{\gamma t} = c_0$$

$m_0 v = eEt$

$m v = eEt$

$v = \frac{eE}{m_0} t$

či $t \to \infty$

$v \to \infty$

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• FOTOEFEKT

FOTONI

-Foton: $p_\nu = \frac{h}{\lambda}$ -Energija: $W = h\nu$, $W = \hbar\omega$

ELEKTRONI

$\lambda_B = \frac{h}{p} = \frac{h}{m_e v}$

$p = \frac{2\pi h}{\lambda \, 2\pi} = k\hbar$

$k = \frac{2\pi}{\lambda}$ VALOVNI VEKTOR, $\hbar = \frac{h}{2\pi}$

• SEVANJE ČT:

- Planckov zakon in Stefanov zakon

• COMPTONSKO SIPANJE

- comptonska valovna dolžina

• ČRTASTI SPEKTRI

- Energijski nivoji

EM Valovanje: $\bar{j} = \bar{w} c_0$, $\bar{j} \propto \overline{E^2}$

ELEKTRON: $p = \hbar k$, $p = mv$; $W = \hbar\omega$, $W = T(+V)$

$T = \frac{1}{2} m v^2 = \frac{1}{2} \frac{m^2 v^2}{m} = \frac{p^2}{2m}$

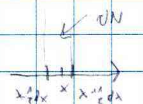
VALOVNA F. ZA DELCE

$p = \hbar k$. $\psi_p(x,t) \propto e^{i\left(\frac{p}{\hbar}x - \frac{W}{\hbar}t\right)} = e^{i(px - Wt)/\hbar}$

$\psi^* \psi$ - verjetnostna gostota elektronov na zaslonu

UKLON CURKA ELEKTRONOV

$\boxed{\frac{dN}{N} = \rho \, dx}$



OSNOVE KVANTNE MEHANIKE

NAČELA KVANTNE MEHANIKE

-NAČELO STATISTIČNEGA OPISA

- Vrsta poskusa s posameznim kvantnim delcem. Ne moremo z gotovostjo napovedati
- V splošnem se močne napovedi za množico delcev
- Vpeljemo verjetnostno gostoto $\rho = \psi^* \psi$

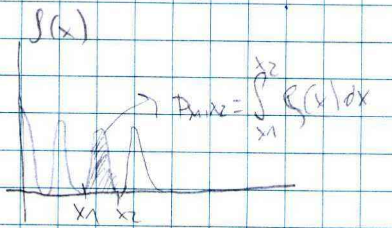
Za vrste lastnosti rečemo z ...

VALOVNA FUNKCIJA

$\psi = \psi_0 e^{i(k\vec{r} - \omega t)}$

$\vec{p} = \hbar k$ — gibalna kol.

$\hbar\omega = W = W_k + W_p \rightarrow$ polna energija elektron



integral verjetnostne gostote: $\int_{-\infty}^{+\infty} \rho(x)\,dx = 1$

Pričakovana vrednost $\langle x \rangle = \int_{-\infty}^{\infty} x \rho\, dx = \int_{-\infty}^{\infty} x \psi^* \psi\, dx = \int_{-\infty}^{\infty} \psi^* x \psi\, dx$

-HEISENBERGOVO NAČELO NEDOLOČNOSTI

$$\boxed{\begin{array}{l} \Delta x \cdot \Delta p_x \geq \hbar \\ \Delta y \, \Delta p_y \geq \hbar \\ \Delta z \, \Delta p_z \geq \hbar \end{array}}$$

gibalna kol. fotona se lahko prenese na elektron

-NAČELO SUPERPOZICIJE

$$\boxed{|\psi|^2 \neq |\psi_1 c_1|^2 + |c_2 \psi_2|^2}$$

OPERATORJI

Ne moremo poznati gibalne količine in lege hkrati. Lahko vemo eno stvar na enkrat

$$\boxed{\psi = \psi_0 e^{i\left(\frac{p_x}{\hbar}x - \frac{W}{\hbar}t\right)}}$$

$i\hbar \frac{\partial \psi}{\partial x} \ldots \frac{i p_x}{\hbar}(i\hbar)\psi = p_x \psi$

$\frac{\partial}{\partial t}\psi = -\frac{iW}{\hbar} \ldots = W\psi$, $\boxed{i\hbar \frac{\partial}{\partial t}\psi = W\psi}$ OP. POLNE ENERGIJE

$\boxed{i\hbar \frac{\partial}{\partial x}\psi = p_x \psi}$ OP. GIB. KOL.

OPERATOR KOMPONENTNE GIBALNE KOLIČINE

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

OPERATOR KIN. ENERGIJE

$$\hat{T} = \frac{\hat{p}^2}{2m} = -\frac{\hbar^2}{2m}\nabla^2$$

$$\nabla^2 = \frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2} + \frac{\partial^2}{\partial z^2}$$

SCHRÖDINGERJEVA ENAČBA