

FIZIKA II

Zapiski predavanj

1 UNI

Šolsko leto 2010/2011
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Skeniranje Damjan Sirnik



UREJANJE DOKUMENTA

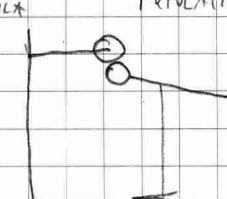
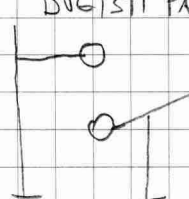
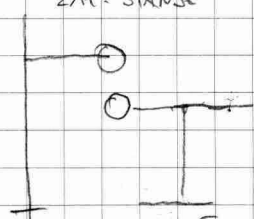
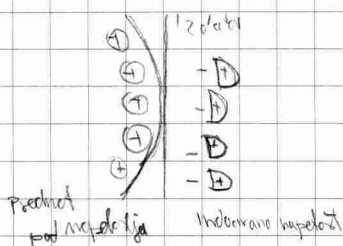
VERZIJA	01.01
DATUM	23.5.2012

OPOMBE

ELEKTRON → JAVNA

Papir je izolator a se lahko tem malpi na električno polje zaradi influence.

Razdaljino $\sim 1\text{ m}$ - el. naboje. Protoni in elektroni. Protoni 2000 težji od elektronov.

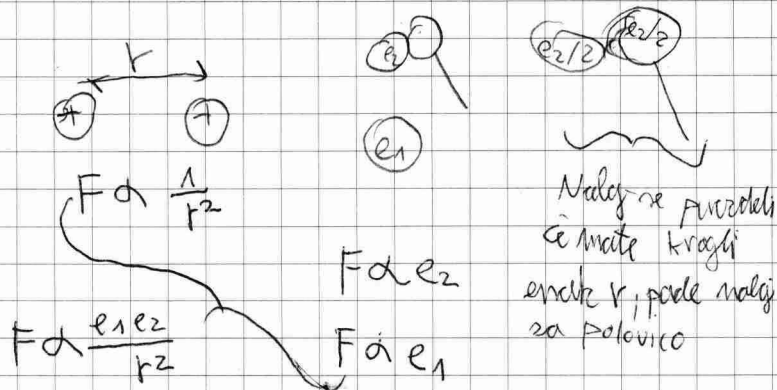


← ⊖ ⊖ → } Odbojna sila
← ⊕ ⊕ → }

⊖ → ⊕ } Privlačna sila

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

Sila el. polja se kvadratno razdalja.



COULOMBOV ZAKON

$$F = K \cdot \frac{q_1 q_2}{r^2}$$

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

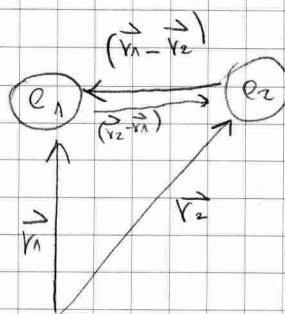
$$K = \frac{1}{4\pi\epsilon_0}$$

ϵ_0 = influenčna konstanta $= 8,85 \cdot 10^{-12} \text{ As/Vm}$

$$F = \frac{q_1 q_2}{4\pi\epsilon_0 r^2}$$

Nima veze z dielektričnostjo; merjena se na prostem prostoru.

$$\epsilon_0 = \frac{1}{4\pi k} \approx 8,85 \cdot 10^{-12} \text{ As/Vm}$$



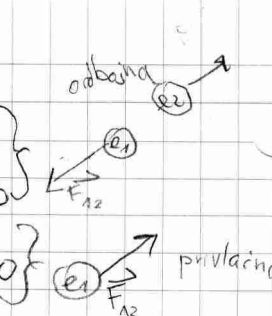
$$\vec{F}_{12} = \frac{q_1 q_2}{4\pi\epsilon_0 r_{12}^2} \underbrace{\left(\frac{\vec{r}_{12}}{r_{12}} \right)}_{\text{enotni vektor}}$$

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

$$\vec{F}_{21} = \frac{q_1 q_2}{4\pi\epsilon_0 r_{21}^2} \left(\frac{\vec{r}_{21}}{r_{21}} \right)$$

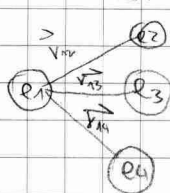
$q_1 > 0, q_2 > 0 : q_1 q_2 > 0$
 $q_1 < 0, q_2 < 0 : q_1 q_2 > 0$
 $q_1 > 0, q_2 < 0 : q_1 q_2 < 0$
 $q_1 < 0, q_2 > 0 : q_1 q_2 < 0$

$\left. \begin{array}{l} q_1 > 0, q_2 > 0 \\ q_1 < 0, q_2 < 0 \end{array} \right\} \text{odbojna}$
 $\left. \begin{array}{l} q_1 > 0, q_2 < 0 \\ q_1 < 0, q_2 > 0 \end{array} \right\} \text{privlačna}$



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

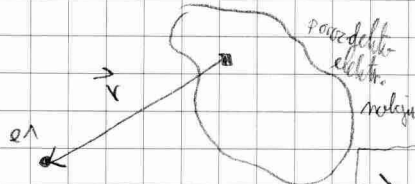
POSLOŠITEV:



št. malcega n. redov

$$\vec{F}_1 = \sum_{j=2}^n \frac{q_1 q_j}{4\pi\epsilon_0 r_{1j}^2} \left(\frac{\vec{r}_{1j}}{r_{1j}} \right)$$

POSLOŠITEV V OKVIRU KONTINUUMSKEGA NABOJA



$$\sum_j \rightarrow \int \quad \begin{array}{l} r_{1j} \rightarrow r \\ q_j \rightarrow dq \end{array}$$

$$\vec{F}_1 = \int \frac{q_1 dq}{4\pi\epsilon_0 r^2} \left(\frac{\vec{r}}{r} \right)$$

$$\begin{aligned} \rho &= \frac{dq}{dv} \Rightarrow dq = \rho dv \\ \sigma &= \frac{dq}{dA} \Rightarrow dq = \sigma dA \\ \lambda &= \frac{dq}{dl} \Rightarrow dq = \lambda dl \end{aligned}$$

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

$$\vec{F}_{12} = \frac{q_1 q_2}{4\pi\epsilon_0 r_{12}^2} \left(\frac{\vec{r}_{12}}{r_{12}} \right)$$

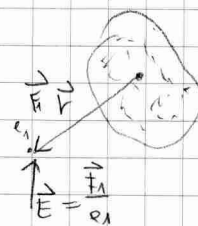
$$\vec{E}_2 = \frac{\vec{F}_{12}}{q_1} = \frac{q_2}{4\pi\epsilon_0 r_{12}^2} \left(\frac{\vec{r}_{12}}{r_{12}} \right)$$

$q_1 \equiv$ testni naboj

POSLOŠITEV:

$$\vec{F}_1 = \int \frac{q_1 dq}{4\pi\epsilon_0 r^2} \left(\frac{\vec{r}}{r} \right)$$

$$\vec{E} = \frac{\vec{F}_1}{q_1} = \int \frac{dq}{4\pi\epsilon_0 r^2} \left(\frac{\vec{r}}{r} \right)$$

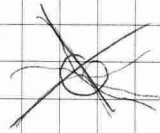
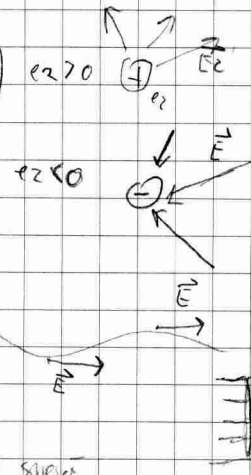


Testni naboj mora biti šim manjši, da ne vpliva na porazdelitev. Velikost testnega naboja li ne vpliva na porazdelitev, ker ϵ_0 ne more biti

Kvadrati - delci 2 nalogam manjšim od e_0 ($1/3, 2/3$ e ipd.) $e_2 > 0$

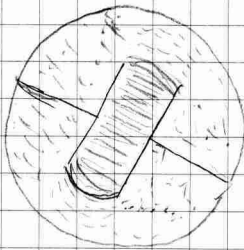
$$\vec{F} = e\vec{E}$$

→ Seta ma el. nalog v el. polji
zadržati $\vec{E}$

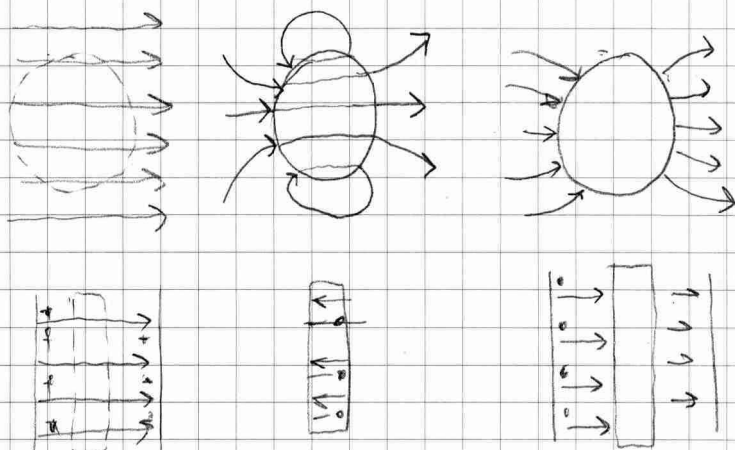


Silnice sene snopi
oz. ne morejo rešati ker hi polji
potem morda da so

VAN DER GRAFOW GENERATOR

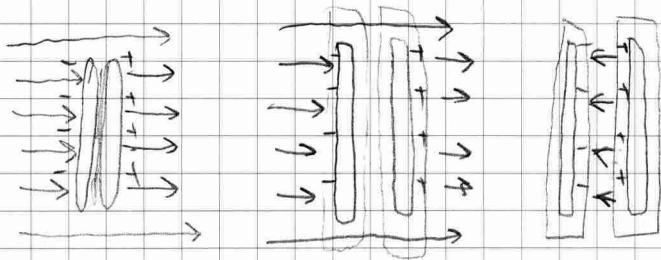


INFLUENCA

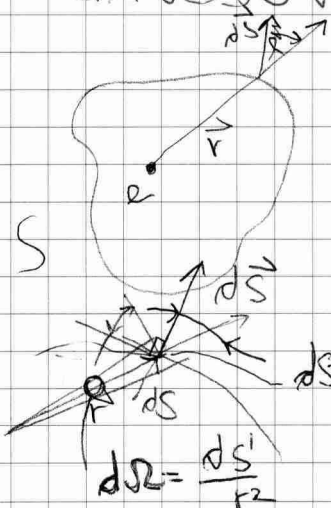


Površina precepnika postane
koncentracijska plošča

NEPOSREDNA MERITEV GOSTOTE EE. POLJA



GAUSSOV ZAKON O ELEKTRIČNEM PRETOKU



$$\vec{E} = \frac{q}{4\pi\epsilon_0 r^2} \frac{\vec{r}}{r}$$

$$\oint_A \vec{E} \cdot d\vec{S} = \oint_A \frac{q \vec{r} \cdot d\vec{S}}{4\pi\epsilon_0 r^3} = \oint_A \frac{q \cos\theta dS}{4\pi\epsilon_0 r^2} = \frac{q}{4\pi\epsilon_0} \oint_A \frac{dS}{r^2}$$

$$= \frac{q}{4\pi\epsilon_0} \oint_A d\Omega = \frac{q}{4\pi\epsilon_0} 4\pi = \frac{q}{\epsilon_0}$$

$$\oint_A \vec{E} \cdot d\vec{S} = \frac{q}{\epsilon_0}$$

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

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

POSREDOVATEL:

$$\oint_A \vec{E} \cdot d\vec{S} = \frac{\sum q_i}{\epsilon_0}$$

$$\sum q_i \rightarrow \int_V \rho(\vec{r}) dV$$

Vol. gostota
naboja

$$\epsilon_0 \oint_A \vec{E} \cdot d\vec{S} = \int_V \rho(\vec{r}) dV$$

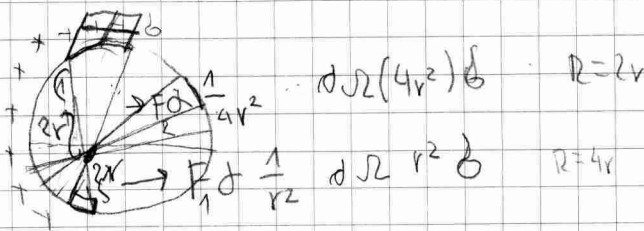
$$\epsilon_0 \vec{\nabla} \cdot \vec{E} = \rho(\vec{r}) - \text{v diferencialni obliki}$$

Druge oblike Coulombovega zakona,
↑ razmerje med oblikami

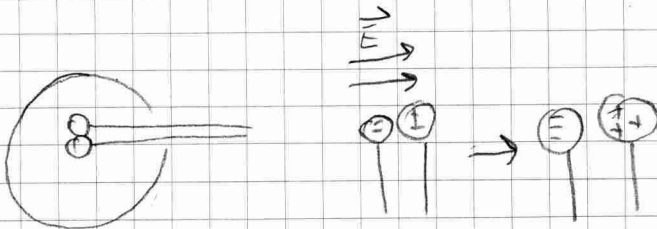
GAUSSOV ZAKON O EL.
PRETOKU V INTEGRALNI
OBLIKI

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

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

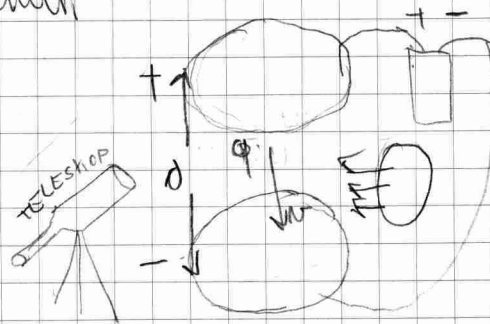
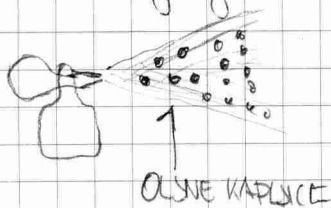


Kjer velji Faradajeva kletka (izpustitev)
potem velja Coulombov zakon

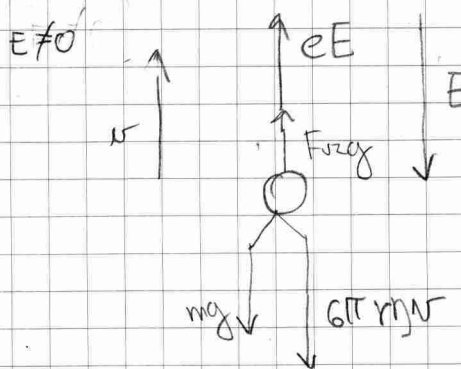
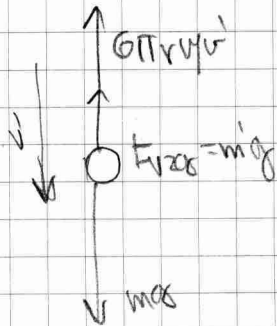


MILLIKANOV POSKUS
-el malec je kvantitativen

28.02.11



$E=0$



ZA STACIONARNO STANJE: $E=0$

ZA $E \neq 0$:

$$mg = m'g + qE$$

$$eE + m'g = mg + qE$$

masa

$$\begin{aligned} & \Rightarrow qE' + \frac{4}{3}\pi r^2 \rho g = \frac{4}{3}\pi r'^2 \rho g \\ & qE' = \frac{4}{3}\pi r^2 \rho g \left(\frac{r'}{r} \right)^3 \\ & \frac{qE'}{2g} = \frac{4}{3}\pi r^2 \rho \left(\frac{r'}{r} \right)^3 \\ & \frac{qE'}{2g} = \frac{4}{3}\pi r^2 \rho \left(\frac{r'}{r} \right)^3 \end{aligned}$$

$$\begin{aligned} & eE - qE' = qE \\ & \Rightarrow eE = qE' + qE \\ & \Rightarrow e = \frac{qE'}{E} \left(\frac{r'}{r} \right)^3 \end{aligned}$$

$$\begin{aligned} m &= \frac{4}{3}\pi r^2 \rho \\ m' &= \frac{4}{3}\pi r'^2 \rho \end{aligned}$$

$$\begin{aligned} e &= e_0, \text{ kjer } 1, 2, 3 \\ e_0 &= 1.6 \cdot 10^{-19} \text{ As} \end{aligned}$$

⇒ el. nabj. ni zvečen, ampak

	(C)	(kg)
Elektron	$-1,60219 \times 10^{-19}$	$9,1095 \times 10^{-31}$
Proton	$+1,60219 \times 10^{-19}$	$1,67261 \times 10^{-27}$
Neutron	0	$1,67492 \times 10^{-27}$

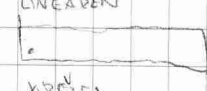
GIBANJE ELEKTRIČNIH NABOJEV V SNOVI (V EL. POLJU)

VAKUUM:
 $E \neq 0$

$$m \frac{d\vec{v}}{dt} = e\vec{E} \Rightarrow \vec{a} = \frac{e\vec{E}}{m} \quad (\text{VELJATA ZA } \frac{v}{c_0} \lesssim 0,1)$$

SVEČILNOST

POSPEŠEVANJE
LINEARNO

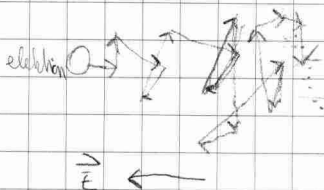



GIBANJE NABOJA V KOVINI:

V KOVINI PREKOVNI ELEKTROM, KI TRAJA DOLGO ČAS, HITROST JE ZELO MALA

JE ZELO MALA

HITROST NE MORE BIT VEČJA OD
SVEČILNE HITROSTI



$$\vec{F}_{av} = -e\vec{E}$$

Newton:

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

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

$\tau = \frac{m}{K}$ RELAKSACIJSKI ČAS

$$\vec{E} = 0: \frac{d\vec{v}}{dt} + \frac{\vec{v}}{\tau} = 0 \Rightarrow \int \frac{d\vec{v}}{\vec{v}} = -\int \frac{dt}{\tau} \Rightarrow \ln \vec{v} = -\frac{t}{\tau} \Rightarrow \vec{v} = \vec{v}_0 \cdot e^{-t/\tau}$$

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

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

Ohmov zakon

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

$$\langle \vec{v} \rangle = -\frac{1}{ne} \vec{J}$$

$$= \frac{1}{ne} \frac{dQ}{dt} = \frac{1}{ne} \frac{dQ}{dt} = eonv$$

RELAKSACIJSKI ČAS

Snov	τ [s]
kovina	$\sim 10^{-14}$
vazlektivna	$\sim 10^{-9}$
v plinu	$\sim 10^{-12}$
sončni kovin	$\sim 10^{-12}$
nevezalni plin	$\sim 10^{-15}$

GIBANJE:

$$\Rightarrow \vec{B} = \frac{e\tau}{m} \vec{E}$$

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

$$J = \frac{I}{S} = \frac{1}{S} \frac{dQ}{dt}$$

$$= \frac{1}{S} \frac{dQ}{dt} = \frac{1}{S} \frac{dQ}{dt} = eonv$$

$$J = neov$$

$$\vec{J} = neo \langle \vec{v} \rangle$$

Ohm's
ZAKON

$$\vec{j} = ne_0 \langle \vec{v} \rangle \quad \vec{v} = \frac{e_0 \tau}{m} \vec{E}$$

$$\vec{j} = ne_0 \frac{e_0 \tau}{m} \vec{E}$$

$$\vec{j} = \frac{ne_0^2 \tau}{m} \vec{E}$$

SPLOŠNA OBLIKA

SPECIFIČNA PREVODNOST / UPORNOST

$$\sigma = \frac{ne_0^2 \tau}{m}$$

$$\frac{I}{S} = \sigma \frac{U}{L}$$

$$\left(\frac{L}{S} \right) I = U$$

$$R = \frac{L}{S \sigma} \quad \sigma = \frac{1}{\rho}$$

$$RI = U$$

$$\sigma_0 = \sigma_0 [1 - \alpha (T - T_0)]$$

Upornost je odvisna od temperature

ELEKTROSTATSKA POTENCIALNA ENERGIJA

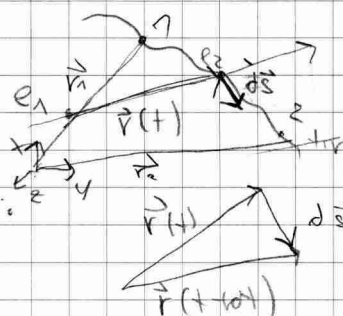
3.3.11

$$\vec{A} = \Delta W_k + W_{\text{eksp}}$$

Delo vseh ostalih sil ni eno gravitacijske
Delo vseh ostalih sil ni eno gravitacijske in električne.

$$\vec{A}_{\text{ost}} + \int \vec{F}_e \cdot d\vec{s} = \Delta W_k + \Delta W_{\text{eksp}}$$

$$A_{\text{ost}} = \Delta W_k + \Delta W_{\text{eksp}} - \int \vec{F}_e \cdot d\vec{s} \quad \text{Nagledamo delo el. sile}$$



$$\vec{F}_e = \frac{e_1 e_2}{4\pi\epsilon_0 r^2} \left(\frac{\vec{r}}{r} \right)$$

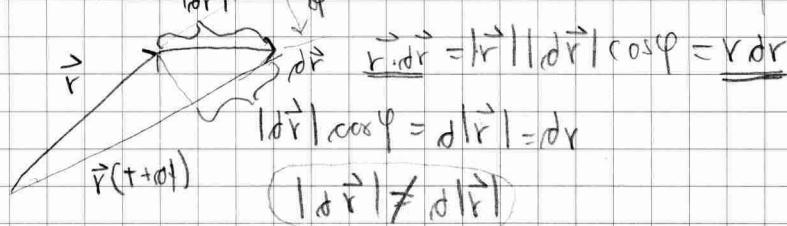
$$d\vec{r} = \vec{r}(t+dt) - \vec{r}(t)$$

$$-\int \vec{F}_e \cdot d\vec{s} = -\int \vec{F}_e \cdot d\vec{r} = -\int \frac{e_1 e_2}{4\pi\epsilon_0 r^2} \frac{\vec{r}}{r} \cdot d\vec{r} = \int_{r_1}^{r_2} \frac{e_1 e_2}{4\pi\epsilon_0 r^2} dr = \frac{e_1 e_2}{4\pi\epsilon_0} \left[-\frac{1}{r} \right]_{r_1}^{r_2} = \frac{e_1 e_2}{4\pi\epsilon_0} \left(\frac{1}{r_1} - \frac{1}{r_2} \right)$$

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

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

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



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

⇒ Ni delo ni po hlini
poti groma, ampak samo
od r1 in r2

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

$$W_e = \frac{e_1 e_2}{4\pi\epsilon_0 r}$$

Com Sol → Program



$$W_e = \frac{q_1 q_2}{4\pi\epsilon_0 r}$$



$$\begin{aligned} r_1 r_2 > 0 & \quad \oplus \oplus \\ & \quad \ominus \ominus \\ r_1 r_2 < 0 & \quad \oplus \ominus \end{aligned}$$

$$A_{\text{ost}} = \Delta W_k + \Delta W_{p,p} - \int \vec{f} \cdot d\vec{s}$$

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

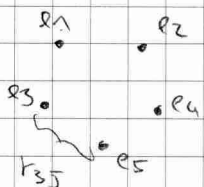
POSPLOŠENO

$$A_{\text{ost}} = 0 \Rightarrow \Delta W_k + \Delta W_{g,p} + \Delta W_e = 0$$

$$\Delta(W_k + W_{g,p} + W_e) = 0$$

$$W_k + W_{g,p} + W_e = \text{konst}$$

POSPLOŠITELJ

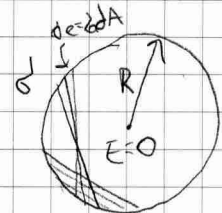


$$W_e = \frac{1}{2} \sum_{i,j} \frac{q_i q_j}{4\pi\epsilon_0 r_{ij}} \cdot \frac{1}{2}$$

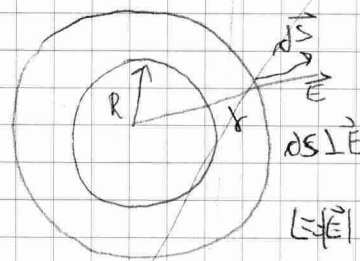
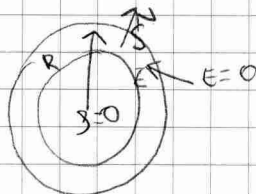
$$W_e = \int_V \frac{1}{2} \epsilon_0 E^2 dV = \int_V \frac{1}{2} \epsilon_0 E^2 dV = \int_V \frac{1}{2} \epsilon_0 E^2 dV$$

$$= \int_R \frac{2 \cdot 6^2 R^4 \pi}{\epsilon_0} \frac{1}{r^2} dr$$

PRIMER



G = konst.



GAUSSOV ZAKON

$$\epsilon_0 \oint \vec{E} \cdot d\vec{s} = \oint \rho \cdot dV$$

$$\epsilon_0 \oint E ds = 4\pi R^2$$

$$\epsilon_0 E(r) \oint ds = 4\pi R^2$$

$$\epsilon_0 E(r) 4\pi r^2 = 4\pi R^2$$

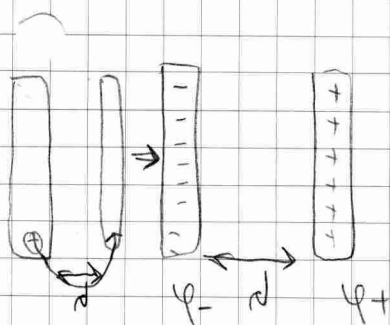
$$\Rightarrow E(r) = \frac{R^2}{\epsilon_0 r^2}$$

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

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

$$\frac{2 \cdot 6^2 R^4 \pi}{\epsilon_0} \left(-\frac{1}{r} \right) \Big|_R^\infty = \frac{2 \cdot 6^2 R^4 \pi}{\epsilon_0 R}$$

$$W_e = \int \frac{1}{2} \epsilon_0 E^2 dV = \frac{2 \cdot 6^2 R^4 \pi \cdot 8 R^3}{8 \epsilon_0 \pi R} = \frac{e^2}{8\pi\epsilon_0 R}$$



ELEKTRIČNI POTENCIAL

$$W_e = \frac{e_1 e_2}{4\pi\epsilon_0 r}$$

Diagram showing two point charges e_1 and e_2 separated by a distance r . Vectors $\vec{r}$ and $\vec{E}$ are shown originating from e_1 . A box contains the formula for the electric field:

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

$$\varphi_1(r) = \frac{W_e}{e_2} = \frac{e_1 e_2}{4\pi\epsilon_0 r e_2} = \frac{e_1}{4\pi\epsilon_0 r}$$

ELEKTRIČNI POTENCIAL

POSPLOŠITEV

Diagram showing a point charge e_i at position $\vec{r}_i$ and a test charge e at position $\vec{r}$. The distance between them is $|\vec{r} - \vec{r}_i|$. A box contains the formula for the electric potential:

$$\varphi(\vec{r}) = \sum \frac{e_i}{4\pi\epsilon_0 |\vec{r} - \vec{r}_i|}$$

ZVEZA MED φ IN $\vec{E}$

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

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

$$y(x)$$

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

$$d\varphi = \frac{\partial \varphi}{\partial x} dx + \frac{\partial \varphi}{\partial y} dy + \frac{\partial \varphi}{\partial z} dz$$

$$= \left(\frac{\partial \varphi}{\partial x}, \frac{\partial \varphi}{\partial y}, \frac{\partial \varphi}{\partial z} \right) \cdot (dx, dy, dz)$$

$$2 \left(d\varphi = \nabla \varphi \cdot d\vec{r} = \text{grad } \varphi \cdot d\vec{r} \right)$$

Nabla operator

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

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

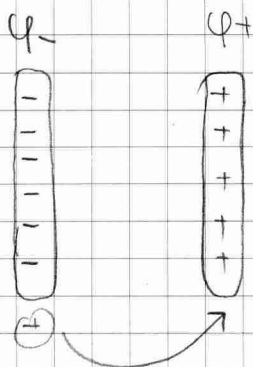
$$W_e = e_2 \varphi(r)$$

↓

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

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

$$\left. \begin{array}{l} d\varphi = d\varphi \\ -\vec{E} \cdot d\vec{r} = \text{grad } \varphi \cdot d\vec{r} \end{array} \right\} \vec{E} = -\text{grad } \varphi$$

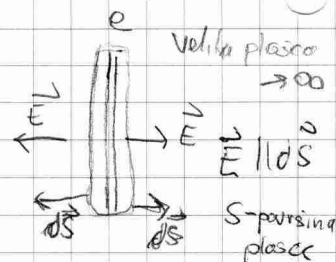


$$A = \Delta W_k + \Delta W_{gp} + \Delta W_e$$

$$dA = de\varphi_+ - de\varphi_- = de(\varphi_+ - \varphi_-) = Ude$$

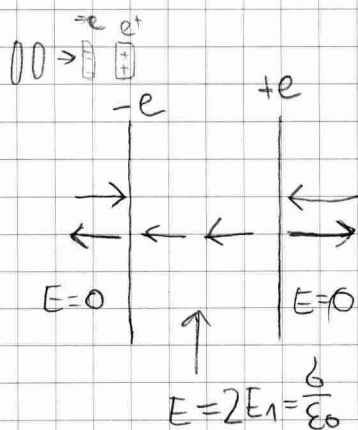
$$\boxed{dA = Ude}$$

$$dA = Ude$$



$$\begin{aligned} \epsilon_0 \oint \vec{E} \cdot d\vec{S} &= \epsilon_0 \int E dS \\ &= \epsilon_0 E \int dS = \epsilon_0 E 2S \\ &= q \end{aligned}$$

$$\epsilon_0 E 2S = q \Rightarrow E = \frac{q}{2\epsilon_0 S}$$



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

$$\int d\varphi = -\int E dx = -El$$

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

$$U = \frac{q}{\epsilon_0 l} \quad C = \epsilon_0 \frac{S}{l}$$

$$U = \frac{q}{\epsilon_0 S}$$

$$q = \epsilon_0 \frac{S}{l} U$$

$$Q = CU$$

$$\Rightarrow U = \frac{Q}{C}$$

$$A = dA = \int U dq = \int_0^Q \frac{q}{C} dq = \frac{Q^2}{2C} = \frac{CU^2}{2} = \frac{1}{2} CU^2$$

ENERGIJA
NAELEKTRENEGA KONDENZATORJA

$$W = \frac{1}{2} \sum_{i,j} \frac{q_i q_j}{4\pi\epsilon_0 r_{ij}} = \dots = \int \frac{1}{2} \epsilon_0 E^2 dV$$

$$\boxed{W = \frac{1}{2} \epsilon_0 E^2}$$

Gostota energije
el. polja kondenzatorja

$$\epsilon=0 \quad \left| \begin{array}{l} E \neq 0 \\ E=0 \end{array} \right. \quad W_C = \frac{1}{2} CU^2 = \frac{1}{2} C E^2 l^2 = \frac{1}{2} \epsilon_0 \frac{S}{l} E^2 l^2 = \frac{1}{2} \epsilon_0 E^2 S l = \frac{1}{2} \epsilon_0 E^2 V$$

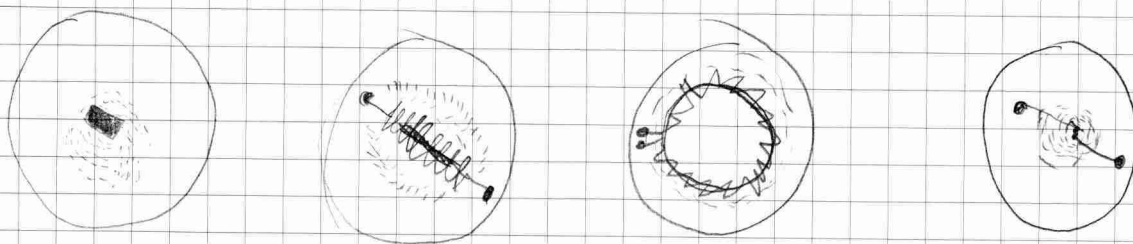
$V = Sl$

TUDI SPLOŠNA IZPELJAVA, TO IZPELJAVA
NA POSEBNEM PRIMERU

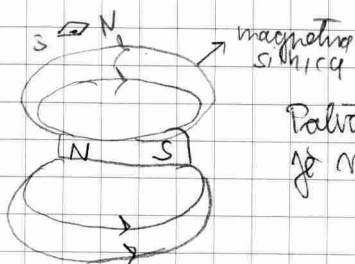
$$\Rightarrow W_E = \frac{1}{2} \epsilon_0 E^2$$

MAGNETNO POLJE

7.3.2011



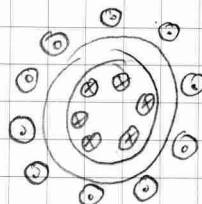
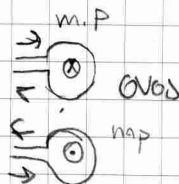
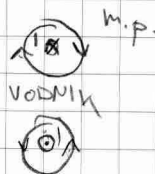
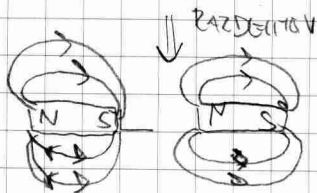
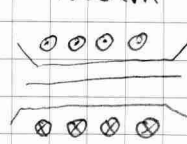
TOROID



Površni magnetni pol

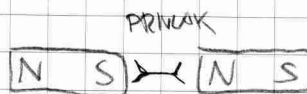
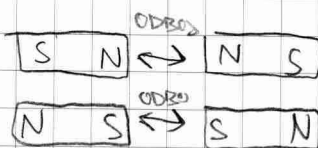


TULSAVA



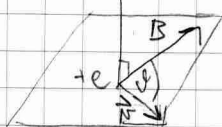
TOROID

N → Severni pol
S → južni pol



V vsaki točki mag. polja je smer določena s smerjo v halici hoke v ravnozemni ležišču (N) pol vesenstva ilhpa magnetna

Desno sučni vijak



$$\text{ENOTA za } B: B_d \frac{F}{eV} = \frac{NS}{A_{sm}} = \frac{N}{Am} = \frac{Nm}{Am^2} = \frac{J}{Am^2} = \frac{VA_s}{Am^2} = \frac{Vs}{m^2} = 1T$$

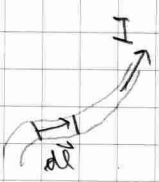
$$\text{DEF } B: \vec{F} = e\vec{v} \times \vec{B}$$

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

V žici

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

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



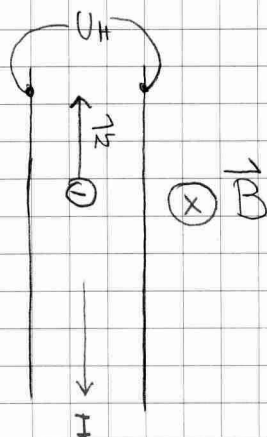
$$\vec{F}_e = I \vec{l} \times \vec{B}$$

RAVEN VODNIK

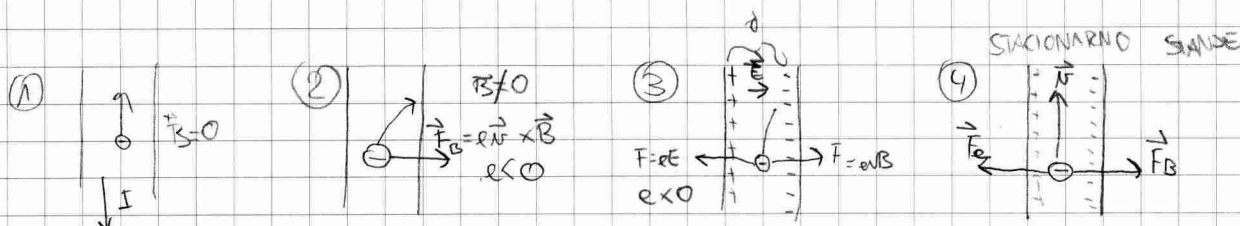
$$d\vec{F} = I d\vec{l} \times \vec{B} \Rightarrow \vec{F}_e = SI d\vec{l} \times \vec{B}$$

SILA NA VODNIK TO KATEREM TEČE TOK I

HALL-ON POŠAV



$$U_H \equiv H_{\text{ALLOVA}} \text{ NAPEČOST}$$



V STACIONARNEM STANJU

$$F_E = F_B$$

$$qE = qvB$$

$$\frac{U_H}{d} = vB$$

Perp. hitrost

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

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

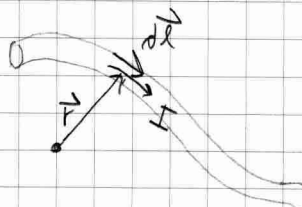
$$\frac{U_H}{d} = \frac{IB}{neS}$$



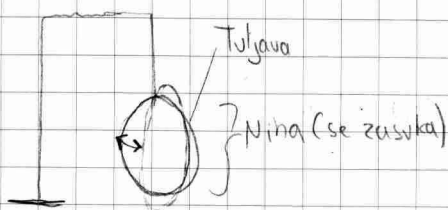
BIOT - SAVARTOV ZAKON

10.3.11

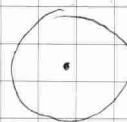
$$\vec{B} = \frac{\mu_0 I}{4\pi} \int \frac{\vec{r} \times d\vec{l}}{r^3}$$



Magnetno polje deluje z navorom



1. PRIMER - OKROGLA TOKOVNA ZANKA

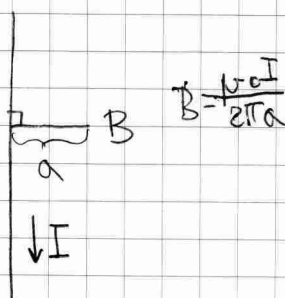


$$\vec{r} \perp d\vec{l}$$

$$|\vec{r}| = r = \text{konst}$$

$$\begin{aligned} \Rightarrow B &= \frac{\mu_0 I}{4\pi} \int \frac{r \, dl}{r^2} = \frac{\mu_0 I}{4\pi r^2} \int dl \\ &= \frac{\mu_0 I \, 2\pi r}{4\pi r^2} = \frac{\mu_0 I}{2r} \end{aligned}$$

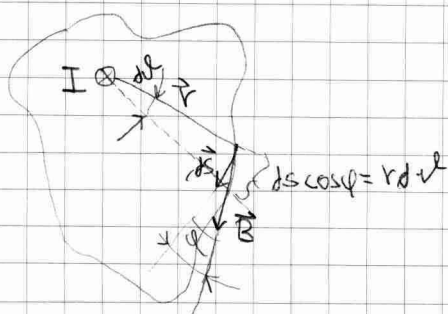
2. PRIMER - DOLG PAVEN VODNIK



AMPEROV ZAKON

Integriramo mag. polje po zaključeni liniji

PRIMER:



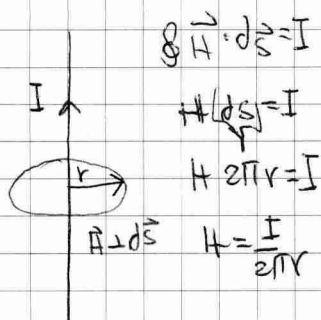
$$\oint \vec{B} \cdot d\vec{s} = \oint B \, ds \cos \varphi = \oint \frac{\mu_0 I \, r \, dl}{2\pi r} = \frac{\mu_0 I}{2\pi} \oint dl = \mu_0 I$$

$$\Rightarrow \oint \vec{B} \cdot d\vec{s} = \mu_0 \int \vec{j} \cdot d\vec{s}$$

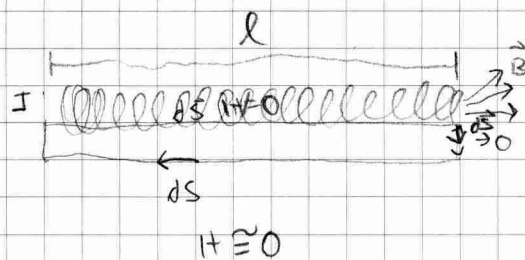
$$\vec{B} = \mu_0 \vec{H}$$

$$\oint \vec{H} \cdot d\vec{s} = \int \vec{j} \cdot d\vec{s}$$

1. PRIMER:



2. PRIMER - DOLGA TULSAVA

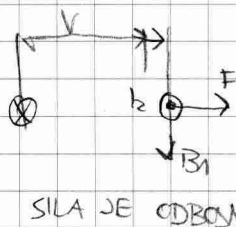
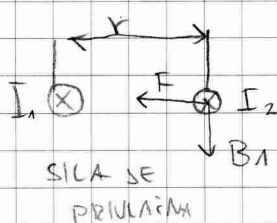


$$\oint \vec{H} \cdot d\vec{s} = H l = N I \Rightarrow H = \frac{N I}{l}$$

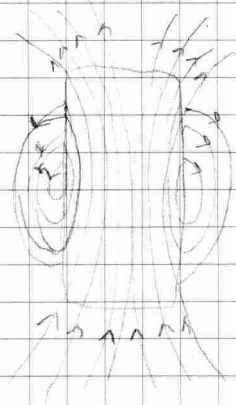
p
st. croscev

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

SILA MED VZPOREDNIMA VODNIKOMA

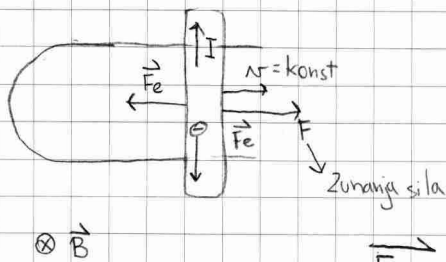


Ć izračunati velikost in smer sile med dvema vzporednima vodnikoma, če par ni vzporedno
 smer par je vzporedno naravnost - odbojna sila
~~Velikost sile med dvema vzporednima vodnikoma~~



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

INDUKCIJA



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

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

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

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

$$\vec{E} = \text{grad } \varphi$$

$$V = \rho \varphi - \oint \vec{E} \cdot d\vec{s}$$

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

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

DELO:

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

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

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

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

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

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

INDUKCIJSKI
ZAKON (POSEBNA OBLIKA)

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

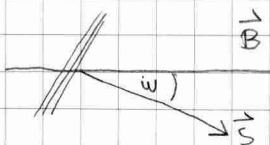
$$U_i = -\frac{\vec{B} \cdot d\vec{s}}{dt} = \frac{d(\vec{B} \cdot \vec{s})}{dt} = -\frac{d\phi_m}{dt}$$

POSPLOŠITEV:

$$\boxed{U_i = -\frac{d\phi_m}{dt}}$$

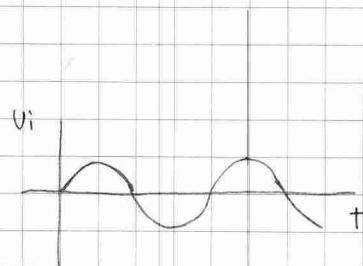
$$\boxed{\phi_m = \int \vec{B} \cdot d\vec{s}}$$

PRIMER:



$$\phi_m = \vec{B} \cdot \vec{s} = BS \cos(\omega t)$$

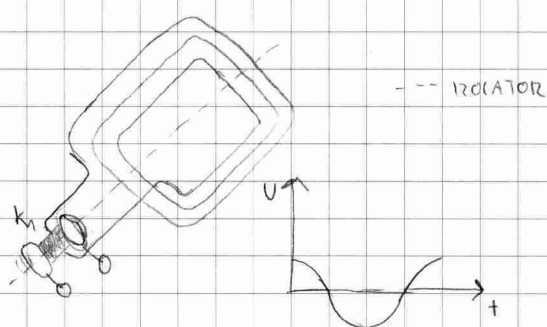
$$|U_i| = \left| \frac{d\phi_m}{dt} \right| = BS \omega \sin(\omega t)$$



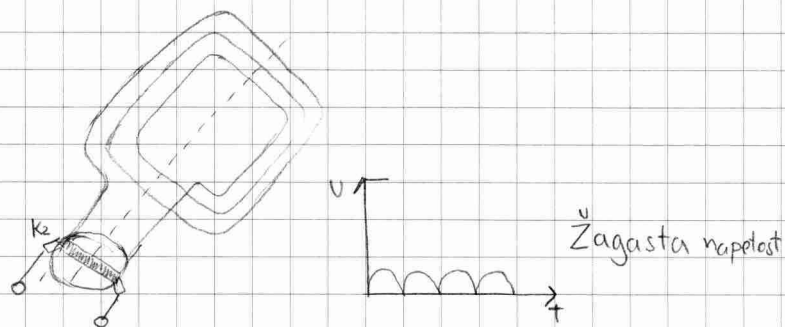
LENZOVO PRAVILO

Inducirana napetost sprožene tok, ki se spira spremembi, ki jo
inducirana napetost sprožila

GENERATORJI ELEKTRIČNEGA TOKA



DINAMOSTATOR S KOLEKTORJEM ZA IZMENIČNO NAPETOST

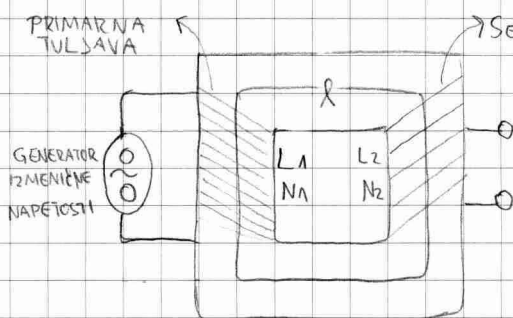


DINAMOSTATOR S KOMUTATORJEM ZA ENOSMERNO NAPETOST

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

kremenitni tok je pomemben zaradi prenosa energije na velike razdalje

TRANSFORMATOR



L - SREDNJI OBSEG SEDRA

Z istim presečnikom napetostni pretoki in dosežemo, da je napetostni pretok skozi tuljavo sklenjen

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

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

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

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

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

Toholonec na sekundarni tuljavi sklenemo skozi Ohmski upor:

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

EFEKTIVNA MOČ:

$$\bar{P} = I_g U_g$$

$$P_1 = P_2$$

$$I_1 U_{g2} = I_2 U_{g1} \Rightarrow \frac{I_{g1}}{I_{g2}} = \frac{U_{g2}}{U_{g1}} = \frac{U_{o2}}{U_{o1}} = \frac{N_2}{N_1}$$

DALJNOVOD

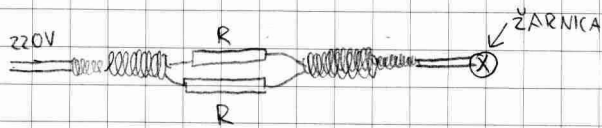
$$P = IU$$



IZGUBA NA DALJNOVODU:

$$P_d = I^2 R_d$$

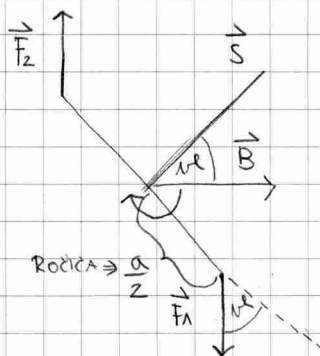
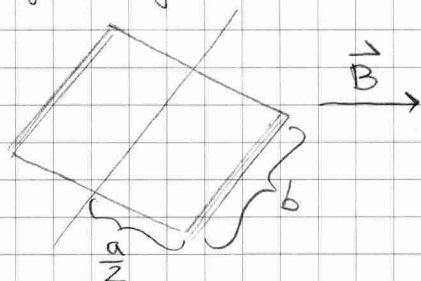
MODEL:



Na principu transformatorja deluje tudi navilni aparat

NAVOR NA TOKOVNO ZANKO

Na tokovno zanko, ki ima magnetni dipolni moment $\vec{p}_m$ v magnetnem polju deluje navor



Ker po žici teče tok dolimo na obeh straneh sile
SILA NA RAVNI VODNIK V $\vec{B}$

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

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

$$= I a b B \sin \alpha = I S B \sin \alpha$$

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

$p_m = IS \rightarrow$ magnetni dipolni moment tokovne zanke

$$p_m = IS$$

Če ima zanka več zavirov:

$$p_m = NIS$$

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

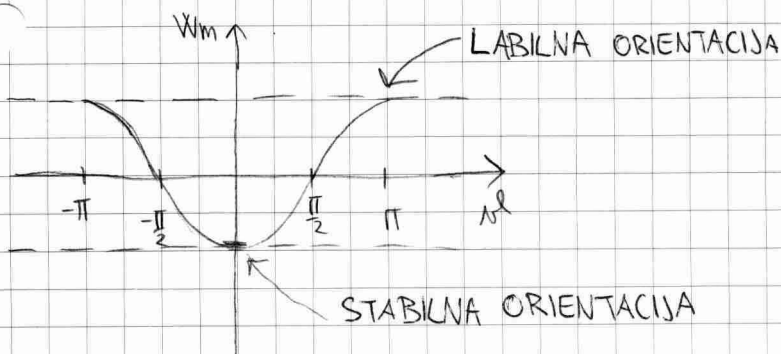
NAVOR NA TOKOVNO ZANKO
ALI MAGNETNI DIPOLNI MOMENT
V VEKTORSKI OBLIKI

$$A = \int M d\alpha = \int p_m B \sin \alpha d\alpha = -p_m B \cos \alpha$$

$$W_m = -p_m B \cos \alpha$$

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

EVA START:



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

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

NIHAJNI ČAS MAGNETNICE

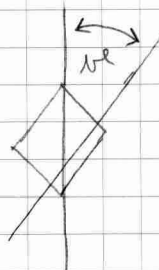
$$M = J\alpha$$

$$\sigma = \frac{d^2 \alpha}{dt^2} \equiv \ddot{\alpha}$$

$$-p_m B \sin \alpha < J \ddot{\alpha}$$

$$\sin \alpha \approx \alpha$$

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

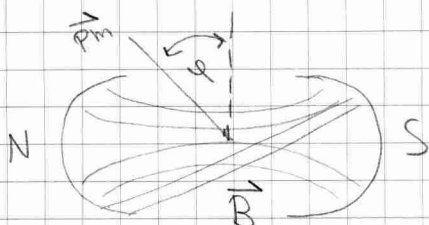


$$\text{REŠITEV: } \alpha = \alpha_0 \sin\left(\left[\frac{2\pi}{t_0}\right]t + \delta\right)$$

$$\ddot{\alpha} = -\alpha_0 \left(\frac{2\pi}{t_0}\right)^2 \sin\left(\left[\frac{2\pi}{t_0}\right]t + \delta\right)$$

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

MAGNETNI MOMENT TULJAVE



$\vec{p}_m$ je mehako vektor pravokoten na $\vec{B}$

$$M = p_m B \sin \alpha = p_m B$$

RAVNOVESNO STANJE

$$M_B = M_D$$

$$p_m B = D\varphi$$

$$N I S B = D\varphi$$

$$I = \frac{D}{N S B} \varphi$$

$$I \propto \varphi$$

konstanta prečnostne vzmeti

Tok JE SORAZMERN ZASUKU

Iglič: Voda je najbolj pomembna tekočina poleg VINA!

MERJENJE TOKOVNEGA SUNKA

$$\int I dt$$

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

$$\int p_m B dt \Rightarrow \int I N S B dt = J \omega$$

$$\int I dt = \frac{J \omega_0}{N S B}$$

$$\varphi = U_0 \sin\left(\frac{2\pi}{T_0} t + 1\right)$$

$$\omega = \frac{d\varphi}{dt} = \frac{2\pi}{T_0} U_0 \cos\left(\frac{2\pi}{T_0} t + 1\right)$$

EVA END

MAXWELLOVE ENAČBE

(OSNOVNI ZAKONI ELEKTROTEHNIKE)

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

ZAKON O ELEKTRIČNEM PRETOKU (GAUSSOV ZAKON)

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

ZAKON O MAGNETNEM PRETOKU

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

ZAKON O NEGATIVNI NAPETOSTI (AMPEROV ZAKON)

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

INDUKCIJSKI ZAKON (FARADAYEV ZAKON)

Dodatno mora veljati še zakon o ohmanitvi nabijev

$$\oint \vec{j}_e d\vec{S} = - \int \frac{\partial \rho_e}{\partial t} dV$$

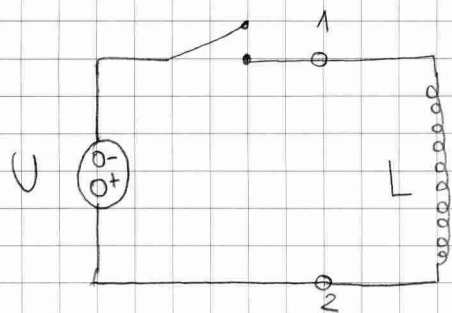
Ko poznamo prostorske odčitnosti $\vec{E}$ in $\vec{B}$:

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

LORENTZOVA SILA

Voda ima dielektričnost okoli 80

LASTNA INDUKCIJA



$$U + U_L = 0$$

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

a) Ob času $t \approx 0$ ~~po~~ priključitvi tiste po tuljavi spreminjamo NARAŠČAJOČ el. tok. Ker je ~~dI/dt > 0~~ $dI/dt > 0$ se v tuljavi inducira napetost, ki ji po LENZOVEM pravilu el. tok $\propto$ nasprotni smeri $\Rightarrow$ TULJAVA DELUJE KRATEK ČAS KOT UPOR

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

b) Ob času $t \approx 0$ ~~po~~ izključitvi tiste po tuljavi spreminjamo PADAJOČ el. tok. Ker je $dI/dt < 0$ se v tuljavi inducira napetost, ki ji po LENZOVEM pravilu el. tok $\propto$ smeri začetnega toka $\Rightarrow$ TULJAVA DELUJE KRATEK ČAS KOT GENERATOR

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

IZPELJAVA:

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

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

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

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

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

ZMENIČNI TOK PO TULJAVI

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

$$U_0 \sin(\omega t) - U_L = 0$$

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

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

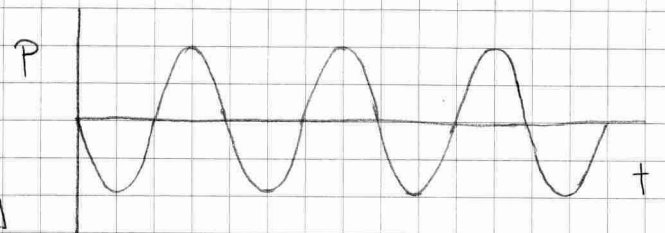
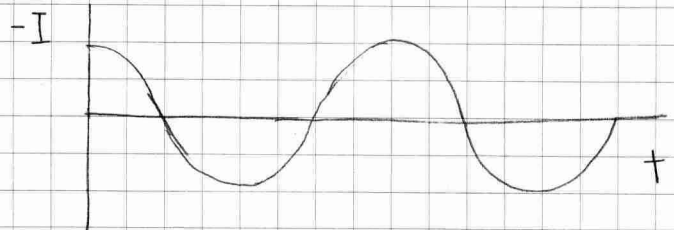
$$dI = \frac{U_0}{L} \sin(\omega t) d(\omega t)$$

$$I = \frac{U_0}{L} \int \sin(\omega t) d(\omega t) = \underbrace{-\frac{U_0}{\omega L} \cos(\omega t)}_{I_0 \sin(\omega t - \frac{\pi}{2})} - \frac{U_0}{L} \sin(\omega t - \frac{\pi}{2})$$

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



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



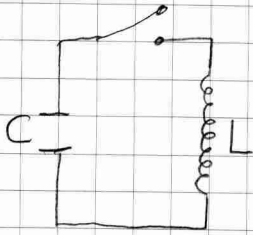
$$\left. \begin{array}{l} I = I_0 \cos(\omega t) \\ U = U_0 \cos(\omega t - \pi) \end{array} \right\} P = IU = I_0 U_0 \cos(\omega t - \pi)$$

$$[\cos \omega t \cos \pi - \sin \omega t \sin \pi]$$

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

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

IDEALNI NIHAJNI KROG



$$U_L + U_C = 0$$

$$e = CU$$

$$U_C(t=0) = U_0$$

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

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

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

Rešitev:

$$I = I_0 \sin(\omega_0 t)$$

$$\frac{d^2 I}{dt^2} = -I_0 \omega_0^2 \sin(\omega_0 t) = -\omega_0^2 I$$

$$\omega_0^2 I = -\frac{1}{LC} I$$

$$\omega_0^2 = \frac{1}{LC}$$

LASTNA FREKVENCA IDEALNEGA NIHAJNEGA KROGA



DIPOLOVA ANTENA
(EM Valovanje)



VRTILNI KONDENZATOR
(Z ZASUKOM SPREMINJAMO
KAPACITETO)

NAPETOST NA TULJAVI

$$U_L = -L \frac{dI}{dt} = LI_0 \omega_0 \cos(\omega_0 t) \rightarrow \text{Največja napetost na tuljavi}$$

NAPETOST NA KONDENZATORJU

$$U_L + U_C = 0 \Rightarrow U_C = -U_L = LI_0 \omega_0 \cos(\omega_0 t) \rightarrow \text{Največja napetost na kondenzatorju}$$

$$W_C = \frac{1}{2} C U_0^2$$

$$U_0 = LI_0 \omega_0$$

$$\int_0^{I_0} U_L I dt = \int_0^{I_0} L \frac{dI}{dt} I dt = \frac{1}{2} L I^2$$

ENERGIJA TULJAVE

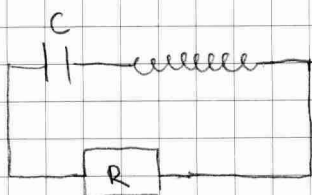
Energija idealnega nih. kroga:

$$W = \frac{1}{2} C U_0^2 = \frac{1}{2} L I_0^2$$

V splošnem:

$$W = \frac{1}{2} C U^2 + \frac{1}{2} L I^2 = \frac{1}{2} C L I_0^2 \omega_0^2 \cos^2(\omega_0 t) + \frac{1}{2} L I_0^2 \sin^2(\omega_0 t) = \frac{1}{2} L I_0^2 [\cos^2(\omega_0 t) + \sin^2(\omega_0 t)] = \frac{1}{2} L I_0^2 = \frac{1}{2} C U_0^2$$

DUŠENI ELEKTRIČNI NIHAJNI KROG



$$U_C + U_L + U_R = 0$$

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

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

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

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

NASTAVEK ZA REŠITEV: $I = I_0 e^{-\beta t} \cos(\omega_0 t)$

β - koeficient dušenja

$$e^{i\omega t} = \cos(\omega t) + i \sin(\omega t)$$

$$I = I_0 e^{-\beta t} e^{i\omega_0 t} = I_0 e^{(i\omega_0 - \beta)t}$$

$$\frac{dI}{dt} = I_0 (i\omega_0 - \beta) e^{(i\omega_0 - \beta)t} = I_0 (-\omega_0^2 - 2\omega_0 \beta i + \beta^2) e^{(i\omega_0 - \beta)t}$$

$$I_0 e^{(i\omega_0 - \beta)t} \left[-\omega_0^2 - 2\omega_0 \beta i + \beta^2 + \frac{R}{L} (i\omega_0) - \frac{R}{L} \beta + \omega_0^2 \right] = 0$$

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

$$-\omega_0^2 + \beta^2 - \frac{R}{L} \beta + \omega_0^2 = 0$$

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

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

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

$\Rightarrow$ Če $R=0$:

$$\beta = 0$$

$$\omega_0' = \omega_0$$

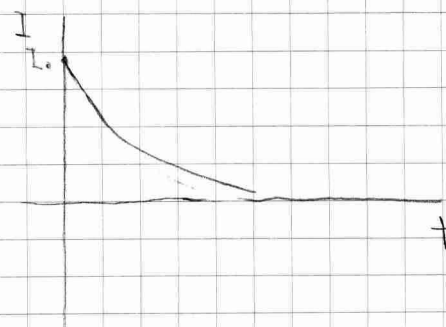
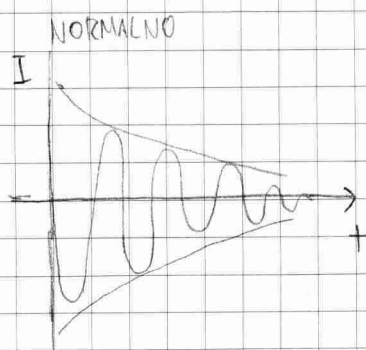
$$I = I_0 \cos(\omega t)$$

$$\beta > \omega_0: \omega_0' = \sqrt{\omega_0^2 - \beta^2} = i \sqrt{\beta^2 - \omega_0^2} = i\delta$$

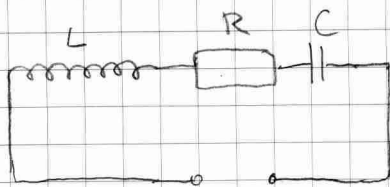
$$I = I_0 e^{-\beta t} e^{i\omega_0 t} = I_0 e^{-\beta t} e^{-\delta t}$$

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

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



V SILSNO NIHANJE EL. NIHANEGA KROGA



$$U_g = U_0 \cos(\omega t)$$

$$I = I_0 e^{i\omega t}$$

$$U_g = U_0 e^{i\omega t}$$

$$I_0 \in \mathbb{R}$$

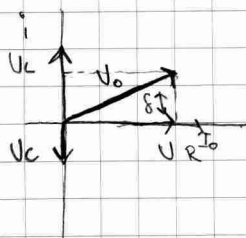
$$U_0 \in \mathbb{C}$$

$$U_g + U_L + U_R + U_C = 0$$

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

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

KAZALČNI DIAGRAM



$$e^{i\omega t} [U_0 i\omega + L I \omega^2 - I R i\omega - \frac{I}{C}] = 0$$

$$i\omega U_0 + L I \omega^2 - I R i\omega - \frac{I}{C} = 0 \quad | : i\omega$$

$$U_0 = -\frac{L I \omega^2}{i i \omega} + I R - \frac{I}{i \omega C}$$

Z → IMPEDANCA

$$U_0 = I_0 \left[\underbrace{+L\omega^2}_{Z_L} + \underbrace{R}_{Z_R} - \underbrace{\frac{1}{\omega C}}_{Z_C} \right] = I_0 \left[R + i \left(L\omega - \frac{1}{\omega C} \right) \right]$$

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

$$Z_R = R$$

$$Z_L = L\omega i$$

$$Z_C = -\frac{i}{\omega C}$$

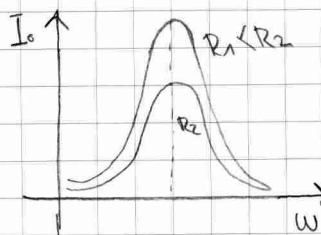
$$U_0 = I_0 Z$$

$$Z = Z_R + Z_L + Z_C$$

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

FAZNI ZAMIK:

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

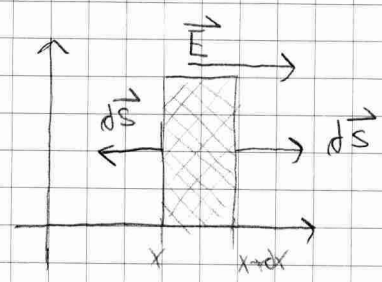


$$\text{MAX: } L\omega_{\text{RES}} - \frac{1}{\omega_{\text{RES}} C} = 0 \Rightarrow \omega_{\text{RES}}^2 = \frac{1}{LC} = \omega_0^2$$

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

$$U_R = I_0 R$$

POISSONOVA ENAČBA



$\rho(x)$ = volumska porazdelitev naboja

$$\epsilon_0 \oint \vec{E} \cdot d\vec{S} = \int \rho dV$$



$$\epsilon_0 [E(x+dx)S - E(x)S] = \rho(x)dxS$$

$$\epsilon_0 \frac{dE}{dx} = \rho(x)$$

$$\epsilon_0 \frac{dE}{dx} = \rho(x)$$

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

$$\epsilon_0 \frac{d}{dx} \left(\frac{d\phi}{dx} \right) = \rho(x) \Rightarrow \frac{d^2 \phi}{dx^2} = -\frac{\rho(x)}{\epsilon_0}$$

POISSONOVA ENAČBA V 1-DIMENZIJI

ISPOVSHEM

$$\vec{E} = \text{grad } \phi$$

$$\epsilon_0 \oint \vec{E} \cdot d\vec{S} = \int \rho dV \Rightarrow \epsilon_0 \text{div } \vec{E} = \rho(\vec{r})$$

$$\epsilon_0 \vec{\nabla} \cdot \vec{E} = \rho(\vec{r})$$
$$\vec{\nabla} = \left(\frac{\partial}{\partial x}, \frac{\partial}{\partial y}, \frac{\partial}{\partial z} \right)$$
$$\vec{E} = (E_x, E_y, E_z)$$

$$\epsilon_0 \left(\frac{\partial E_x}{\partial x} + \frac{\partial E_y}{\partial y} + \frac{\partial E_z}{\partial z} \right) = \rho(\vec{r})$$

NAZRA

$$\epsilon_0 \vec{\nabla} \cdot \vec{E} = \rho(\vec{r})$$
$$\epsilon_0 \vec{\nabla} \cdot (-\nabla \phi) = \rho(\vec{r})$$
$$-\epsilon_0 \nabla^2 \phi = \rho(\vec{r}) \Rightarrow \nabla^2 \phi(\vec{r}) = -\frac{\rho(\vec{r})}{\epsilon_0}$$

$$\Delta \phi = \frac{\rho}{\epsilon_0}$$

POISSONOVA ENAČBA V 3-DIMENZIJI

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

$$\Delta \phi(\vec{r}) = -\frac{\rho(\vec{r})}{\epsilon_0}, \Delta = \vec{\nabla} \cdot \vec{\nabla} = \left(\frac{\partial}{\partial x}, \frac{\partial}{\partial y}, \frac{\partial}{\partial z} \right) \cdot \left(\frac{\partial}{\partial x}, \frac{\partial}{\partial y}, \frac{\partial}{\partial z} \right) = \frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2} + \frac{\partial^2}{\partial z^2}$$

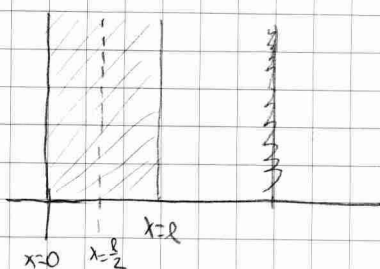
$$\frac{\partial^2 \phi(\vec{r})}{\partial x^2} + \frac{\partial^2 \phi(\vec{r})}{\partial y^2} + \frac{\partial^2 \phi(\vec{r})}{\partial z^2} = -\frac{\rho(\vec{r})}{\epsilon_0}$$

DIELEKTRIČNA KONSTANTA $\epsilon_r(\vec{r})$

$$\vec{\nabla} \cdot [\epsilon_0 \epsilon_r(\vec{r}) \vec{\nabla} \phi] = -\rho(\vec{r})$$

Resenje FEM - Comsol

PP - FINSIRAN NABOJ



$$\frac{d^2\varphi}{dx^2} = \frac{\rho_0}{\epsilon_0}, \quad \rho = \text{konst}$$

$$\frac{d\varphi}{dx} = -\frac{\rho_0}{\epsilon_0}x + B$$

$$\varphi(x) = -\frac{\rho_0 x^2}{2\epsilon_0} + Bx + C$$

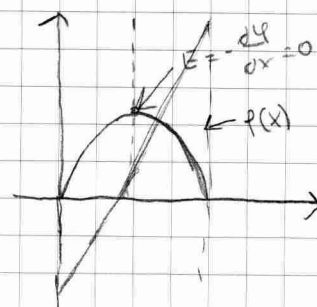
$$\varphi(x=\frac{l}{2})=0 \Rightarrow E(x=\frac{l}{2})=0$$

$$E(x) = -\frac{d\varphi}{dx} = \frac{\rho_0}{\epsilon_0}x - B$$

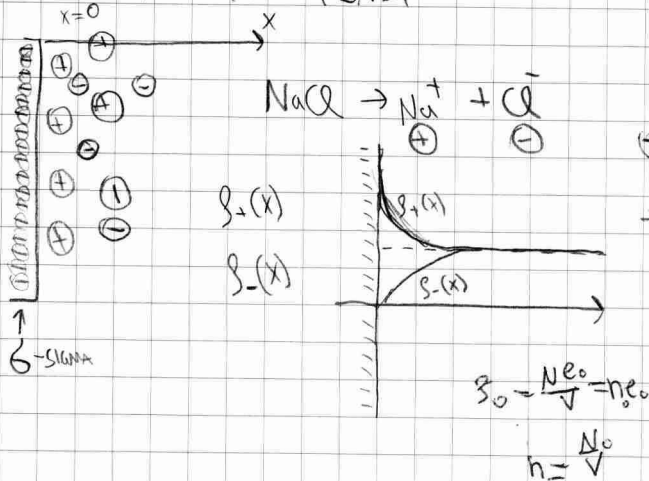
$$E(x=\frac{l}{2}) = \frac{\rho_0 l}{2\epsilon_0} - B = 0 \Rightarrow B = \frac{\rho_0 l}{2\epsilon_0}$$

$$\varphi(x) = -\frac{\rho_0 x^2}{2\epsilon_0} + \frac{\rho_0 l}{2\epsilon_0}x$$

$$\varphi(x=0), \varphi(x=l) = 0$$



PP2: - EL. DVO SNA PLAST



IDEALNI PLIN MAXWELLOVA PORAZENLJIVOST

$$e^{-\frac{W_{\text{pot}}}{kT}} \quad \text{BOLTZMANOVA FAKTOR}$$

$$\begin{aligned} +W &= e_0 \varphi(x) \Rightarrow \rho_+(x) = \rho_0 e^{-\frac{W}{kT}} = \rho_0 e^{-\frac{e_0 \varphi}{kT}} \\ +W &= -e_0 \varphi(x) \Rightarrow \rho_-(x) = \rho_0 e^{-\frac{W}{kT}} = \rho_0 e^{-\frac{-e_0 \varphi}{kT}} \end{aligned}$$

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

$$\frac{d^2\varphi}{dx^2} = \frac{\rho_0}{\epsilon_0} \left(e^{-\frac{e_0 \varphi}{kT}} + e^{\frac{e_0 \varphi}{kT}} \right) = \frac{2\rho_0}{\epsilon_0} \text{sh}\left(\frac{e_0 \varphi}{kT}\right)$$

$$\frac{d^2\varphi}{dx^2} = \frac{2\rho_0}{\epsilon_0} \text{sh}\left(\frac{e_0 \varphi}{kT}\right) = \frac{2n e_0}{\epsilon_0} \text{sh}\left(\frac{e_0 \varphi}{kT}\right)$$

$$\epsilon_0 \rightarrow \epsilon_r \epsilon_0$$

$$\epsilon_r \approx 78.5$$

$$\frac{d^2\varphi}{dx^2} = \frac{2n e_0}{\epsilon_r \epsilon_0} \text{sh}\left(\frac{e_0 \varphi}{kT}\right)$$

$$\frac{d^2\varphi}{dx^2} = -\frac{zn_0 e_0}{\epsilon_r \epsilon_0} \left(\frac{e_0 \varphi}{kT} \right) + \frac{e_0 \varphi}{kT}$$

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

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

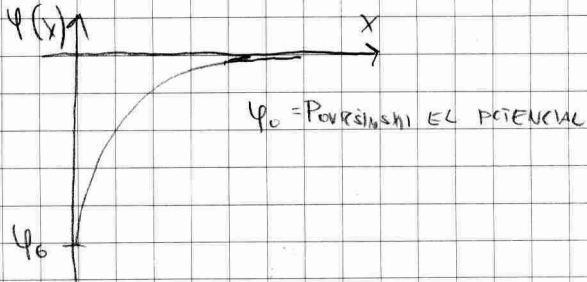
$$\frac{d^2\varphi}{dx^2} = -\frac{zn_0 e_0}{\epsilon_r \epsilon_0} \frac{e_0 \varphi}{kT}$$

$$\frac{d^2\varphi}{dx^2} = -\frac{zn_0 e_0^2}{\epsilon_r \epsilon_0 kT} \varphi \rightarrow K^2$$

$$\Rightarrow K = \sqrt{\frac{zn_0 e_0^2}{\epsilon_r \epsilon_0 kT}}$$

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

LINEARIZIRANO
PB ENACBA



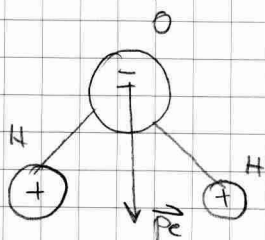
$$E = 0$$

DIELEKTRIČNE LASTNOSTI SNOVI

POLARNE - Molekule imajo permanentni dipolni moment

NEPOLARNE - imajo zelo majhen dipolni moment zaradi 0. Če jih damo v el. polje pa dolga indukcija dipolni moment - zaradi tega ni permanentni.

POLARNA MOLEKULA

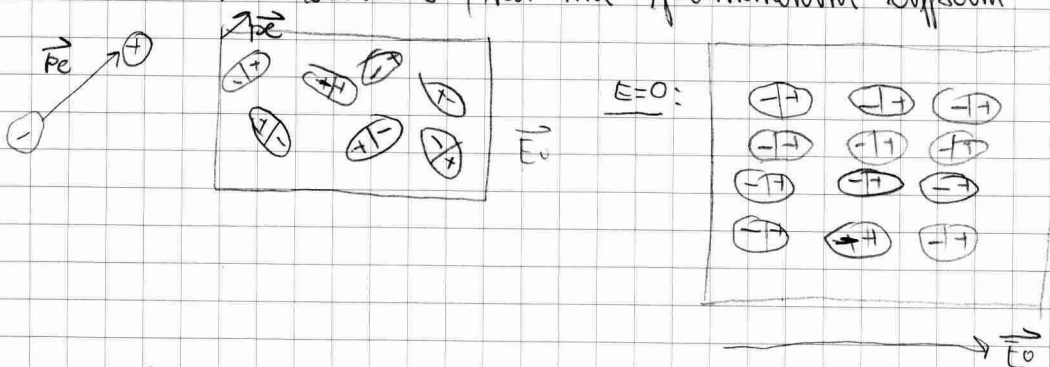


NEPOLARNA MOLEKULA

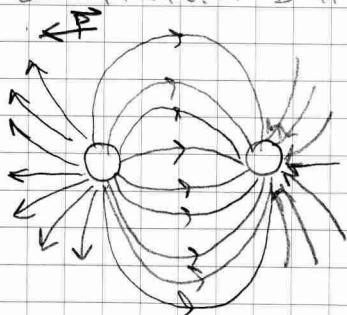
$$E_0 = 0 : \begin{pmatrix} + \\ - \end{pmatrix}$$

$$E \neq 0 : \uparrow \vec{E}_0 \begin{pmatrix} + \\ - \end{pmatrix} \text{ INDUCIRANI DIPOLNI MOMENT}$$

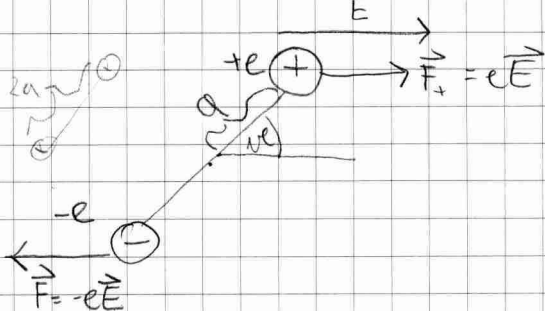
⇒ Voda dielektričnost okoli 80, ker ima permanentni dipolni moment.



ELEKTRIČNI DIPOL



SILA IN NAVOR V ZUNANJEM POLJU DIPOLA



$$M = M_+ + M_- = aeE + (-a)(-e)E = 2aeE \sin \alpha$$

$$M = \underbrace{edE \sin \alpha}_{p \cdot d} = pE \sin \alpha$$

$$\vec{M} = \vec{p} \times \vec{E}$$

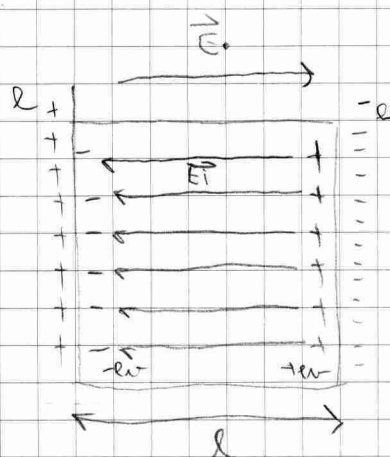
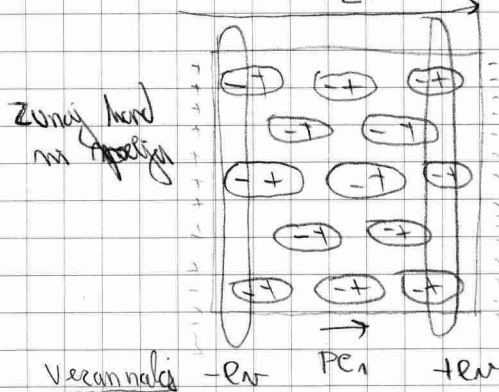
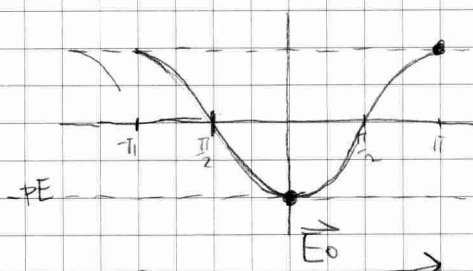
$$W_e = \int_{\alpha_{\min}}^{\alpha_{\max}} M d\alpha = \int_{\alpha_{\min}}^{\alpha_{\max}} pE \sin \alpha d\alpha = -pE \cos \alpha \Big|_{\alpha_{\min}}^{\alpha_{\max}} = -\vec{p} \cdot \vec{E}$$

$$W_e = -\vec{p} \cdot \vec{E}$$

$$\begin{aligned} \alpha=0 & \uparrow \vec{p} \uparrow \vec{E} : W_e = -pE \\ \alpha=\pi & \uparrow \vec{p} \uparrow \vec{E} : W_e = +pE \end{aligned}$$

- Najmanjša energija
- Največja energija

Večji tump manj orientiran; manjša količina orientiranja



$$\begin{aligned} \langle \rho(x) \rangle &= \rho(x) - \frac{\partial \rho}{\partial x} \\ \langle \rho(x) \rangle &= \rho(x) - \nabla \cdot \vec{P} \\ \epsilon_0 \nabla \cdot \vec{E} &= \langle \rho(x) \rangle \\ \nabla \cdot (\epsilon_0 \nabla \vec{P}) &= \langle \rho(x) \rangle \end{aligned}$$

CELOTNO POLJE:

$$\begin{aligned} E &= E_0 - E_1 \\ E &= E_0 - \frac{P}{\epsilon_0} \end{aligned}$$

POLARIZACIJA:

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

DIPOLNI MOMENT VE. NAMEN: $\epsilon_0 \nabla \cdot \vec{P} = \rho$
 $N \langle \vec{p} \rangle = \epsilon_0 \nabla \cdot \vec{P}$

OD ENJE MOL:

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

✓

$$D = \epsilon_0 E + P$$

$$D = \epsilon_0 E + \epsilon_0 \chi E$$

$$D = \epsilon_0 (1 + \chi) E$$

$\epsilon = 1 \rightarrow \chi$ ϵ - dielektrische

NEPOLARNE MOLEKULE

$\vec{E} = 0$  $p_e = 0$
 $\vec{E} \neq 0$ 

$eE = h\nu$ INDUKSI RAN: DIPOLUS MUKAT

$$d = \frac{eE}{\hbar} \rightarrow p_e = d_e = \frac{e\hbar G}{\hbar}$$

$$p_e dE \quad \boxed{p_e = \frac{d^2 E}{d\epsilon}}$$

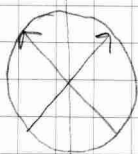
$$P = n p e = \frac{n e^2 E}{\pi} \quad \angle 60^\circ$$

POLARNE MOLEKULE

$$P = \epsilon_0 \kappa E$$

A diagram illustrating the decomposition of a vector into components. A vector is shown pointing upwards and to the right. A horizontal line is drawn from the base of the vector to the right, labeled with the symbol $\vec{E}$. A vertical dashed line is drawn from the tip of the vector down to the horizontal line. The angle between the vector and the horizontal line is labeled θ . The vector itself is labeled $\vec{P}_c$.

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



$$\langle \cos \theta \rangle = \frac{\int \cos \theta \, d\Omega}{\int d\Omega}$$

$$W_d = -P_e E \cos \alpha l$$

P

Kinetische potentiell

$$Wip \sim k(x-x_0)^2 - C$$
$$F = - \frac{\partial Wip}{\partial x} = -k(x-x_0) < -kx + kx_0$$

$$\epsilon_0 \chi = \frac{n e^2}{\kappa} \Rightarrow \epsilon_0 = 1 + \chi = 1 + \frac{n e^2}{\epsilon_0 \kappa} \left. \vphantom{\frac{n e^2}{\epsilon_0 \kappa}} \right\} \lim_{\kappa \rightarrow \infty} \epsilon \rightarrow 1$$

$$|p_e| = p_e$$

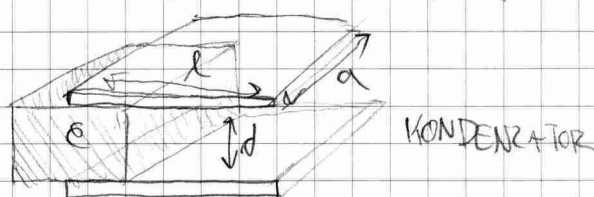
$$2A \frac{Pe}{hT} \ll 1: \quad \langle \cos \theta \rangle \approx \frac{Pe}{8kT}$$

$$P = n_A R T = \frac{n_A R T}{3 h^2}$$

$$\Rightarrow \epsilon_0 \chi = \frac{n p e^2}{3 k T} \Rightarrow \chi = \frac{n p e^2}{3 \epsilon_0 k T}$$

$$\epsilon = 1 + \chi = 1 + \frac{N p e^2}{3 \epsilon_0 k T}$$

SILA NA DIELEKTRIK



Ko notujemo dielektrik med plošči kondenzatorja (do globočine x) se moč na ploščah spremeni

$$e = C_0 U_0 = \epsilon_0 \frac{S}{d} U_0 \Rightarrow \text{konstanta razve. } x$$

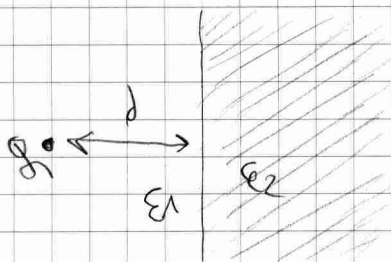
Imej $C_0 = \epsilon_0 \frac{S}{d}$ = kapaciteta pri $x=0$ in U_0 napolnjen med ploščama;

Pri $x \neq 0$: Sistem obravnava kot dva neperiodno vezana kondenzatorja

$$W(x) = \frac{1}{2} \frac{Q^2}{C} = \frac{1}{2} \frac{C_0^2 U_0^2}{\epsilon_0 \frac{ax}{d} + \epsilon_0 \frac{a(l-x)}{d}} = \frac{1}{2} \frac{C_0^2 U_0^2}{\epsilon_0 \frac{ax}{d} (\epsilon - 1) + \epsilon_0 \frac{a(l-x)}{d}}$$

SILA NA DIELEKTRIK = sila med materialom med ploščami in dipol v dielektriku

$$F = - \frac{dW(x)}{dx} = \frac{1}{2} U_0^2 \frac{\epsilon a x l}{d} \frac{(\epsilon - 1)}{(\epsilon - 1)x + l}$$

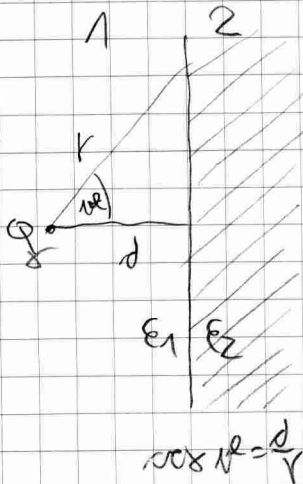


$\epsilon_1 > \epsilon_2 \Rightarrow F_x > 0$ odhajna sila stran od meje plošče

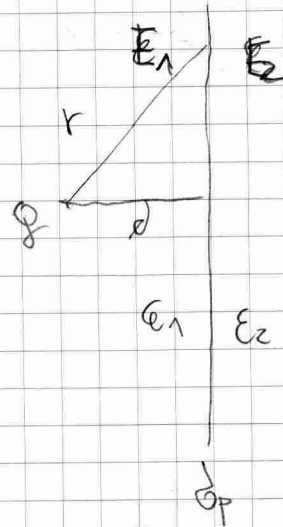
$\epsilon_1 < \epsilon_2 \Rightarrow F_x < 0$ privlačna sila proti meji plošči

$$F = \frac{1}{4\pi\epsilon_0\epsilon_1} \frac{(\epsilon_1 - \epsilon_2)}{(\epsilon_1 + \epsilon_2)} \frac{q^2}{4d^2}$$

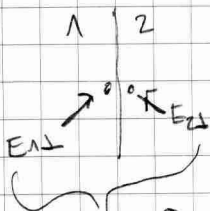
SILA NA TOČKASTI NABOJ V BLIZINI MESE DVEH DIELEKTRIKOV



MODEL:
Predpostavim, da
na desni strani ϵ_2 ni
ničelno ϵ_1 in
pa upoštevam
s površinsko
naboje σ_p na
meji.



$$E_p = -\frac{\sigma_p}{2\epsilon_0\epsilon_1}$$



$$E_{1\perp} = \frac{q}{4\pi\epsilon_0\epsilon_1} \frac{1}{r^2} \frac{d}{r} - \frac{\sigma_p}{2\epsilon_0\epsilon_1}$$

$$E_{2\perp} = \frac{q}{4\pi\epsilon_0\epsilon_1} \frac{1}{r^2} \frac{d}{r} + \frac{\sigma_p}{2\epsilon_0\epsilon_1}$$

Vr. polja skozi stični površini

ROBNI POGOJ

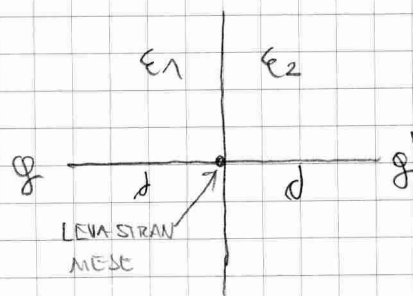
$$\Rightarrow -\epsilon_1 E_{1\perp} + \epsilon_2 E_{2\perp} = 0 \Rightarrow \sigma_p \Rightarrow E_p = -\frac{\sigma_p}{2\epsilon_0\epsilon_1} = -\frac{\epsilon_1 - \epsilon_2}{\epsilon_1 + \epsilon_2} \frac{1}{4\pi\epsilon_0\epsilon_1} \frac{q}{r^2} \frac{d}{r}$$

ROBNI POGOJ

$$\epsilon_1 E_{1\perp} dA + \epsilon_2 E_{2\perp} dA = 0$$

PRISTAVEK: in električnem polju na levi strani
maja zračnik $\epsilon_1 \neq \epsilon_2$ torej ima polje
trikotno obliko.

$$q' = \frac{\epsilon_1 - \epsilon_2}{\epsilon_1 + \epsilon_2} q \quad \text{v mediju } \epsilon = \epsilon_1$$



SNOV V MAGNETNEM POLJU

$$\boxed{W_p = -\vec{p}_m \cdot \vec{B}} \rightarrow \begin{array}{l} \theta = 0^\circ: W_p = -p_m B \quad \vec{p}_m \uparrow \uparrow \vec{B} \\ \theta = \pi: W_p = +p_m B \quad \vec{p}_m \downarrow \uparrow \vec{B} \end{array}$$

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

Vzmenjajoč magn. polje se preferenčni magnetni moment $\vec{p}_m$ in smer zmanjšuje polo,
in pa se skladno z Lenzovim pravilom

$$\boxed{B = B_0 + B_m} \rightarrow \text{Neto-magn. polje}$$

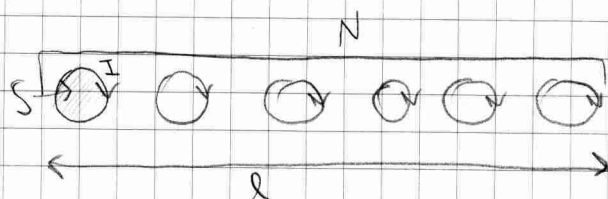
Paramagneti - permanentni dipolni moment

Diamagneti - nimajo permanentnega dipolnega momenta

Vsebi paramagnet je tudi diamagnet

1-DIMENZIONALNI PRIMER

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



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

$$\boxed{V = lS} \quad \text{VOLUME } N$$

$$\boxed{IS = p_m} \quad \text{MAGNETNI MOMENT}$$

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

Magnetizacija je odziva na magnetno polje

$$M = \chi H$$

↑
SUSCEPTIBILNOST

$$B = B_0 + B_m = B_0 + \mu_0 M \quad \rightarrow M = \chi H =$$

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

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

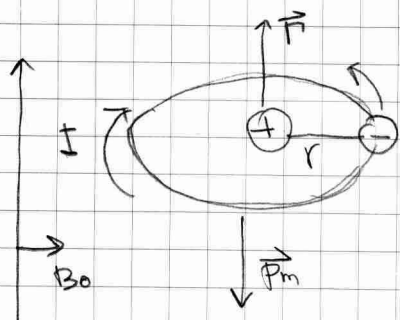
$$\boxed{\vec{B} = \mu_0 \mu \vec{H}}$$

PARAMAGNETI $\rightarrow$ Susceptibilnost > 0 , Permeabilnost > 1
 DIAMAGNETI: $\rightarrow$ Susceptibilnost < 0 , Permeabilnost < 1

χ zelo velika $\Rightarrow \mu(H) \gg 1$
 $B \propto H$ močta razmeroma } FEROMAGNETI

ISINGOV MODEL

KLASIČNI MODEL DIAMAGNETIZMA



$$\vec{\Gamma} \text{ VRTILNA KOLIČINA}$$

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

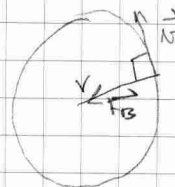
$$p_n = IS = \frac{e_0 \hbar \pi r^2}{2\pi R}$$

$$= \frac{e_0}{2me} \frac{m_e v r}{\Gamma}$$

$$S = \pi r^2$$

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

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



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

Newtonov zakon:

$$m_e a_r = F_B$$

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

$$m_e v = e_0 r B$$

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

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

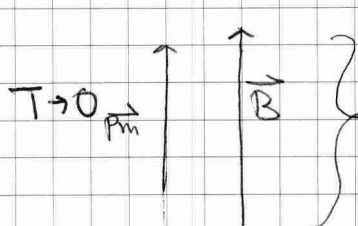
$$M = n p_m = - \frac{n e_0^2 \hbar^2}{2me} H$$

$$M = - \frac{N_0 n e_0^2 \langle r^2 \rangle}{2me} H \Rightarrow \chi = - \frac{N_0 n e_0^2 \langle r^2 \rangle}{2me}$$

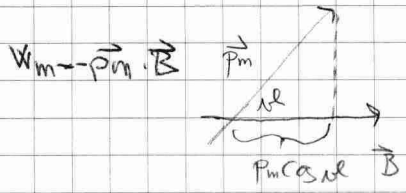
χ SUSCEPTIBILNOST

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

PARAMAGNETI



$\alpha = 0$
 $W_p = -p_m B$



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

$n = \frac{N}{V}$
 $\langle \cos \alpha \rangle = \frac{\int \cos \alpha e^{-\frac{W_m}{kT}} d\Omega}{\int e^{-\frac{W_m}{kT}} d\Omega}$ → Prostorčni kot

Temperaturna energija kT

$L(x) = \text{LANGEVINOVA funkcija}$

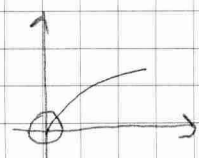
$\Rightarrow \frac{p_m B}{kT} < 1 \approx \frac{p_m B}{3kT}$

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

$M = \chi H$
↑ SUSCEPTIBILNOST

Če je $\frac{p_m B_0}{kT} \ll 1$:

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

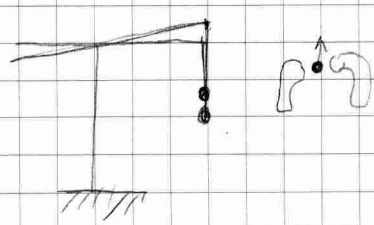


$M = C \frac{B_0}{T}$
 $C = \frac{n p_m^2}{3k}$

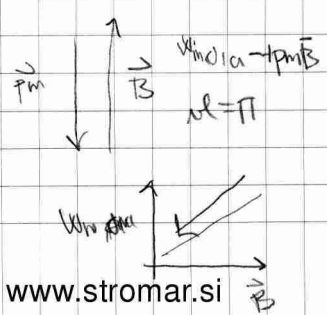
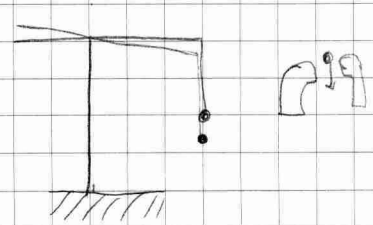
Curieov zakon

POSKUS

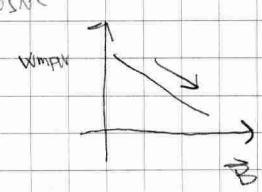
DIAMAGNET



PARAMAGNET



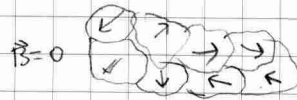
$W_m = \vec{p}_m \cdot \vec{B} = -p_m B \cos \alpha$
 $W_{m, \pi} = -p_m B$
 $\alpha = 0$



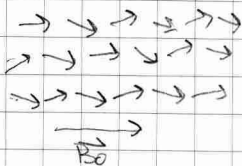
FEROMAGNETI

Isingov model

MAGNETNO STANJE SNOVI - s pamerno domen rešitja

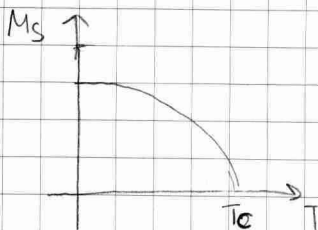


Vrste feromagnetov so tist feromagnet, ki temperatura dovolj povišamo
začnejo feromagneti prenehajo



Vrednoti domen v
Zmagnitni mag-polje B_0
 N ni neodvisna
 $\mu \Rightarrow$ posr. permeabilnost

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

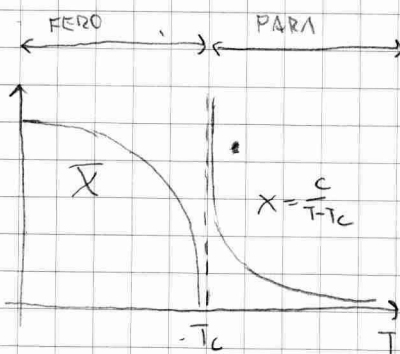


$T_c \Rightarrow$ Curiejeva temp.
Spontana magnetizacija začne domati

Če je $T \geq T_c$ feromagnetni snovi izgubijo spontano magnetizacijo in
postanejo paramagnetni.

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

$$\chi = \frac{C}{T - T_c}$$

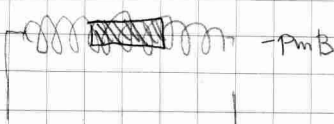


$\chi > 0 \Rightarrow \mu > 1$: PARAMAGNETI
 $\chi < 0 \Rightarrow \mu < 1$: DIAMAGNETI

χ zelo velik $\Rightarrow \mu(H) \gg 1$
 B in H nista sorazmerna - feromagnetni snovi

BERKHANSEN-OV POSTOP

Snov n. tuljavo obkroži pol. polje in n. magnet

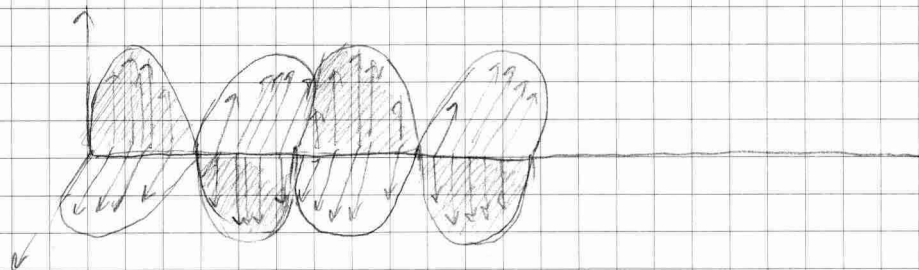


Medsebojno se magnetirajo. Dipolni momenti se
zadržijo med se

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

Snovi se zelo obratujejo domati

ELEKTRO - MAGNETNO VALOVANJE



MAXWELLOVE ENAČBE:

$$\left. \begin{aligned} \oint \vec{E} \cdot d\vec{s} &= -\frac{\partial}{\partial t} \int \vec{B} \cdot d\vec{s} \\ \oint \vec{B} \cdot d\vec{s} &= \frac{\partial}{\partial t} \int \vec{D} \cdot d\vec{s} \end{aligned} \right\}$$

$$\left. \begin{aligned} \frac{\partial^2 E}{\partial x^2} &= \frac{1}{\epsilon_0 \mu_0} \frac{\partial^2 C}{\partial t^2} \\ \frac{\partial^2 H}{\partial x^2} &= \frac{1}{\epsilon_0 \mu_0} \frac{\partial^2 H}{\partial t^2} \end{aligned} \right\} \text{VALOVNI ENAČBI}$$

Rešitev: Potujemo nekakšno:

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

$$\left. \begin{aligned} \frac{\partial^2 E}{\partial x^2} &= -E_0 k^2 \cos(\omega t - kx) \\ \frac{\partial^2 E}{\partial t^2} &= -E_0 \omega^2 \cos(\omega t - kx) \end{aligned} \right\} \text{ o/0}$$

$$\Rightarrow k = \frac{\omega}{c_0} \quad \frac{\frac{\partial^2 E}{\partial x^2}}{\frac{\partial^2 E}{\partial t^2}} = \frac{k^2}{\omega^2} = \frac{\omega^2}{\omega^2 c_0^2} = \frac{1}{c_0^2} \Rightarrow \frac{\partial^2 E}{\partial x^2} = c_0^2 \frac{\partial^2 E}{\partial t^2} \quad \left. \begin{aligned} c_0^2 &= \frac{1}{\epsilon_0 \mu_0} \\ c_0 &= \frac{1}{\sqrt{\epsilon_0 \mu_0}} \end{aligned} \right\}$$

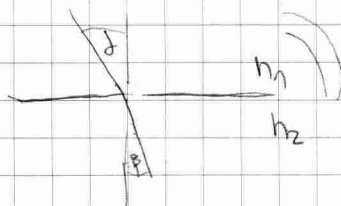
$c_0 \approx 3 \cdot 10^8 \text{ m/s}$

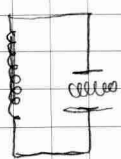
$$\begin{aligned} \epsilon &\neq 1 & \epsilon_0 &\rightarrow \epsilon \epsilon_0 \\ \mu &\neq 1 & \mu_0 &\rightarrow \mu \mu_0 \end{aligned}$$

ZA PROZIRNE SNALI

$$\mu = 1 \quad c = \frac{1}{\sqrt{\epsilon \epsilon_0 \mu_0}} = \frac{c_0}{\sqrt{\epsilon}}$$

$$n = \sqrt{\epsilon} \Rightarrow \text{LOVNI KOEFICIENT}$$

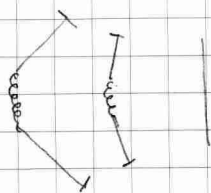




$$\omega_0 = \frac{1}{\sqrt{LC}}$$

$$L \propto N^2$$

$$C \propto \frac{1}{d}$$



DIPOLNA ANTENA

GOSTOTA ENERGIJSKEGA TOKA V EM VALOVANJU Z.U.M

$$\vec{S} = \vec{W} \vec{C}_0$$

$$C_0 = \frac{1}{\sqrt{\epsilon_0 \mu_0}}$$

$$\vec{E} = \vec{B} \times \vec{C}_0 \Rightarrow E = B C_0$$

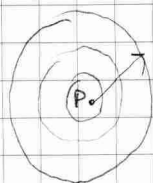
$$W = W_E + W_B = \frac{1}{2} \epsilon_0 E^2 + \frac{1}{2} \mu_0 B^2 = \frac{1}{2} \epsilon_0 E^2 + \frac{1}{2} \mu_0 \frac{E^2}{C_0^2} = \frac{1}{2} \epsilon_0 E^2 + \frac{1}{2} \frac{\mu_0}{\epsilon_0} \frac{E^2}{C_0^2}$$

$$= \frac{1}{2} \epsilon_0 E^2 + \frac{1}{2} \frac{E^2}{\mu_0 C_0^2} = \frac{1}{2} \epsilon_0 E^2 + \frac{1}{2} \frac{E^2 \epsilon_0 \mu_0}{\mu_0} = \epsilon_0 E^2$$

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

$$\epsilon_0 E_0^2 \cos^2(\omega t - kx) = \frac{1}{2} \epsilon_0 E_0^2$$

$$\vec{S} = \vec{W} \vec{C}_0 = \frac{1}{2} \epsilon_0 E_0^2 \vec{C}_0$$



$$S = 4\pi r^2$$

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

Gostota energijskega toka
pada & hkrati tudi nihanje

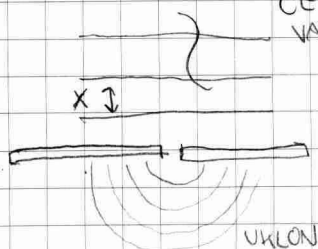
Poskus:

$$C_0 = \frac{18,2m}{60ns} = \frac{18,2 \cdot 10^{-9}}{60} \approx 3 \cdot 10^8 m/s$$

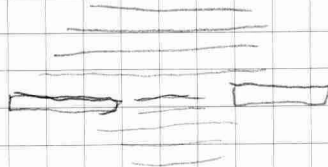
Dolgi elm - valci $\rightarrow$ so razpusti, se uklanjajo na obeh

ČEREA DEJA
VALOVNE DOLŽINE

ČEREA VCEJA



UKLON

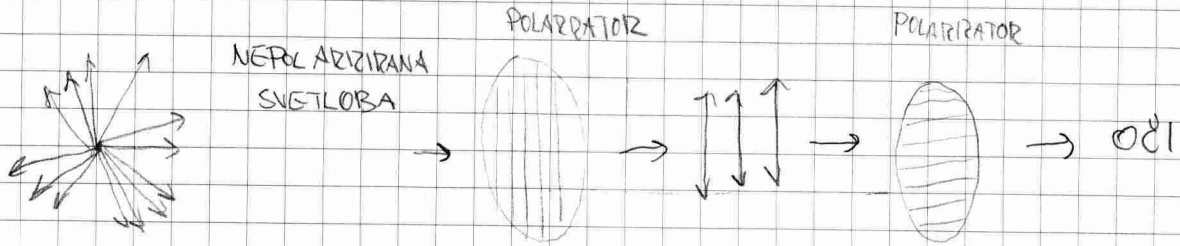


FM TV in mobilnih
oddajnikih se že ravnajo
valci na širjo

Določijo se širjo karadi uklona

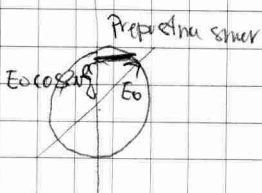
POLARIZACIJA

POLARIZACIJA



Črna svetloba, svetlo svetlo, svetlo svetlo

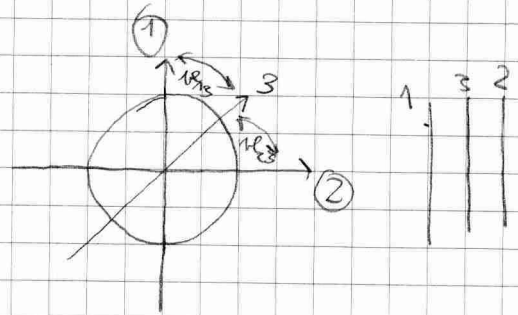
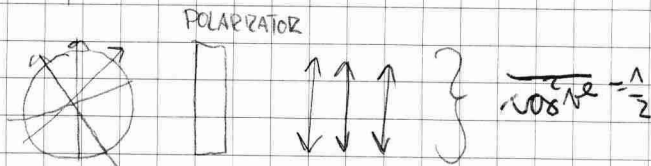
$$\bar{I} = \bar{I}_0 \cos^2 \theta = \frac{1}{2} \epsilon_0 E_0^2 \cos^2 \theta$$



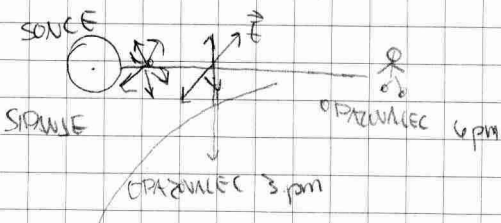
$$\bar{I}_{\text{upodna}} = \frac{1}{2} \epsilon_0 E_0^2 \cos^2 \theta$$

$$\bar{I}_{\text{prep}} = \frac{1}{2} \epsilon_0 E_0^2 \sin^2 \theta$$

$$\text{Prepodnost} = \frac{\bar{I}_{\text{prep}}}{\bar{I}_{\text{up}} + \bar{I}_{\text{prep}}} = \frac{\frac{1}{2} \epsilon_0 E_0^2 \sin^2 \theta}{\frac{1}{2} \epsilon_0 E_0^2 \cos^2 \theta + \frac{1}{2} \epsilon_0 E_0^2 \sin^2 \theta} = \sin^2 \theta$$

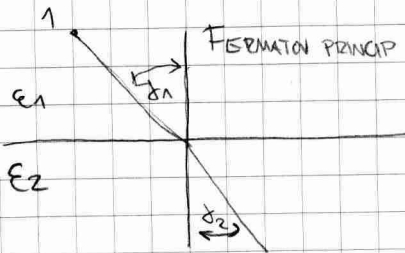


To je zmnoženje svetlosti polarizacije, to ni absorpcija



LOMNI ZAKON

7.4.11



FERMATOV PRINCIP

$$c_1 = \frac{c_0}{\sqrt{\epsilon_1}} = \frac{c_0}{n_1}, n_1 = \sqrt{\epsilon_1}$$

$$c_2 = \frac{c_0}{\sqrt{\epsilon_2}} = \frac{c_0}{n_2}, n_2 = \sqrt{\epsilon_2}$$

$$\frac{\sin \delta}{\sin \beta} = \frac{c_1}{c_2}$$

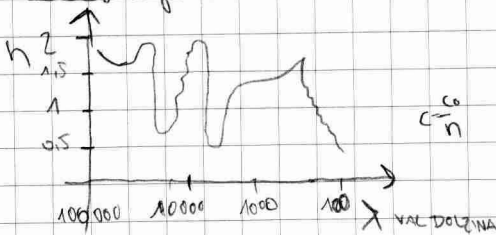
LOMNI ZAKON

$$\frac{\sin \delta}{\sin \beta} = \frac{n_2}{n_1}$$

m

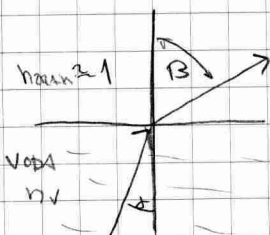
TOTALNI ODBOS ↑

Disperzija - odvisnost lomnega količnika od valovne dolžine



Odvien zaradi tega, ker imajo molekule v medijih neke lastne nihanje zave.

TOTALNI ODBOS



$$\delta = \delta_c$$

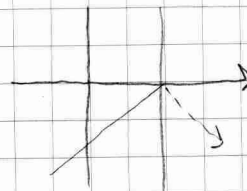
$$\beta = \frac{\pi}{2}$$

$$\frac{\sin \delta}{\sin \beta} = \frac{n_2}{n_1}$$

$$\sin \delta_c = \frac{n_2}{n_1}$$

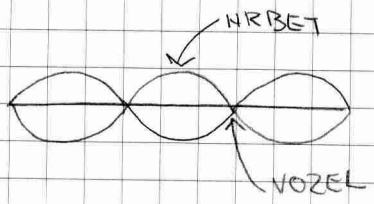
$$\delta_c = \arcsin\left(\frac{n_2}{n_1}\right)$$

→ KRITIČNI



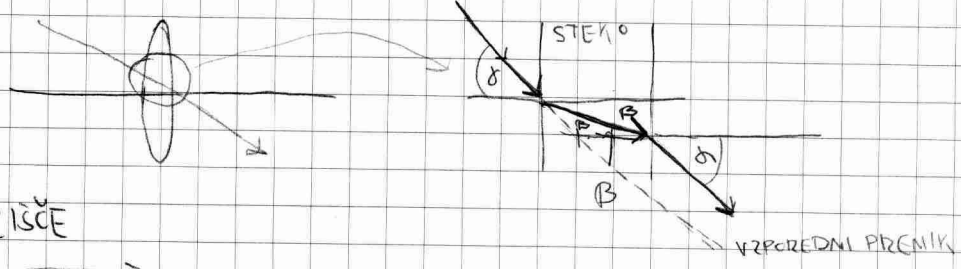
M.4.11

STOJNO EM VALOVANJE

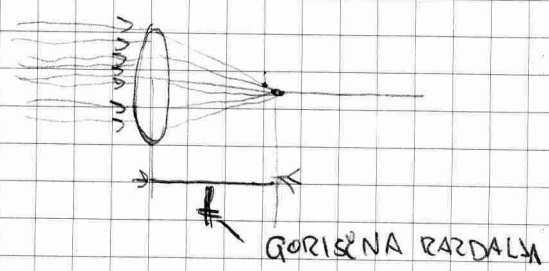


OPTIČNI APARATI

TANKE LEČE

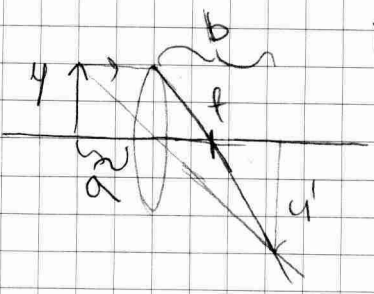


GORIŠČE



Razpršilna in zbiralna leča

KONVEKSIJNA LEČA



ENACIBA

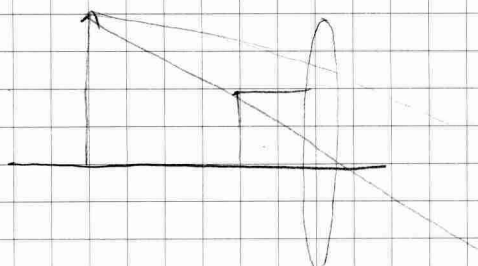
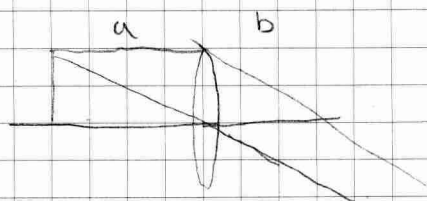
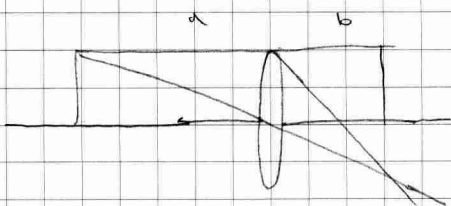
$$\frac{1}{a} + \frac{1}{b} = \frac{1}{f}$$

$$\frac{1}{f} = \frac{1}{a} + \frac{1}{a'} = \frac{1}{a} + \frac{1}{a-f}$$

POVEČAVA

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

BIKONVEKSNA LEČA



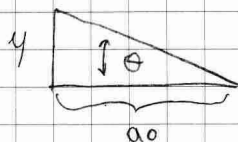
NČ NE VIDMO NA ZASLONU

LUPA

$a_0 \equiv$ NORMALNA ZORNA RAZDALJA

$$M = \frac{\tan \theta''}{\tan \theta} = \frac{y a_0}{f u} = \frac{a_0}{f}$$

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



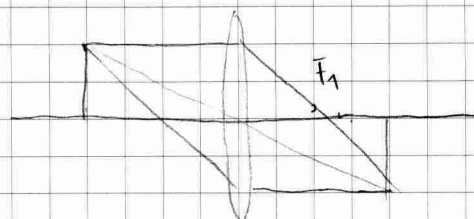
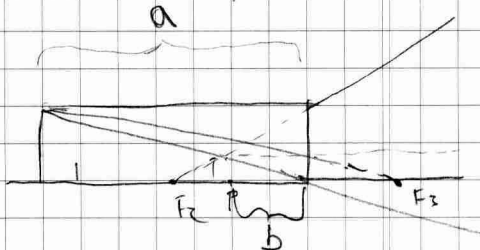
$$\tan \theta = \frac{y}{a_0}$$

BIKONKAVNA LEČA

$$f < 0$$

$$a > 0$$

$$b > 0$$



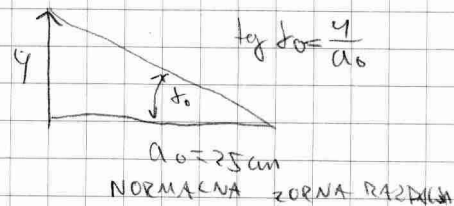
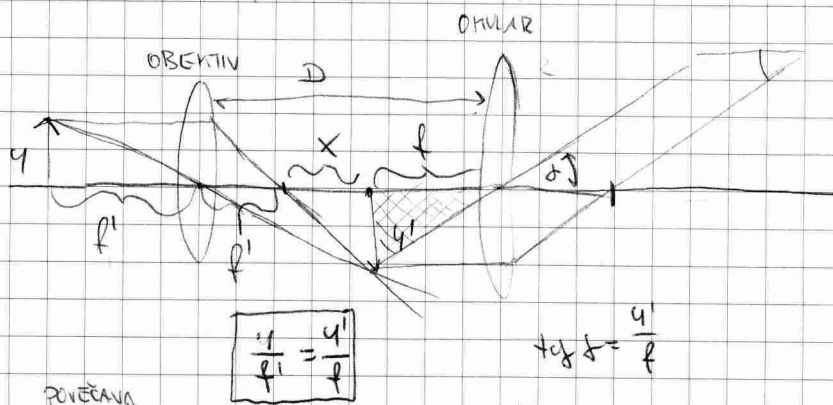
SISTEM DVEH LEČ

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

$s =$ razdalja med lečama

NADOMESTNA GORIŠČNA
RAZDALJA

MIKROSKOP



POVEČAVA

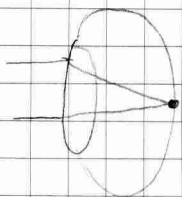
$$\frac{y'}{f'} = \frac{y}{f}$$

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

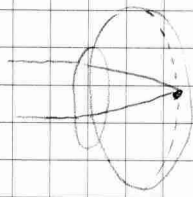
$$M = \frac{\tan \delta}{\tan \delta_0} = \frac{y' a_0}{f y} = \frac{x a_0}{f f'} = \frac{(D - f - f') a_0}{f f'}$$

LOČLJIVOST
(valovna dolžina)

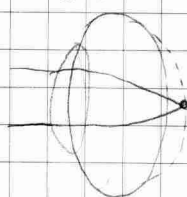
NORMALNO OKO



KRATKOVIDNO OKO

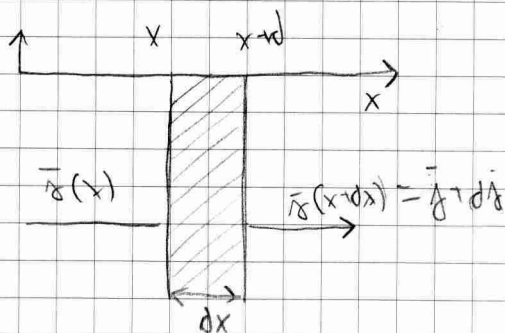


DALJNOVIDNO OKO



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

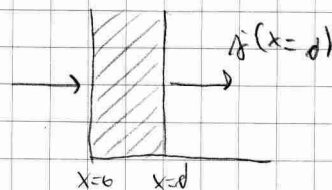
ABSORPCIJA



$$dI = -\alpha I dx$$

$$dI = -\alpha I dx$$

ABSORPCIJSKI
KOEFICIENT



$$\ln \frac{I(x=d)}{I_0} = \ln \frac{I_0 \cdot \exp(-\alpha d)}{I_0} = -\alpha d$$

$$I(x=d) = I_0 \cdot \exp(-\alpha d)$$

EKSPONENTNI
ZAKON

$$\frac{dI}{I} = -\alpha dx$$

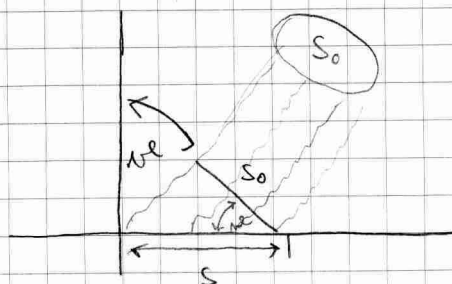
$$\int_{I_0}^{I(x=d)} \frac{dI}{I} = -\alpha \int_0^d dx$$

$$\ln \frac{I(x=d)}{I_0} = -\alpha d$$

FOTOMETRIJA

14.4.11

OSVETLEJENOST



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

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

GOSTOTA ENERGIJSKEGA TOKA Φ

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

$$= \frac{P}{S_0} \cos \theta \rightarrow \text{Energijski tok na enoto}$$

SVETILNOST

1. TOČKASTO TELO



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

$$\bar{J} = \frac{I}{r^2}$$

I - svetilnost

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

4π - polni prostorski kot

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

2. PLOSKOVNO SVETILO



$$I = B_0 S$$

↑
SVETLOST



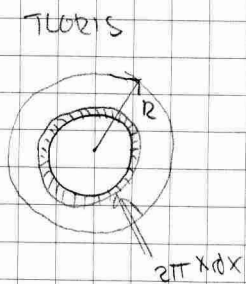
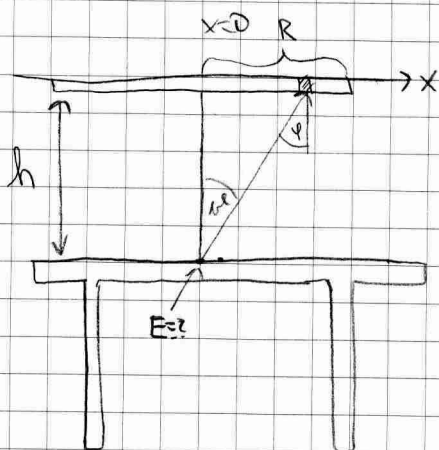
$$\cos \phi = \frac{S'}{S}$$

$$S' = S \cos \phi$$

B0 - svetlost

$$I = BS' = BS \cos \phi$$

Svetlost odhaja od točke. Če ni odhaja od točke pravimo točkasto svetilo
LAMBERTOVO SVETILO



$$dE = \frac{dI}{r^2} \cos \theta = \frac{\lambda 2\pi x dx \cos \theta}{r^2}$$

$$dI = \lambda 2\pi x dx \cos \theta$$

$$r = \sqrt{x^2 + h^2}$$

$$E = \int \frac{2\pi \lambda \cos^2 \theta x dx}{r^2}$$

$$= \frac{\pi \lambda}{2} (1 - \cos 2\theta)$$

Limeta - zelo velika svetila ($R \rightarrow \infty \Rightarrow B_m \rightarrow \frac{\pi}{2}$) $\cdot \cos(2\frac{\pi}{2}) = 1$

$$E_{\infty} = \pi \lambda$$

INTERFERENČNI POSAVI PRI EMV

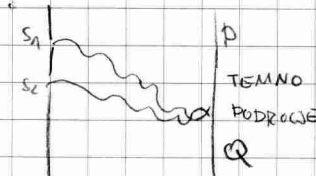
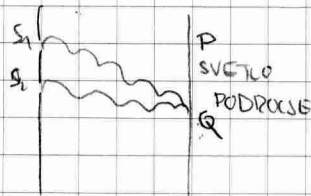
INTERFERENCA



HEYGENSOV PRINCIP

TOČKA KOTIŠČINA - vsaka točka površine S1 in S2 deluje kot vir - razširja se kot koncentrični krogi

YOUNGOV POSKUS



Travno razlika med enim in drugim svetlobnim žarkom mora biti konstantna

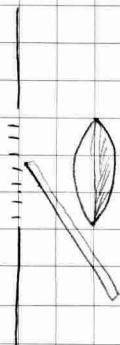
Eni svetlobni žarki so koherentni svetlobni žarki - vrh-na-vrh

Huygensovo načelo vsako točko valovne fronte obravnava kot vir koncentričnih valov

OPTIČNA MREŽICA → več 1000 rez - 600 rez na mm

→ Dobimo več pik

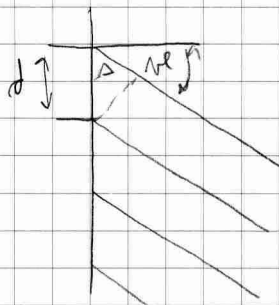
CENTRALNA



$$I = I_0 \frac{\sin^2(\pi b \sin \theta / \lambda)}{(\pi b \sin \theta / \lambda)^2}$$

$$I = I_0 \frac{\sin^2(\pi b \sin \theta / \lambda)}{(\pi b \sin \theta / \lambda)^2} \cdot \frac{\sin^2(\pi d \sin \theta / \lambda)}{\sin^2(\pi d \sin \theta / \lambda)}$$

VLONSKA MREŽICA



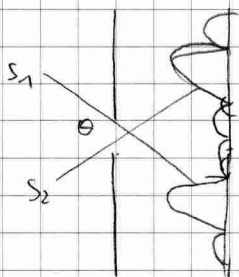
Pravilje za svetlobo:

$$\Delta - d \sin \alpha = N \lambda$$

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



LOČLJIVOST svetla svetla



Pri optičnih mikroskopih svetlobo lahko zmanjšamo valovno dolžino

⇒ Kalimo elektronske mikroskopske svetlobo, ker elektronske svetlobo imajo veliko manjšo valovno dolžino.

FOBNARIC

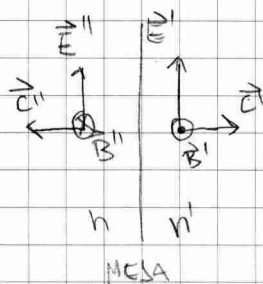
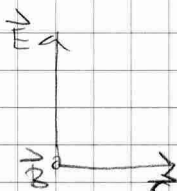
$$\vec{E} = \vec{B} \times \vec{c}$$

$$E = Bc$$

$$c_0 = \frac{1}{\sqrt{\epsilon_0 \mu_0}}$$

$$c = \frac{1}{\sqrt{\epsilon \mu}}$$

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



$$E + E'' = E'$$

$$B + B'' = B'$$

$$H + H'' = H'$$

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

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

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

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

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

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

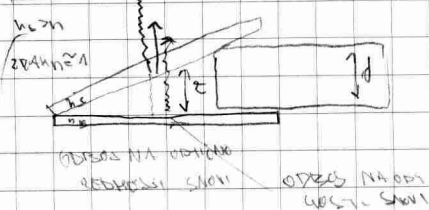
$$E - E' = \frac{2E}{1 + \frac{n'}{n}} \frac{n'}{n} = \frac{2E}{\frac{n}{n'} + 1} = \frac{2n'}{n + n'} E$$

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

$n > n'$ - Odboj na optično mešanici svetla. $\vec{E}$ se odboji z isto silo

$n < n'$ - Odboj na optično mešanici svetla. $\vec{E}$ se odboji z manjšo silo

PP:



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

ZA OSLAČITEV

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

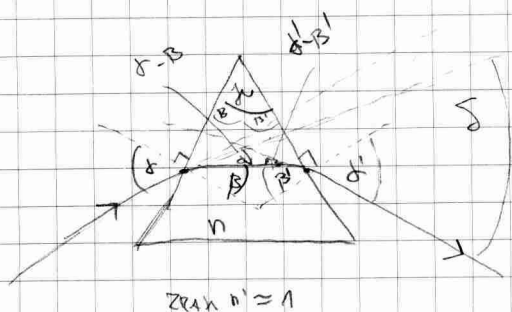
$N=1,2,3,\dots$

$$\Rightarrow 2z = N\lambda_0 - \frac{\lambda_0}{2}$$

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

$$\Delta z \approx \frac{\lambda_0}{2} \approx 200 \text{ nm}$$

PRIZMA (LOM SVETLOBE)



$$\frac{\sin \delta}{\sin \beta} = \frac{n \beta}{\beta} = n$$

$$\frac{\sin \beta'}{\sin \delta'} = \frac{1}{n}$$

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

$$\Rightarrow \delta \approx (n-1)\delta$$

$$\text{Maj/min loma: } \frac{\delta}{\beta} = n \Rightarrow \delta = n\beta$$

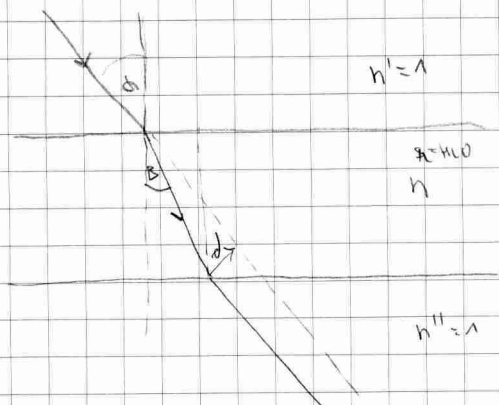
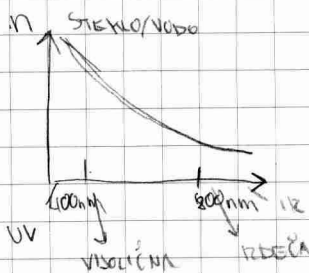
$$\frac{\beta'}{\delta'} = \frac{1}{n} \Rightarrow \delta' = n\beta'$$

DISPERZNA:

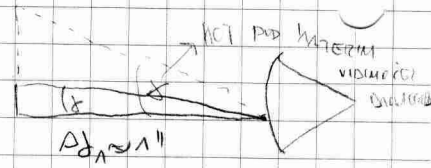
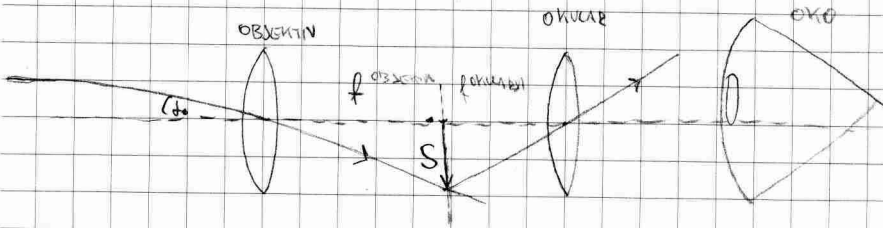
$$c = c(\lambda)$$

$$n = n(\lambda)$$

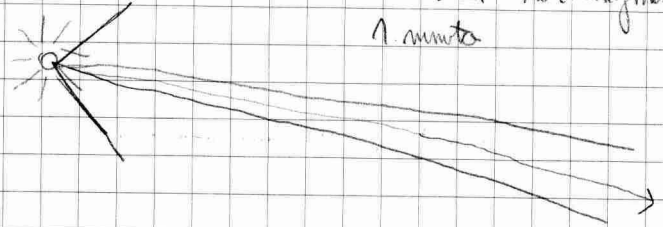
$$\delta(\lambda) = (n(\lambda) - 1)\delta$$



DALSNOGLED



Oko udi svetlo največje 1. minuta

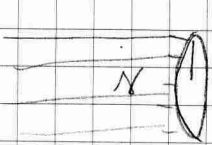


POVEČAVA

$$M = \frac{h}{h_0} = \frac{l}{l_0} = \frac{f_0}{f_e} = \frac{\text{daljina objekta}}{\text{daljina očala}}$$

V. čim povečava:

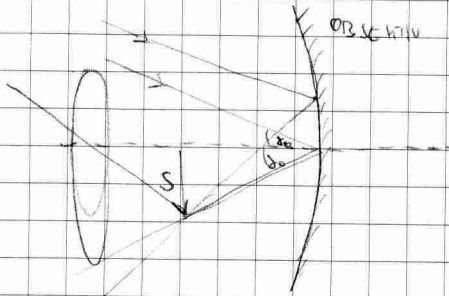
$$M = \frac{\frac{S}{l_0}}{\frac{S}{l_0}} = \frac{l_0}{l_0}$$



$$P_e = P_0 = \frac{P}{4\pi r^2} \pi r_0^2$$

OSVETLEENOST SLIME

$$\gamma \propto \frac{r_0^2}{r^2}$$



V sredo ni Fesmanica na vajah. No v sredo bo spet Šarka in se naj ne navadja če kdaj kaka zanka v roko pred tablo

MODERNA FIZIKA

POSEBNA TEORIJA RELATIVNOSTI (INERCIALNI - NEPOSPEŠENI OPAZOVALNI SIST.)

9.5.11

1. GALILEJEVA TRANSFORMACIJA

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

$$y = y'$$

$$z = z'$$

$$t = t'$$

ABSOLUTNI ČAS

$$v_x = v_x' + v_0$$

2.) MAXWELL

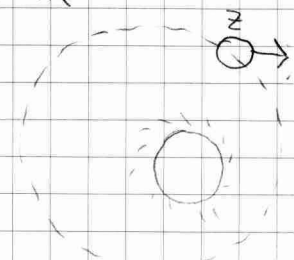
EMV:

$$c_0 = \frac{1}{\sqrt{\epsilon_0 \mu_0}} = \text{konst}$$

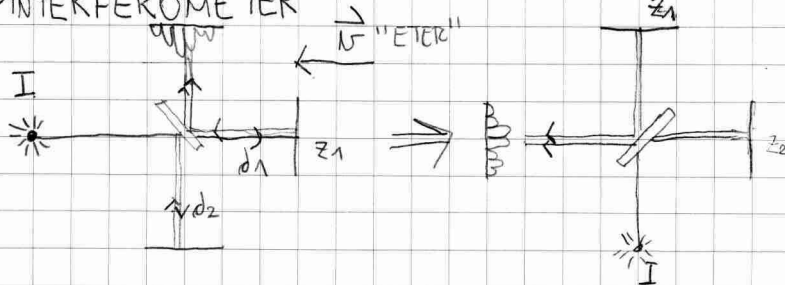
? Neki minimalni $\Rightarrow$ uvedejo ETHER

EKSPERIMENT MICHELSONA IN MORLEY

"ETER"



INTERFEROMETER



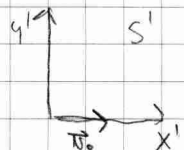
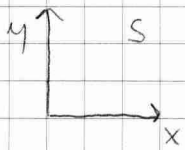
ALBERT EINSTEIN (1905):

DVE GLAVNI NAČELI:

1) Hkrati svetlobe $c_0 = \text{konst}$

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

LORENTZOVE TRANSFORMACIJE



$y=y' \quad z=z'$
 $x = \gamma(x' + v_0 t')$
 $x' = \gamma(x - v_0 t)$
 $\gamma = \gamma(v) \rightarrow$ FUNKCIJA HITROSTI
 PRVI ČAS NI ABSOLUTEN

$$\begin{aligned}
 \frac{x}{\gamma} &= x' + v_0 t' \Rightarrow t' = \frac{1}{v_0} \left(\frac{x}{\gamma} - x' \right) = \frac{1}{v_0} \left(\frac{x}{\gamma} - \gamma(x - v_0 t) \right) \\
 &= \gamma \left(t - \frac{x}{v_0} \left(1 - \frac{1}{\gamma^2} \right) \right) \\
 &= \gamma \left(t - \frac{dx}{v_0} \left(1 - \frac{1}{\gamma^2} \right) \right) \\
 \frac{dx'}{dt'} &= \frac{\gamma(dx - v_0 dt)}{\gamma \left(dt - \frac{dx}{v_0} \left(1 - \frac{1}{\gamma^2} \right) \right)} \\
 &= \frac{\frac{dx}{dt} - v_0}{1 - \frac{dx}{dt} \frac{1}{v_0} \left(1 - \frac{1}{\gamma^2} \right)} = \frac{v_x - v_0}{1 - \frac{v_x v_0}{c^2} \left(1 - \frac{1}{\gamma^2} \right)}
 \end{aligned}$$

- Homogenost prostora in časa
- izotropnost prostora

$$v_x = c_0 \Rightarrow v_x' = c_0$$

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

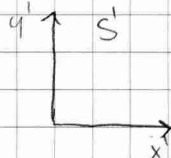
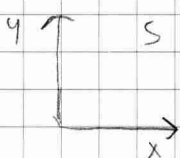
$$\begin{aligned}
 &\Rightarrow 1 - \frac{v_0}{c_0} \left(1 - \frac{1}{\gamma^2} \right) = 1 - \frac{v_0}{c_0} \\
 &1 - \frac{1}{\gamma^2} = \frac{v_0^2}{c_0^2} \\
 &\frac{1}{\gamma^2} = 1 - \frac{v_0^2}{c_0^2}
 \end{aligned}$$

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

$$t' = \gamma \left(t - \frac{v_0}{c_0^2} x \right)$$

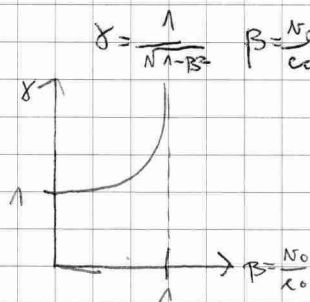
$$v_x' = \frac{v_x - v_0}{1 - \frac{v_x v_0}{c_0^2}}$$

DOKAZA SE ZALOZI NA ISTEM MESTU ($t_1 = t_2 - \Delta t$)



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

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



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

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

$$v_y = \frac{dy}{dt} = \frac{dy'}{\gamma \left(dt' - \frac{v_0}{c_0^2} dx' \right)} = \frac{\frac{dy'}{dt'}}{\gamma \left(1 - \frac{v_0}{c_0^2} \frac{dx'}{dt'} \right)} = \frac{v_y'}{\gamma \left(1 - \frac{v_0 v_x'}{c_0^2} \right)}$$

$$v_z = \frac{dz}{dt} = \frac{v_z'}{\gamma \left(1 - \frac{v_0 v_x'}{c_0^2} \right)}$$

Čas in prostorske koordinate nista neodvisni $\rightarrow$ Določile

SOČASNOST JE RELATIVNA

9.5.11

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

PODALIŠANJE (DILATACIJA) ČASA

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

$$\Delta t = t_2 - t_1 = \gamma$$

↓
LASTNI ČAS
(VRA MIRONJE)

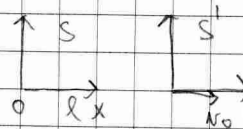
$$\Delta t' = t_2' - t_1' = \gamma t_2 - \gamma t_1 = \gamma(t_2 - t_1)$$

$$\Delta t' = \gamma \cdot \Delta t = \gamma$$

čas med dogodkoma največji v lastnem sistemu. Drugi daljši

SKRČENJE DOLŽINE

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



$$\Delta x = x_2 - x_1 = l \quad \text{at } t_2' = t_1' = 0$$

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

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

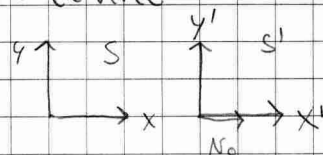
$$l = \gamma \cdot l'$$

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

ŠTIRIRAZSEŽNI PROSTOR $\equiv$ PROSTOR-ČAS (PROSTOR MIKOWSKEGA)

Dogodek opišemo "Svetovni četverec"

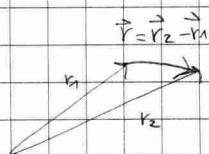
$${}^4X = (\underbrace{ct}_{\text{ČASOVNI DEL}}, \underbrace{x, y, z}_{\text{PROSTORNI DEL}})$$



$$\beta = \frac{v}{c}$$

$$\begin{aligned} ct &= \gamma(ct' - \beta x') \\ x &= \gamma(x' - \beta ct') \\ y &= y' \quad z = z' \end{aligned}$$

"KLASIČNO" 3D:



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

Dobrima oz. slabim produkt tega vekt. je invarianta

"ŠTIRIRAZSEŽNI PROSTOR":

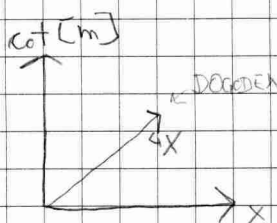
$${}^4X \cdot {}^4X = -c^2 t^2 + x^2 + y^2 + z^2$$

↓
PREDZNAK DRUGAČEN

SVETOVNI ČETVEREC

${}^4X \equiv X^\mu \rightarrow$ STANOVIK - TJO NAPIŠE

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



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

$${}^4X \cdot {}^4X = -c^2 t^2 + x^2 + y^2 + z^2$$

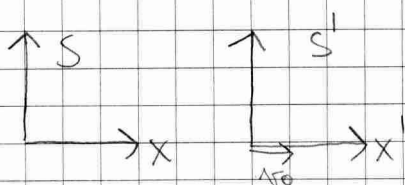
$$\text{ali} = c^2 t^2 - x^2 - y^2 - z^2$$

STANOVIK

} DVE RAZLIČNI SIGNATURI

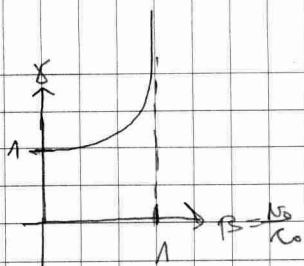
$${}^4U = (\underbrace{U_0}_{\text{ČASOVNI DEL}}, \underbrace{U_1, U_2, U_3}_{\text{PROSTORNI DEL}})$$

LORENTZOVE TRANSFORMACIJE



S, S' neposredna - INERCIALNA
Če li kila preprosta in imeli sistemske roke

$$U_0 = \gamma(U_0' - \beta U_1'), \quad \beta = \frac{v}{c}, \quad \gamma = \frac{1}{\sqrt{1-\beta^2}}$$



$$\begin{aligned} \gamma_0' &= \gamma(\gamma_0 - \beta v_1) \\ \gamma_1' &= \gamma(\gamma_1 - \beta \gamma_0) \\ \gamma_2' &= \gamma_2 \\ \gamma_3' &= \gamma_3 \end{aligned}$$

ČETVEREC HITROSTI

$${}^4u = \frac{d^4x}{d\gamma} = \frac{d^4x}{dt} \cdot \gamma$$

γ -LASTNI ČAS

"Moving clock runs slow"

$${}^4u = \gamma \left(c_0 \frac{dt}{dt_1} \frac{dx}{dt_1} \frac{dy}{dt_1} \frac{dz}{dt_1} \right) = \gamma (c_0, v_x, v_y, v_z)$$

$$= \gamma(c_0, v)$$

$$t = \gamma \cdot \tau$$

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

ČETVEREC GIBALNE KOLIČINE

$\vec{G} = m\vec{v}$ v klasični fiz. G , v - moment P

$${}^4p = m_0 {}^4u = (m_0 \gamma c_0, m_0 \gamma \vec{v})$$

$$= \left(\frac{E}{c_0}, \vec{p} \right)$$

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

RELATIVISTIČNA GIBALNA KOLIČINA

$$m\gamma = m_0 \gamma \text{ RELATIVISTIČNA MASA}$$

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

POLNA ENERGIJA

$$E_0 = m_0 c_0^2$$

MIRONNA
ENERGIJA

$$\begin{aligned} E &= W \\ W_K &= T \end{aligned}$$

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

$$\Rightarrow W_K = m_0 c_0^2 \left(\frac{1}{\sqrt{1 - \frac{v^2}{c_0^2}}} - 1 \right) = m_0 c_0^2 \left(1 + \frac{1}{2} \frac{v^2}{c_0^2} + \mathcal{O}\left(\frac{v^4}{c_0^4}\right) - 1 \right)$$

TAYLORJEVA VRSTILA

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

$$\text{Pri } v \ll c_0 : W_K \approx \frac{1}{2} m_0 v^2$$

${}^4u, {}^4u = \text{invarianta}$

LASTNI SISTEM ($v=0$)

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

$$E^2 = E_0^2 + c_0^2 p^2$$

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

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

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

$$\frac{E}{p} = \frac{m_0 \gamma c^2}{m_0 \gamma v} = \frac{c^2}{v}$$

DELEC $v=c_0$ (Skrajni primer)

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

Da se delec lahko zgleda s svetlobno energijo mora imeti $m_0 = 0$

NEWTONOV ZAKON V ŠTIRIRAZSEŽNI OBLIKI

KLASIČNO

$$\vec{F} = \frac{d\vec{G}}{dt} \quad \vec{G} = m\vec{v}$$

RELATIVISTIČNO

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

↑
PROSTORNA ENERGIJA

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

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

Čeberski deli na maselektron delec:

$${}^4F = \left(\frac{e\gamma \vec{E} \cdot \vec{v}}{c_0}, \quad e\gamma (\vec{E} + \vec{v} \times \vec{B}) \right)$$

↑
SILNOST ELEKTR. POLJA

KRAŠENI DELI:

$$\boxed{\frac{d\vec{p}}{dt} = e(\vec{E} + \vec{v} \times \vec{B})} \quad \boxed{\vec{p} = m_0 \gamma \vec{v}}$$

ČASOVNI DEL:

$$\frac{e}{c_0} \frac{dE}{dt} = \frac{e\gamma \vec{E} \cdot \vec{v}}{c_0} \Rightarrow \Delta E = e \int \vec{E} \cdot \vec{v} d\tau = -e\Delta\varphi$$

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

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

$$v = -\int \vec{E} \cdot d\vec{r} = v_2 - v_1$$

$$v \equiv \varphi$$

OHRANITVENI ZAKONI

$$\gamma F = \frac{d(\gamma p)}{d\gamma} \Rightarrow \Delta \gamma p = \int \gamma F d\gamma$$

$$\int \gamma F d\gamma = 0 \Rightarrow \Delta \gamma p \Rightarrow \boxed{\begin{matrix} \Delta E = 0 \\ \Delta p = 0 \end{matrix}}$$

MAXWELLOVE ENAČBE

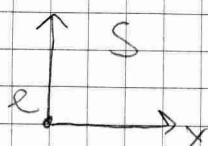
Vektor zbiravec potenciala $\gamma A = \left(\frac{\varphi}{c_0}, \vec{A} \right)$ $\varphi \equiv V$

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

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

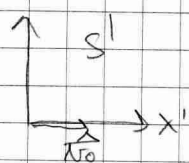
GOSTOTA NABOJA
 $\vec{j} = \left(\gamma \cdot c_0, \vec{j} \right)$
 GOSTOTA ELEKTRO

PRIMER: Točkovni naboje mase m in sistema S



$S: \varphi = \frac{e}{4\pi\epsilon_0 r} \quad \vec{A} = 0$

$$\begin{aligned} \gamma_0' &= \gamma(\gamma_0 - \beta \gamma_1) \\ \gamma_1' &= \gamma(\gamma_1 - \beta \gamma_0) \end{aligned}$$



$S': \frac{\varphi'}{c_0} = \gamma \left(\frac{\varphi}{c_0} - \beta A_x \right) = \gamma \frac{\varphi}{c_0} = \gamma \frac{e}{4\pi\epsilon_0 \gamma c_0 r}$
 $\varphi' = \gamma \frac{e}{4\pi\epsilon_0 r}$

$$A_x' = \gamma \left(A_x - \beta \frac{\varphi}{c_0} \right) = \gamma \beta \frac{\varphi}{c_0} = \gamma \frac{\gamma_0}{c_0} \frac{e}{4\pi\epsilon_0 r} \neq 0$$

MAXWELLOVE ENAČBE S ČETVECI

$$\square \gamma A = \mu_0 \gamma j$$

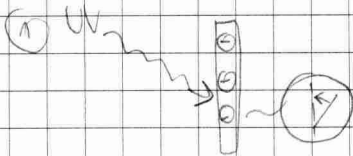
$$\square = \frac{1}{c_0^2} \frac{\partial^2}{\partial t^2} - \frac{\partial^2}{\partial x^2} - \frac{\partial^2}{\partial y^2} - \frac{\partial^2}{\partial z^2}$$

FOTOEFEKT

18.5.11

Poskus

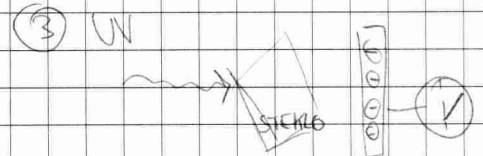
- Z UV svetlobo na žilico. Če navedemo magnetno, malo je in računamo
- Če pa postavimo pa ne
- Če pa imamo drugačnega pa ne



UV žarek izlaga elektrone iz plošče



Pravilni poslušaj potegne izlaga elektrone manj



V steklu se UV del optično absorbira

Za izlaganje Z^- mra liti izlaga elektrone $\downarrow$. Tega se ne da navedeti s klasično fiziko

$$\bar{I} = \alpha \bar{W} \propto E^2 \quad \leftarrow \text{izlaga elektrone kot EMW}$$

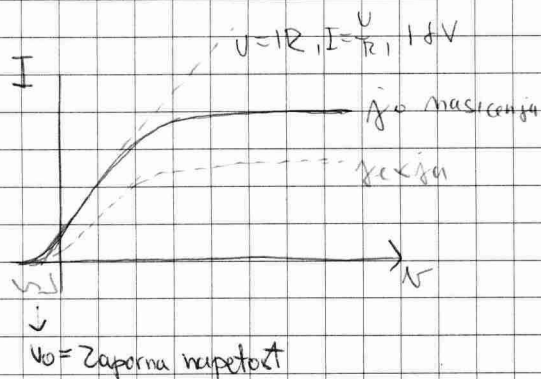
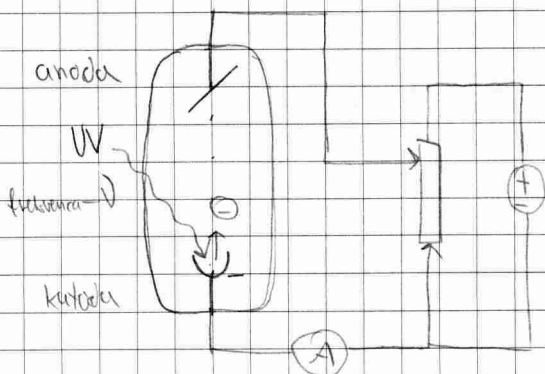
$$E_{\text{abs}} \propto \bar{I} S \quad \text{površina plošče}$$

$$E_{\text{abs}} = \alpha \bar{I} S \quad \alpha - \text{odločilo}$$

$E_{\text{abs}} \propto t$ li morali doli ~~obsejati~~, pa lo imel izlaga W za izlaga Verana W skupaj to me gre

Emisija se isto leta objavi 3 različne stvari

FOTOCELIKA

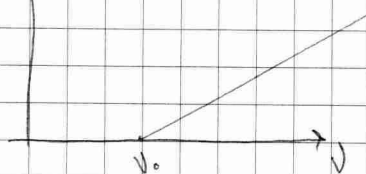


$\bar{I}$ = gostota energijskega toka

Plata nastane, ko vsi e^- navedejo
Zaporna napetost potegne, ker se ne more izlaga. Potegne da vsi e^- navedejo

$$\frac{m_e v_{\max}^2}{2} = e_0 V_0 = A e \quad W_k \rightarrow W_{pe}$$

||
 $W_{k\max}$ je odvisna od V_0 , lahko merimo
 $W_{k\max}(V) \rightarrow W_{k\max}$



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

$$W_{k\max} = h\nu - W_{\text{izstop}}$$

absorbirana energija

→ vezavna energija elektronov

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

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

$h\nu [J]$

Namreči imajo energijo, kar v različni smeri se razdeljuje, nekateri trčijo v atome

Korake razumevanja: $W_{\text{ass}} \rightarrow \nu$

Klasici se ν E_0 , E_{stop} $\propto E_0^2$

Energija fotonov je proporcionalna $\rightarrow$ Energija fotonov

Fotoni imajo gibalno količino, mase pa nimajo
 Pri trkih se oblikujejo polna energija

$$W_{\text{polna}} = W_0 \rightarrow T_{\text{kinetika}}$$

$$W_0 = m_0 c^2$$

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

FOTON: $W_0 = 0$ - lastna energija

$$W^2 = c_0^2 p^2 \quad - \text{rel. gibalna količina}$$

$$W = h\nu \quad - \text{Polna energija}$$

$\downarrow$

$$c_0 p \rightarrow \text{Gibalna kol. fotona}$$

$$p = \frac{W_0}{c_0} = \frac{h\nu}{c_0}$$

$$c_0 = 2\lambda$$

$$\Rightarrow p = \frac{h}{\lambda}$$

rel. gibalna kol. fotona

Št. absorbovanih fotonov:

$$N_\nu = \frac{P}{h\nu} = \frac{A \cdot S}{h\nu} = \frac{A \cdot S}{h\nu}$$

Material	λ (nm)
platina	230
volfram	280
strebro	290
Al, cink	340
kadmij	560

redelovno delo

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

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

POZITRON $\oplus$ $W_0 = m_0 c^2 = 0,511 \text{ MeV}$
ELEKTRON $\ominus$

$T_{\text{lim. en.}}$ $N=0$
 $\oplus \rightarrow \ominus$ $\text{ko trčata, masi izgubita}$

V relativni fiziki seveda obmenita neke gibalne in polne energije, če mi svinčar-
zmenjnih sil

Nastane dva γ -fotona $\leftarrow \gamma' \rightarrow \gamma$

Obmenita $\propto E$ in P

1.) Obmenita polne energije

$$W_0 + T_p + W_0 = h\nu - h\nu'$$

2.) Obmenita gibalne količine:

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

gib. kol.
pozitrona

$\Rightarrow \nu, \nu'$

$$c_0 P = W$$

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

$$c_0 P = m_0 c P$$

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

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

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

Interferenčni izop.: z ravnimi e^- svetlobo na kristal grafita
interferenca

Prejemo enakolično svetlobo lahko opazujemo kot naključje ali kot delce
kot z delci lahko kot z naključnim delcem

de Broglie: Propozicija o delcih kot valovih - kar ni tako enostavno

$P = \frac{h}{\lambda}$, splošno delci so valovi!

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

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

$$W = cP$$

$$P = \frac{W}{c} = \frac{h\nu}{c} = \frac{h}{\lambda}$$

GIBALNA KOL
FOTONOV

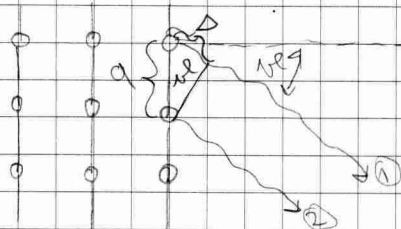
$$\lambda_B = \frac{h}{mv}$$

de Broglie
 $m_e = 9,1 \cdot 10^{-31}$ kg

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

Večji napetost
manjša valovna
dolžina

A.) Majhna $U_0 \Rightarrow$ majhna W_k , velika λ_B



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

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

B.) Velika napetost $U_0 \Rightarrow$ večja W_k , manjša λ_B

Braggova sponja

$$U_0 = 1500V$$

$$\lambda_B \approx 0,052nm$$

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

de Broglie

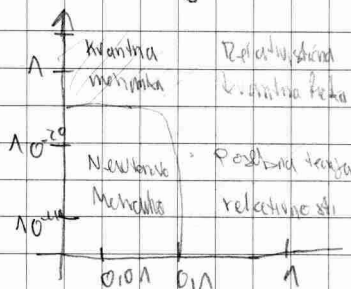
Newtonova - mehanika

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

$$\vec{v} = \frac{d\vec{r}}{dt}$$

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

Schrödinger E - mehanika Newtonova mehanika



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

Ne da se hitrost določi leže na hitrost
Al eno al drugo

de Broglie prvi hvala h relativistom fiz

Rel. brzina:

$$\vec{p} = m_0 \gamma_e \vec{v} \rightarrow m_0 \vec{v} \quad \text{Newtonova mehanika}$$

$$\gamma = m_0 c^2 (\gamma_e - 1) \rightarrow \frac{m_0 v^2}{2} \quad \frac{v}{c} \rightarrow 0$$

Tipične velikosti:

Radij modifikacij celice
Radij protona

$$5 \times 10^{-11} \text{ m} \sim 10^{-10} \text{ m} = \text{\AA}$$

$$1,2 \cdot 10^{-15} \text{ m} \sim 10^{-15} \text{ m}$$

Debeli medeni
\$10^{-10} - 10^{-15} \text{ m}\$

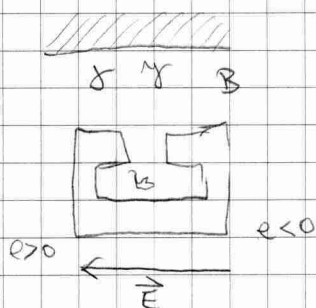
MEGLIČNA CELICA

Zrak z nečisto pravo simetrično presečno presekanjem, da se oblik

\$\rightarrow\$ z nečisto pravo simetrično presekanjem PREVAJEN

\$\rightarrow\$ krogi prave se vse na cikelizacijo namaka konci in tudi nečisto

\$\rightarrow\$ sledi malih delcev gostejše kalibracije



$$\vec{r}_e = e \vec{v} \times \vec{B}$$

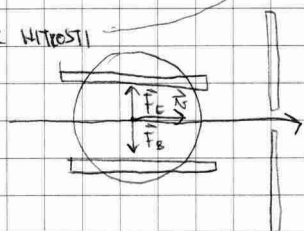
$$\vec{F}_E = e \vec{E}$$



Lahko manjverina žarka z magn. poljem

\$\rightarrow\$ klna delcev z enako hitrostjo

SELEKTOR HITROSTI



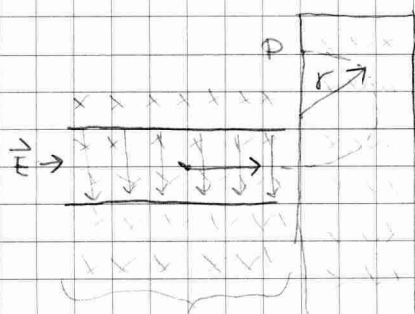
$$\vec{F}_B = e \vec{v} \times \vec{B}$$

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

$$e v B = e E$$

$$N = \frac{E}{B}$$

MASNI SPENTROMETER



Selektor hitrosti

$$m a r = e v B_0$$

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

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

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

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

1856-1940

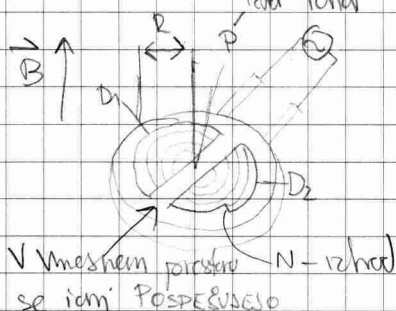
Thomsonov aparat za merjenje $e/m \rightarrow$ Specifični naboj
hotehni žarka $\rightarrow$ elektroni

Thomson: $\frac{e}{m} \sim 0.77 \cdot 10^{11} \text{ As/kg}$

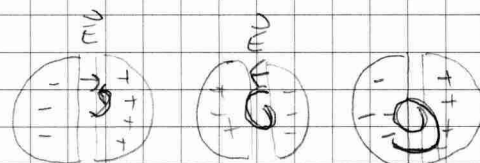
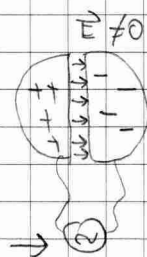
CIKLOTRON

2 rotili elektroni $\rightarrow D_1, D_2$

Vseučelnarstvo
fiziološki
razvoj



V elektradah 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 intenzit. B

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

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

CIKLOTRONSKA
FREKVENCA

Frekvenca pri veliki
intenzit. postane odvisna
od intenzit.

SINHROCIKLOTRON

$\vec{P} = m \gamma \vec{v}$

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

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

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

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

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

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

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

$\gamma m_0 a_T = e v B$

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

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

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

$\frac{2\pi}{t_0} = \frac{2\pi r}{t_0} = \frac{2\pi}{t_0} \frac{\gamma m_0 v}{e B} = \frac{2\pi \gamma m_0}{e B}$

$\boxed{\nu_c = \frac{1}{t_0} = \frac{e B}{2\pi \gamma m_0} = \frac{1}{\gamma} \left[\frac{e B}{2\pi m_0} \right]}$

ν_c

$$\frac{d\vec{p}}{dt} = e\vec{E}$$

Σ me remember das
wen hier ni benutzen

$$\frac{d(m\gamma v)}{dt} = eE$$

$$\frac{d(m\gamma v)}{dt} = eE$$

$$\int \frac{d(m\gamma v)}{dt} dt = \int eE dt$$

$$E = \text{konst.} \\ \text{B-11E}$$

$$m\gamma v = eE \int dt = eEt$$

$$\rightarrow m\gamma v = eEt$$

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

$$\frac{\frac{v}{c}}{\sqrt{1 - \left(\frac{v}{c}\right)^2}} = \left(\frac{eE}{m_0 c}\right) t = \gamma t / (1)^2$$

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

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

$$\Rightarrow \boxed{\gamma = \frac{1}{\sqrt{1 - \gamma^2}}}$$

$$\rightarrow \lim_{t \rightarrow \infty} v = c_0 \frac{dt}{dt} = c_0$$

$$\begin{aligned} m\gamma v &= eEt \\ m\gamma v &= eEt \\ v &= \frac{eEt}{m_0} + \\ c & \rightarrow \infty \\ \Rightarrow v & \rightarrow c \end{aligned}$$

• FOTOEFEKT

FOTONI

- FOTON: $P = \frac{h}{\lambda}$

- ENERGIJA: $W = h\nu$
 $W = \hbar \omega$

• SEVANJE BT:

- Planckov zakon in Stefanov zakon

• COMPTONSKO SIFRANJE

- Comptonova valovna dolžina

• ŽRASTI SPEKTRI

- Energijski nivoji

EM Valovnjak: $\bar{\lambda} = \frac{h}{p}$
 $\bar{\lambda} \propto \sqrt{E}$

ELEKTRON:

$P = \hbar k$, $P = mV$
 $W = \hbar \omega$, $W = T + V$

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

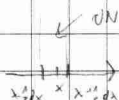
VALOVNA F. ZA DELECE

Postavitev: $\Psi(x,t) \propto e^{i(\frac{P}{\hbar}x - \frac{W}{\hbar}t)} = e^{i(px - wt)/\hbar}$

$\Psi^* \Psi$ - Verjetnostna gostota elektronov na razdalji

WILSON CURVA ELEKTRON

$\frac{dN}{N} = p dx$



OSNOVE KVANTNE MEHANIKE

NAČELA KVANTNE MEHANIKE

- NAČELO STATISTIČNEGA OPISA

- Izboljša pristop do posameznih lastnosti delcev in moremo z golčasto nepravilno
- V splošnem se moremo nepravilno zbirati množico delcev
- Vrednotimo verjetnostno gostoto $\rho = \psi^* \psi$
za določeno lastnost, npr. energijo in položaj

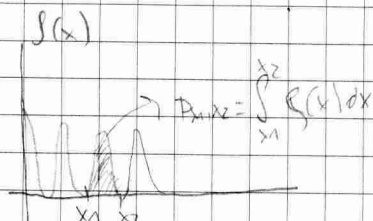
VALOVNA FUNKCIJA

$$\psi = \psi_0 e^{i(kx - \omega t)}$$

$$\vec{p} = \hbar \vec{k}$$

- Gibalna količina

$$\hbar \omega = W = W_k + W_p \rightarrow \text{povprečna energija elektrona}$$



$$\text{Integral verjetnostne gostote: } \int_{-\infty}^{\infty} S(x) dx = 1$$

Priljubljeno 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 NEODLOČNOSTI

$$\Delta x \cdot \Delta p_x \geq \hbar$$

algebra kol. položaja in gibalne količine elektrona

$$\Delta y \cdot \Delta p_y \geq \hbar$$

$$\Delta z \cdot \Delta p_z \geq \hbar$$

- NAČELO SUPERPOZICIJE

$$|\psi|^2 = |\psi_1 c_1|^2 + |\psi_2 c_2|^2$$

OPERATORJI

Ne moremo razviti glavnih lastnosti in lege hkrati. Lahko razvimo eno lastnost, ne enkrat.

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

$$i\hbar \frac{\partial \psi}{\partial x} = \frac{1}{\hbar} p_x (i\hbar) \psi = p_x \psi$$

$$\frac{\partial \psi}{\partial t} = -\frac{iW}{\hbar} \psi = W \psi ; i\hbar \frac{\partial \psi}{\partial t} = W \psi \quad \text{OP. POLNE E. VREDNOSTI}$$

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

OPERATOR KOMPONENTNE GIBSKE KOLIČINE

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

OPERATOR KIN. ENERGIJE

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

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

SCHRODINGERJEVA ENAČBA