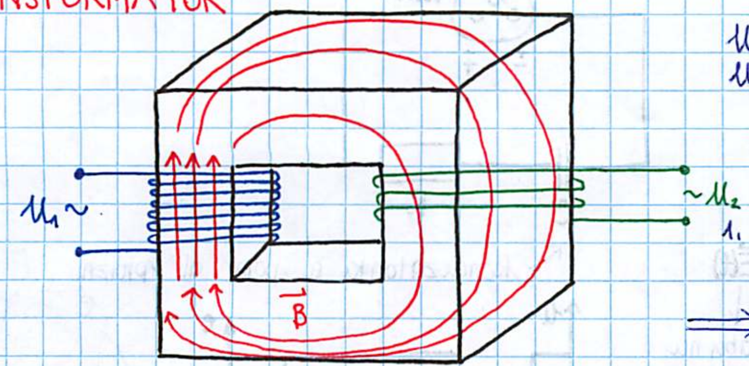
TRANSFORMATOR



$U_1 = U_0 \cos\omega t$

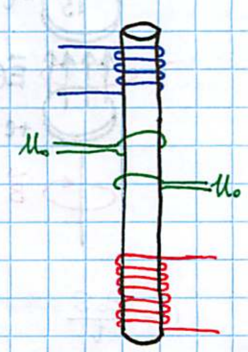
$U_1 = U_{10} \cos\omega t \Longrightarrow B(t) \Longrightarrow U_2 = U_{20}\cos(\omega t + \delta)$

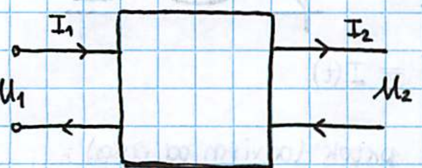
Brez dokaza:

U_0 ustreza 1 navoju:

1. $U_1 = N_1 U_0$ $\longrightarrow$
   $U_2 = N_2 U_0$

$\Longrightarrow \boxed{\frac{U_2}{U_1} = \frac{N_2}{N_1}}$





2. Energijski zakon
   $P = IU$ ... koliko dela opraviš na sekundo $\frac{de}{dt} U = \frac{dA_e}{dt}$

   $I_1 U_1 = I_2 U_2$

Če se transformator segreje, je to zato, ker odstopa od zgornje enačbe.

$N_1 = 400$ navojev $\quad N_2 = 4$ (0,5 debela bakrena žica)

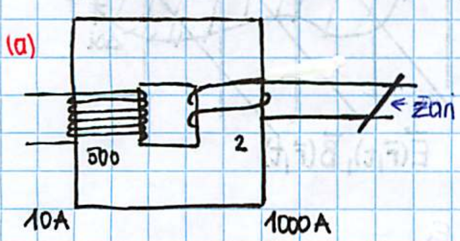
$U_1 = 220\,V \quad U_2 = 2V$

$I_1 \cong 10A \quad I_2$ velikostni razred $1000\,A$

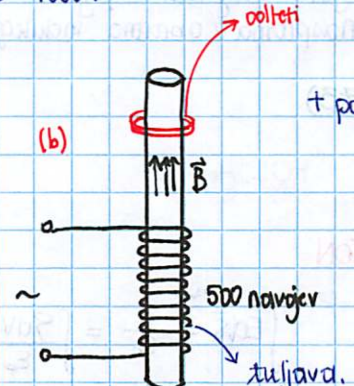
$P = 2200\,W$

Poskusi:

(a)

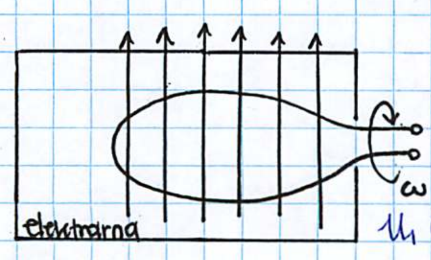


(b)

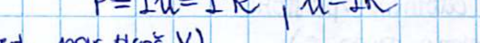


+ poskus s kositrom:
Ker je I_2 zelo velik, je $T \ggg 0$, kositer se stopi.

(c)



U_1 (razred par tisoč V)



$P = IU = I^2R \quad , U = IR$

$\omega = 2\pi\, 50\,Hz$

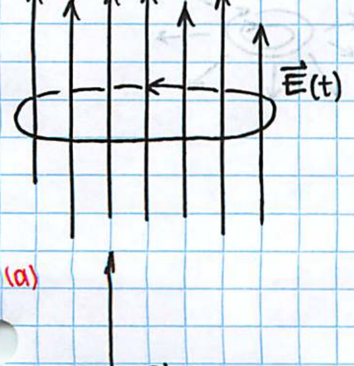
$U_0 = \cos(\omega t + \delta)$

V industriji jakih tokov želijo tok po daljnovodih znižati, zvišati pa želijo U_1, katero v mestih zmanjšajo, ker je prenevarno.

$U = 10\,kV$ v mestih

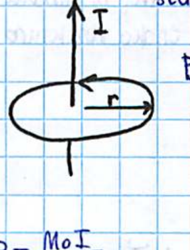
$U = 1000\,kV$ med mesti

PREMIKALNI TOK



Amperov zakon:

Statičen tok!

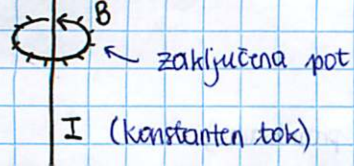


$B = \frac{\mu_0 I}{2\pi r}$

$\frac{1}{\mu_0}\oint \vec{B}\,d\vec{s} = I$

$\oint \vec{E}\,d\vec{s} = 0$ (statično polje)

(a)



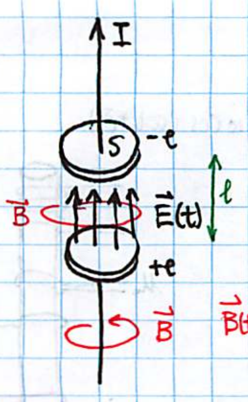
$B = \frac{\mu_0 I}{2\pi r}$

Zaključeno pot razdelimo na majhne koščke, seštevamo, integriramo, ... Amperov zakon $\Longrightarrow \frac{1}{\mu_0}\oint \vec{B}\,d\vec{s} = I$

konstanten tok

točkasto telo pada z $1/r^2$ (kvadratom razdalje)
točk. telo enak. razp. po žici pa pada z razdaljo ($1/r$

(b)

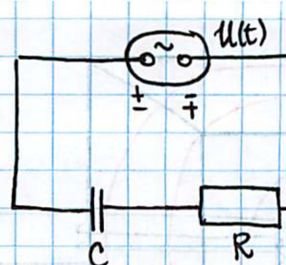


Tok ni konstanten, saj je odvisen od časa, I(t) (niha). Električno polje pravtako niha, tj. $\vec{E}(t)$

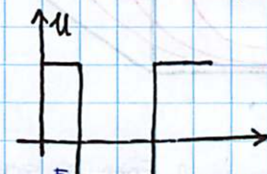
naboj na ploščah spreminjamo.

razdalja med ploščama

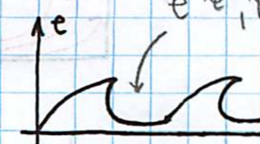
$C = \frac{\varepsilon_0 S}{l}$



kondenzator, ki se polni ali prazni



$\Longrightarrow$



$e^{-\frac{t}{\tau}}, \tau = RC$

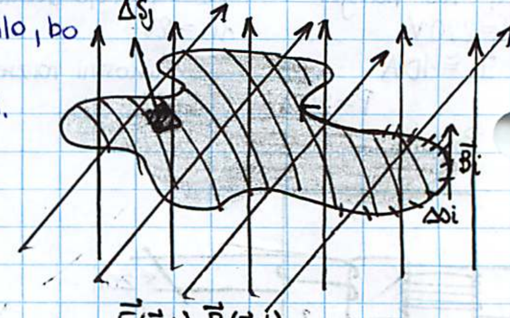
$$I = \frac{de}{dt} = \frac{dCu}{dt} = \frac{dCEl}{dt} = \frac{d\varepsilon_0}{dt} SE\, l/l = \varepsilon_0 \frac{dSE}{dt} = \varepsilon_0 \frac{d\Phi_e}{dt}, \quad \Phi_e = \int \vec{E} d\vec{S} = I(t)$$

električni pretok (odvisen od časa)
Če je tok konstanten, je ta izraz $=0$!

Maxwell je enačbi za tok iz (a) dodal še tok I(t):

$$\frac{1}{\mu_0} \oint \vec{B} d\vec{s} = I + \varepsilon_0 \frac{\partial}{\partial t} \int \vec{E} d\vec{S}$$

če se bo električno polje spreminjalo, bo nastajalo magnetno polje.
Tj nasprotna / obratna indukcija.

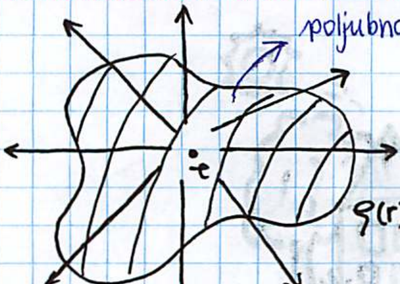


$\vec{E}(\vec{r},t), \vec{B}(\vec{r},t)$

MAXWELLOVE ENAČBE (1867-1873)

AKSIOMI ELEKTROMAGNETNEGA POLJA

1. Maxwellova enačba ~ GAUSSOV ZAKON

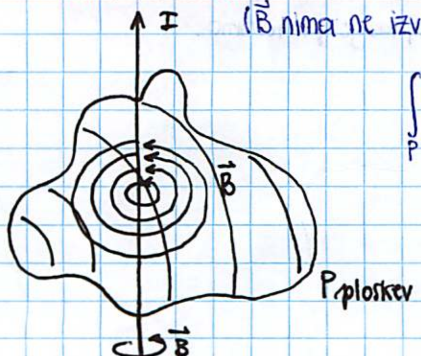


$$\int_P \vec{E} d\vec{S} = \frac{e}{\varepsilon_0} = \int \frac{\rho dV}{\varepsilon_0} = \sum_{i=1}^{n} \frac{e_i}{\varepsilon_0}$$

(tj. po zaključni poti)

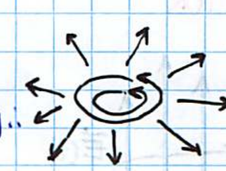
$\rho(r)$... gostota naboja
(če integriramo gostoto naboja po celotnem prostoru dobimo ravno e)

2. Maxwellova enačba
($\vec{B}$ nima ne izvira ne ponora)



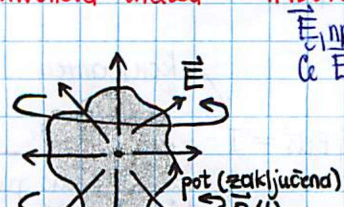
$$\int_P \vec{B} d\vec{S} = 0$$

$= e_M$ ← Vsota magnetnih nabojev, ki še niso bili najdeni.
Če bi jih našli, bi imela tako $\vec{E}$ kot $\vec{B}$ enako strukturo silnic, tj.:



3. Maxwellova enačba ~ INDUKCIJSKI ZAKON

$\vec{E}$, npr. statično
Če $\vec{E}(t)$, potem se pojavi magnetno polje $\vec{B}(t)$.



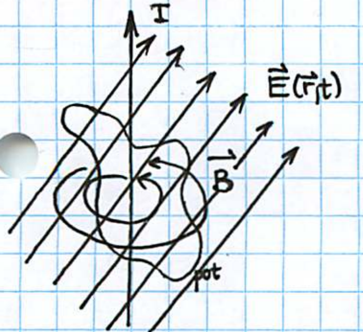
$$\oint \vec{E} d\vec{s} = 0 - \frac{\partial}{\partial t} \int_{\text{ploskev}} \vec{B} \cdot d\vec{S}$$

če je od časa neodvisno, tj. statično

$\Updownarrow$
Im (še ni čisto em)

Če $\exists$ $\dot{u}$, potem $\oint \vec{E} d\vec{s} \neq 0$ (npr. da e navzgor in navzdol premikamo)

4. Maxwellova enačba



$$\oint_{pot} \vec{B} d\vec{s} = \mu_0 I + \varepsilon_0 \mu_0 \frac{\partial}{\partial t} \int_{ploskev} \vec{E} d\vec{S}$$

$\int \vec{j} d\vec{S}$

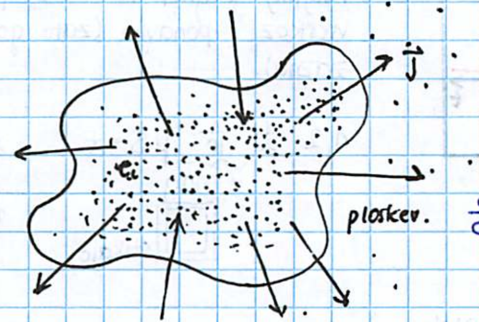
gostota

5. .... enačba

$\int_{<P} \rho dV$ gostota naboja po prostornini

└ integriramo naboje pod ploskvijo

$$\frac{\partial}{\partial t} \int \rho dV + \int \vec{j} d\vec{s} = 0$$



$\left(\frac{de}{dt} = I \right)$

$$\frac{\partial}{\partial t} \int_{<P'} \rho dV = -\int \vec{j} \vec{S} = -I$$

gostota toka $\vec{j} = \frac{dI}{dS}$ $[A/m^2]$

Maxwellove enačbe v diferencialni obliki:

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

$\nabla \cdot \vec{E} = \frac{\partial E_x}{\partial x} + \frac{\partial E_y}{\partial y} + \frac{\partial E_z}{\partial z}$ divergenca $\vec{E}$

$\nabla \times \vec{B} = \left(\frac{\partial}{\partial y} B_z - \frac{\partial}{\partial z} B_y, \frac{\partial}{\partial z} B_x - \frac{\partial}{\partial x} B_z, \frac{\partial}{\partial x} B_y - \frac{\partial}{\partial y} B_x \right)$ rotor $\vec{B}$

1. $\nabla \cdot \vec{E} = \frac{\rho(\vec{r},t)}{\varepsilon_0}$

2. $\nabla \cdot \vec{B} = 0$

   $\frac{\partial \rho}{\partial t} + \nabla \vec{j} = 0$

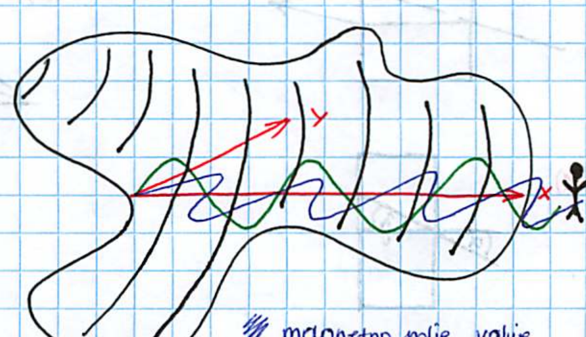
3. $\nabla \times \vec{E} = -\frac{\partial \vec{B}}{\partial t}$

4. $\nabla \times \vec{B} = \mu_0 \vec{j} + \varepsilon_0 \mu_0 \frac{\partial}{\partial t} \vec{E}$

$$\nabla \times \nabla \times \vec{E} = -\frac{\partial}{\partial t} \underbrace{\nabla \times \vec{B}}_{4} = -\frac{\partial}{\partial t} \left(\mu_0 \vec{j} + \varepsilon_0 \mu_0 \frac{\partial}{\partial t} \vec{E} \right) = -\frac{\partial}{\partial t} \mu_0 \vec{j} - \varepsilon_0 \mu_0 \frac{\partial^2}{\partial t^2} \vec{E}$$

$\rho = 0$
$j = 0$
↓
VAKUUM

med dvema ploščama
kondezatorja ni ne nabojev
ne tokov



magnetno polje valuje v pravokotni ravnini

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

$\nabla \times \nabla \times \vec{E} = -\frac{\partial^2}{\partial t^2} \frac{1}{c^2} \vec{E}$ } $\nabla^2 \vec{E} = -\frac{\partial^2}{\partial t^2} \frac{1}{c^2} \vec{E}$

$\nabla \cdot \vec{E} = 0$

$\nabla^2 = \left(\frac{\partial^2}{\partial x^2}, \frac{\partial^2}{\partial y^2}, \frac{\partial^2}{\partial z^2} \right)$

$$\frac{\partial^2}{\partial x^2} E_x + \frac{\partial^2}{\partial y^2} E_x + \frac{\partial^2}{\partial z^2} E_x = -\frac{1}{c^2} \frac{\partial^2}{\partial t^2} E_x$$

v 1D: → enako še za y in z

$\Longrightarrow \frac{\partial^2 E_x}{\partial x^2} = -\frac{1}{c^2} \frac{\partial^2}{\partial t^2} E_x$ valovna enačba

$\ddot{u} + \omega^2 u = 0$ $\Longrightarrow \cos \omega t$

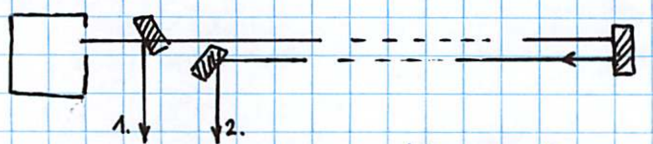
$\Longrightarrow e^{\pm \omega t}$

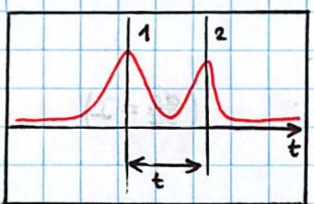
$$\nabla \times \nabla \times \vec{B} = \nabla \times \mu_0 \vec{j} + \varepsilon_0 \mu_0 \frac{\partial}{\partial t} \nabla \vec{E}$$

HITROST SVETLOBE (ELEKTROMAGNETNEGA VALOVANJA)

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

$c = \sqrt{\frac{1}{\varepsilon_0 \mu_0}} = 299792458 \ (\in \mathbb{N}) \ m/s \approx 3 \cdot 10^8 \ m/s$

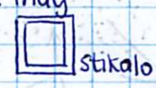




1,2 ... premika

Najprej je graf le ⎯⎍⎯, saj se ta vseskozi ponavlja (zato ga osciloskop zazna).

$1{,}2 \cdot \frac{1}{2} \cdot \underbrace{\frac{1}{10}}_{\times\ \text{mag}} \ \mu s = t$ $\qquad \ell = 18{,}17 m$

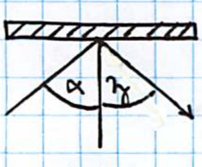


$v = \frac{\ell}{t} = \frac{18{,}17m}{1{,}2 \cdot 0{,}05 \cdot 10^{-6} \mu s} = 3 \cdot 10^8 \ m/s$

OPTIKA Z MIKROVALOVI

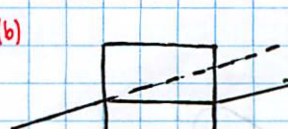
Mobitel ~ $\nu = 10^9$ Hz

$\lambda = 2{,}8$ cm

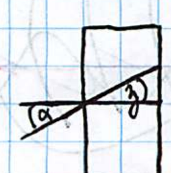
(a) 

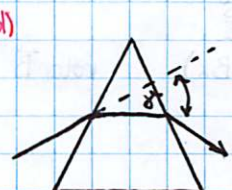
„Odbojni žarek"

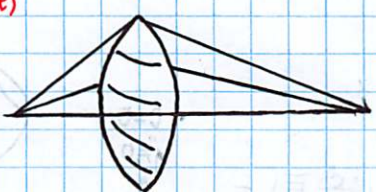
$\alpha = \gamma$

(b) 

„lomni žarek"

(c) 

(d) 

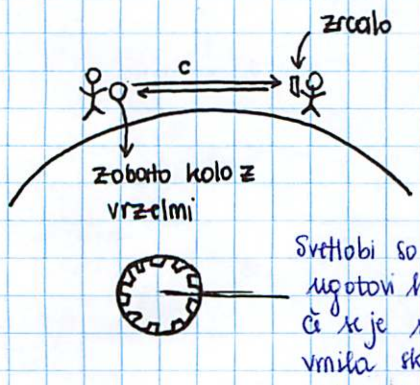
(e) 

Valovanje po kristalu:
Ko val zadene prvi atom, ta zaniha, pojavi se spremenljivo magnetno polje, posledično še električno polje (tj. atom seva), po katerem val nadaljuje z isto frekvenco. Prvega začuti drugi atom in tako naprej. Mikroval oz. val potuje skozi kristal s faktorjem 1'6, potem pa pa pot nadaljuje z isto hitrostjo, kot jo je imel pred „vstopom" v kristal.

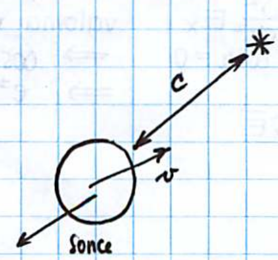
(POSEBNA) SPECIALNA TEORIJA RELATIVNOSTI

1. Hitrost svetlobe je konstantna (že prej znana ugotovitev, ki je prispevala k nastanku teorije relativnosti leta 1904/05), tj.: $c = \sqrt{\mu_0 \varepsilon_0} \cong 3 \cdot 10^8 \ m/s$.
Hitrost svetlobe lahko merimo na veliko načinov, npr.

Maxwellova oblika valovne enačbe:
$E'' = \frac{1}{c^2} \ddot{E}$

(a) 

Svetlobi so lahko ugotovili hitrost, le-če se je svetloba vrnila skozi (vrzel) zobato kolo.

(b) 

Meritve so bile natančne že okrog leta 1900.