Fizika 2 - izpeljave

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Kazalo

1 Valovna enačba

1.1

Faradejev 185 in Amperov 187 zakon lahko združimo v valovno enačbo.

1.2

- $$\vec{J} = 0$$
- $$\vec{D} = \epsilon_0 \vec{E}$$
- $$\vec{B} = \mu_0 \vec{H}$$
- $$\vec{E} = (0, E_y(x,t), E_z(x,t))$$
- $$\vec{H} = (0, H_y(x,t), H_z(x,t))$$

1.3

$$\begin{vmatrix} \vec{i} & \vec{j} & \vec{k} \\ \frac{\partial}{\partial x} & \frac{\partial}{\partial y} & \frac{\partial}{\partial z} \\ E_x & E_y & E_z \end{vmatrix} = \left(\frac{\partial E_z}{\partial y} - \frac{\partial E_y}{\partial z}, \frac{\partial E_x}{\partial z} - \frac{\partial E_z}{\partial x}, \frac{\partial E_y}{\partial x} - \frac{\partial E_x}{\partial y} \right) = \left(0, -\frac{\partial E_z}{\partial x}, \frac{\partial E_y}{\partial x}\right) =$$

$$= -\mu_0 \left(\frac{\partial H_x}{\partial t}, \frac{\partial H_y}{\partial t}, \frac{\partial H_z}{\partial t} \right) = -\mu_0 \left(0, \frac{\partial H_y}{\partial t}, \frac{\partial H_z}{\partial t} \right) \quad (1)$$

$$\frac{\partial E_z}{\partial x} = \mu_0 \frac{\partial H_y}{\partial t} \quad (2) \qquad \frac{\partial E_y}{\partial x} = -\mu_0 \frac{\partial H_z}{\partial t} \quad (3)$$

1.4

$$\begin{vmatrix} \vec{i} & \vec{j} & \vec{k} \\ \frac{\partial}{\partial x} & \frac{\partial}{\partial y} & \frac{\partial}{\partial z} \\ H_x & H_y & H_z \end{vmatrix} = \left(\frac{\partial H_z}{\partial y} - \frac{\partial H_y}{\partial z}, \frac{\partial H_x}{\partial z} - \frac{\partial H_z}{\partial x}, \frac{\partial H_y}{\partial x} - \frac{\partial H_x}{\partial y} \right) = \left(0, -\frac{\partial H_z}{\partial x}, \frac{\partial H_y}{\partial x}\right) =$$

$$= \epsilon_0 \left(\frac{\partial H_x}{\partial t}, \frac{\partial H_y}{\partial t}, \frac{\partial H_z}{\partial t} \right) = \epsilon_0 \left(0, \frac{\partial H_y}{\partial t}, \frac{\partial H_z}{\partial t} \right) \quad (4)$$

$$\frac{\partial H_z}{\partial x} = -\epsilon_0 \frac{\partial E_y}{\partial t} \quad (5) \qquad \frac{\partial H_y}{\partial x} = \epsilon_0 \frac{\partial E_z}{\partial t} \quad (6)$$

1.5

$$\frac{\partial E_y}{\partial x} = -\mu_0 \frac{\partial H_z}{\partial t} \qquad \frac{\partial H_z}{\partial x} = -\epsilon_0 \frac{\partial E_y}{\partial t}$$

$$\frac{\partial^2 E_y}{\partial x \partial t} = -\mu_0 \frac{\partial^2 H_z}{\partial t^2} \qquad \frac{\partial^2 H_z}{\partial x^2} \frac{1}{-\epsilon_0} = \frac{\partial^2 E_y}{\partial t \partial x}$$

1.6

$$\frac{\partial^2 E_y}{\partial x^2} \frac{1}{-\mu_0} = -\epsilon_0 \frac{\partial^2 E_y}{\partial t^2} \tag{7}$$

1.7

$$E_y = E_0 \cos(\omega t - kx); \omega = 2\pi f, k = \frac{\omega}{c_0} \tag{8}$$

$$\frac{\partial^2 E_y}{\partial x^2} = -k^2 E_y; \frac{\partial^2 E_y}{\partial t^2} = -\omega^2 E_y \tag{9}$$

$$k^2 E_y \frac{1}{-\epsilon_0 \mu_0} = \omega^2 E_y = \frac{\omega^2}{c_0^2} \frac{1}{-\epsilon_0 \mu_0} E_y \tag{10}$$

1.8

$$\frac{1}{\epsilon_0 \mu_0} = c_0^2 \tag{11}$$

2 Lomni količnik

2.1

$$c = \frac{1}{\sqrt{\epsilon_r \epsilon_0 \mu_r \mu_0}}; c_0 = \frac{1}{\sqrt{\epsilon_0 \mu_0}} \tag{12}$$

$$n = \frac{c}{c_0} = \sqrt{\frac{\epsilon_0 \mu_0}{\epsilon_r \epsilon_0 \mu_r \mu_0}} = \frac{1}{\sqrt{\epsilon_r \mu_r}} \tag{13}$$

3 Lomni zakon

3.1

Minimiziramo čas preleta žarkov od točke A do točke B, ki sta v različnih medijih z različnimi n.

3.2

$t(\alpha, \beta)$ ima ekstrem, če je $dt = 0$

$$t = t_1 + t_2 \tag{14}$$

$$t = \frac{s_1}{c_1} + \frac{s_2}{c_2} \tag{15}$$

$$t = \frac{h_1}{\cos(\alpha) * c_1} + \frac{h_2}{\cos(\beta) * c_2} \tag{16}$$

$$dt = \frac{\partial t}{\partial \alpha} d\alpha + \frac{\partial t}{\partial \beta} d\beta = 0 \tag{17}$$

$$\frac{h_1 \sin(\alpha)}{\cos^2(\alpha) * c_1} d\alpha = -\frac{h_2 \sin(\beta)}{\cos^2(\beta) * c_2} d\beta \tag{18}$$

$$\frac{d\alpha}{d\beta} = -\frac{h_2}{h_1} \frac{c_1}{c_2} \frac{\sin(\beta)}{\sin(\alpha)} \frac{\cos^2(\alpha)}{\cos^2(\beta)} \tag{19}$$

3.3

L je razdalja med točkama po y osi, ker je konstantna, je $dL = 0$

$$L = l_1 + l_2 = \frac{h_1}{\tan(\alpha)} + \frac{h_2}{\tan(\beta)} \tag{20}$$

$$dL = \frac{h_1}{\cos^2(\alpha)} d\alpha + \frac{h_2}{\cos^2(\beta)} d\beta = 0 \tag{21}$$

$$\frac{h_1}{\cos^2(\alpha)} d\alpha = -\frac{h_2}{\cos^2(\beta)} d\beta \tag{22}$$

$$\frac{d\alpha}{d\beta} = -\frac{h_2}{h_1} \frac{\cos^2(\beta)}{\cos^2(\alpha)} \tag{23}$$

3.4

$$-\frac{h_2}{h_1}\frac{c_1}{c_2}\frac{\sin(\beta)}{\sin(\alpha)}\frac{\cos^2(\alpha)}{\cos^2(\beta)} = -\frac{h_2}{h_1}\frac{\cos^2(\beta)}{\cos^2(\alpha)} \tag{24}$$

$$\Rightarrow \frac{\sin(\beta)}{\sin(\alpha)} = \frac{c_1}{c_2} = \frac{\frac{c_0}{n_1}}{\frac{c_0}{n_2}} = \frac{n_2}{n_1} \tag{25}$$

$$\Rightarrow n_1 \sin(\alpha) = n_2 \sin(\beta) \tag{26}$$

4 Odbojni zakon

$$t = t_1 + t_2 \tag{27}$$

$$t = \frac{s_1}{c} + \frac{s_2}{c} \tag{28}$$

$$t = \frac{h}{\cos(\alpha) * c} + \frac{h}{\cos(\beta) * c} \tag{29}$$

$$dt = \frac{\partial t}{\partial \alpha} d\alpha + \frac{\partial t}{\partial \beta} d\beta = 0 \tag{30}$$

$$\frac{h \sin(\alpha)}{\cos^2(\alpha) * c} d\alpha = -\frac{h \sin(\beta)}{\cos^2(\beta) * c} d\beta \tag{31}$$

$$\frac{d\alpha}{d\beta} = -\frac{\sin(\beta)}{\sin(\alpha)} \frac{\cos^2(\alpha)}{\cos^2(\beta)} \tag{32}$$

4.1

L je razdalja med točkama po y osi, ker je konstantna, je $dL = 0$

$$L = l_1 + l_2 = \frac{h}{\tan(\alpha)} + \frac{h}{\tan(\beta)} \tag{33}$$

$$dL = \frac{h}{\cos^2(\alpha)} d\alpha + \frac{h}{\cos^2(\beta)} d\beta = 0 \tag{34}$$

$$\frac{h}{\cos^2(\alpha)} d\alpha = -\frac{h}{\cos^2(\beta)} d\beta \tag{35}$$

$$\frac{d\alpha}{d\beta} = -\frac{\cos^2(\alpha)}{\cos^2(\beta)} \tag{36}$$

4.2

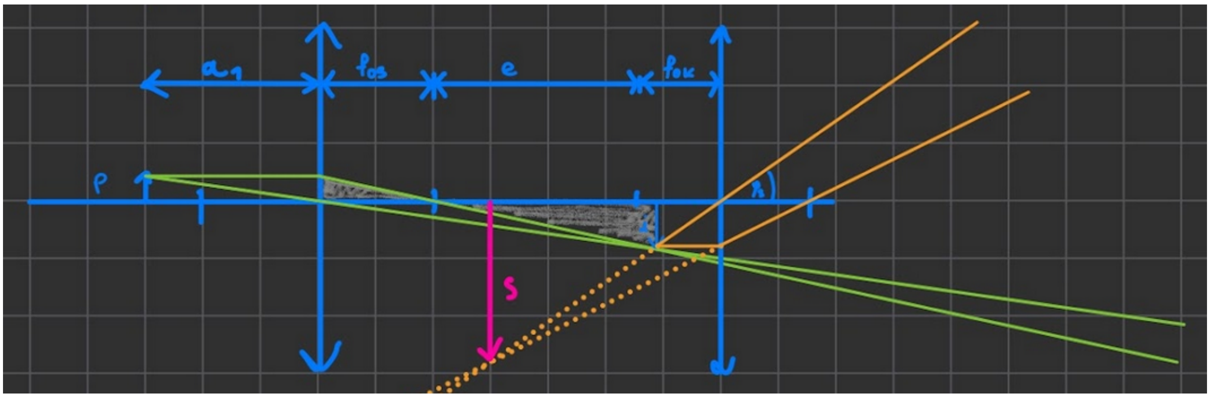
$$-\frac{\sin(\beta)}{\sin(\alpha)} \frac{\cos^2(\alpha)}{\cos^2(\beta)} = -\frac{\cos^2(\alpha)}{\cos^2(\beta)} \tag{37}$$

$$\Rightarrow \frac{\sin(\beta)}{\sin(\alpha)} = 1 \tag{38}$$

$$\Rightarrow \sin(\alpha) = \sin(\beta) \tag{39}$$

$$\Rightarrow \alpha = \beta \tag{40}$$

5 Mikroskop



$$\tan(\varphi_1) = \frac{p}{x_0} \tag{41}$$

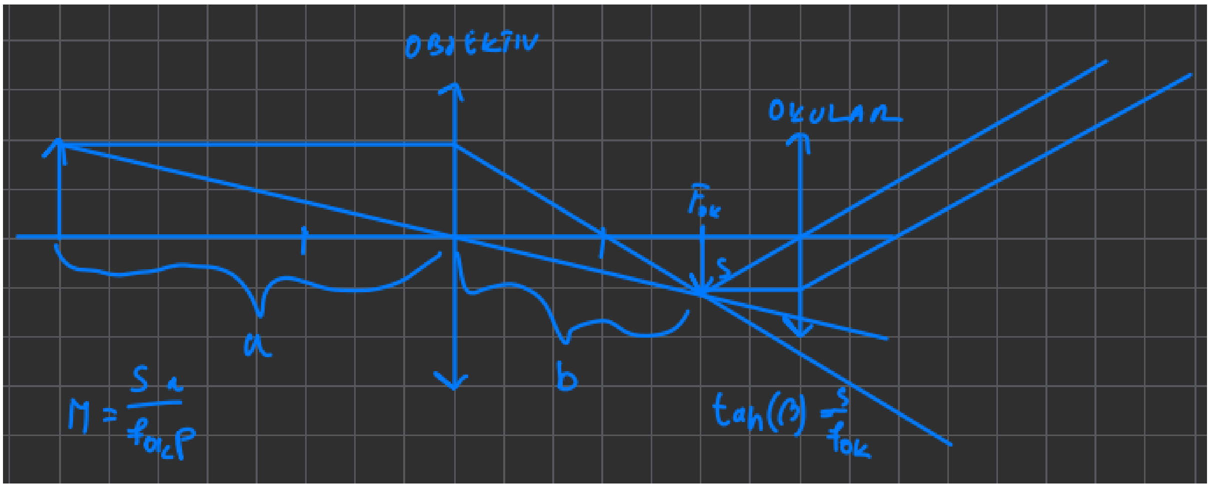
$$\tan(\varphi_2) = \frac{i}{f_{ok}} \tag{42}$$

$$\frac{i}{e} = \frac{p}{f_{ob}} \tag{43}$$

$$M = \frac{\tan(\varphi_2)}{\tan(\varphi_1)} \tag{44}$$

$$M = \frac{e x_0}{f_{ok} f_{ob}} \tag{45}$$

6 Daljnogled



$$\tan(\varphi_1) = \frac{p}{a} = \frac{s}{b} \tag{46}$$

$$\tan(\varphi_2) = \frac{s}{f_{ok}} \tag{47}$$

$$\frac{1}{f_{ob}} = \frac{1}{a} + \frac{1}{b} \Rightarrow b = \frac{af_{ob}}{a - f_{ob}} \tag{48}$$

$$M = \frac{\tan(\varphi_2)}{\tan(\varphi_1)} = \frac{b}{f_{ok}} \tag{49}$$

$$M = \frac{af_{ob}}{f_{ok}(a - f_{ob})} \tag{50}$$

7 Absorpcija EM valovanja

Telo debeline x in koeficientom absorpcije μ bo absorbira svetlobni tok j. Tanko telo debeline dx absorbira svetlobni tok dj

$$dj = -\mu j dx \tag{51}$$

$$\frac{1}{j} dj = -\mu dx \tag{52}$$

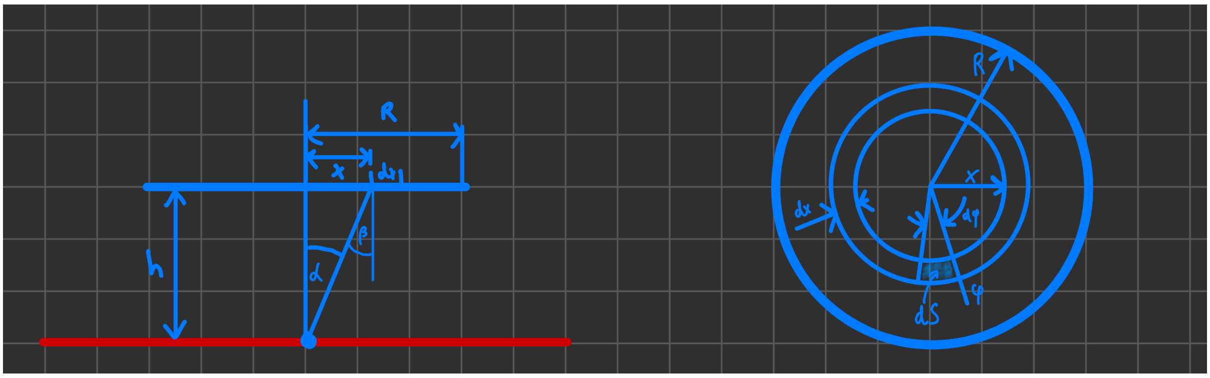
$$\int_{j_0}^{j(x)} \frac{1}{j} dj = -\mu \int_0^x dx \tag{53}$$

$$\ln(j(x)) - \ln(j_0) = -\mu x \tag{54}$$

$$\ln\left(\frac{j(x)}{j_0}\right) = -\mu x \tag{55}$$

$$j(x) = j_0 e^{-\mu x} \tag{56}$$

8 Okrogla luč po Lambertovem zakonu



8.1

$$B(\theta) = B_0 \tag{57}$$

$$dI = B(\theta)\cos(\beta)dS \tag{58}$$

$$dS = xd\varphi dx \tag{59}$$

$$dS = \int_0^{2\pi} xdxd\varphi \tag{60}$$

$$dS = 2\pi xdx \tag{61}$$

$$dI = B_0\cos(\beta)2\pi xdx \tag{62}$$

$$dE = \frac{dI}{r^2}\cos(\beta) \tag{63}$$

$$dE = \frac{B_0}{r^2}\cos^2(\beta)2\pi xdx \tag{64}$$

8.2

$$r = \sqrt{x^2 + h^2} \tag{65}$$

$$\cos(\beta) = \frac{h}{r} \tag{66}$$

$$r = \frac{h}{\cos(\beta)} \tag{67}$$

$$\tan(\beta) = \frac{x}{h} \Rightarrow x = h\tan\beta \tag{68}$$

$$\frac{1}{\cos^2(\beta)}d\beta = \frac{1}{h}dx \tag{69}$$

$$dx = h\frac{1}{\cos^2(\beta)}d\beta \tag{70}$$

8.3

$$\beta(x) = \text{arctan}\left(\frac{x}{h}\right) \tag{71}$$

$$\beta(0) = 0 \tag{72}$$

$$\beta(R) = \beta_0 = \text{arctan}\left(\frac{R}{h}\right) \tag{73}$$

8.4

$$E = \int dE = \int_0^\beta \frac{B_0 \cos^2(\beta) \cos^2(\beta) 2\pi h \sin(\beta) h}{h^2 \cos(\beta) \cos^2(\beta)} d\beta \tag{74}$$

$$E = \int_0^\beta B_0 \sin(\beta) \cos(\beta) 2\pi d\beta \tag{75}$$

$$E = B_0 \pi \int_0^\beta \sin(2\beta) d\beta \tag{76}$$

$$E = B_0 \pi \int_0^{2\beta} \sin(u) du; u = 2\beta \Rightarrow du = 2d\beta \tag{77}$$

$$E = \frac{B_0 \pi}{2} (-\cos(u))|_{u=0}^{2\beta} \tag{78}$$

$$E = \frac{B_0 \pi}{2} (1 - \cos(2\beta)) \tag{79}$$

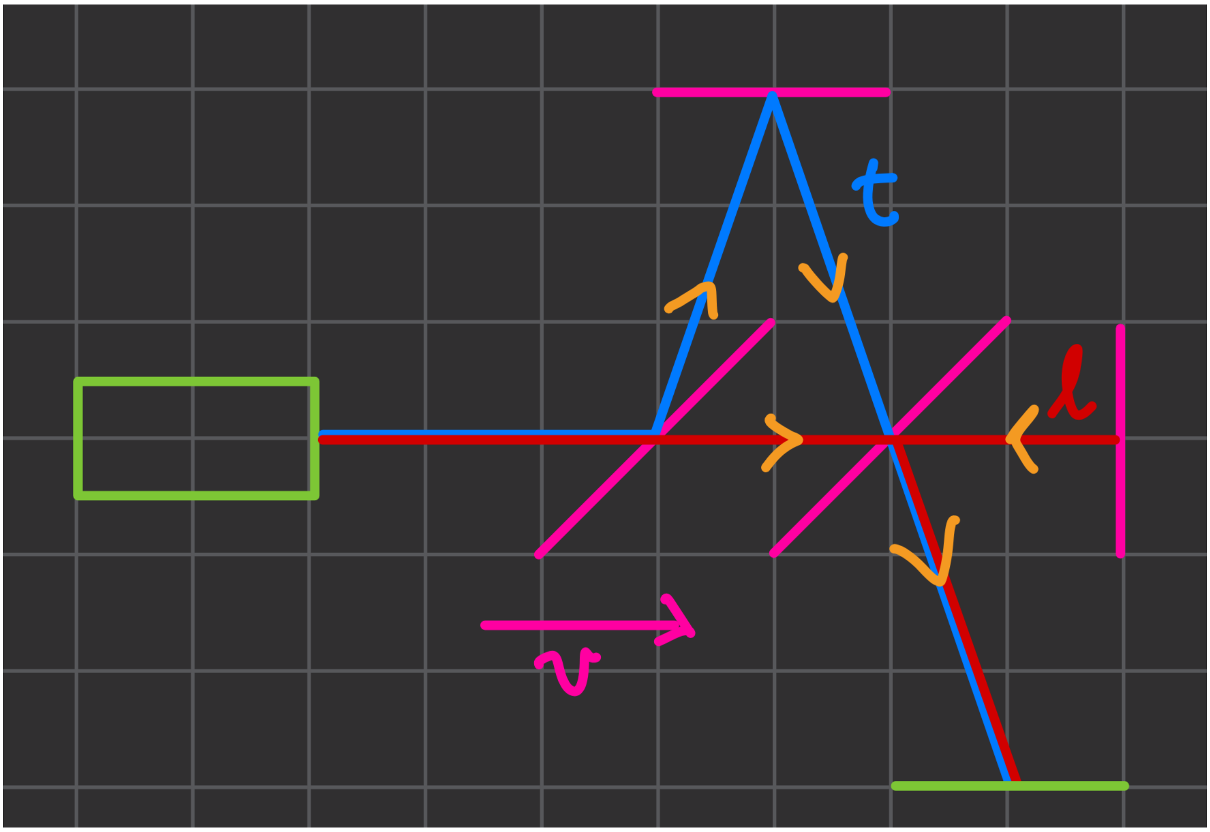
$$\tag{80}$$

8.5

Če je R velik

$$\lim_{R \to \infty} E = \lim_{\beta \to \frac{\pi}{2}} \frac{B_0 \pi}{2} (1 - \cos(2\beta_0)) = \frac{B_0 \pi}{2} (1 - \cos(\pi)) = \frac{B_0 \pi}{2} (1 + 1) = B_0 \pi \tag{81}$$

9 Michelson-Morleyev interferometer



9.1

$$T_t = \frac{2L}{\sqrt{c^2-v^2}}$$

$$T_t = \frac{2L}{\sqrt{c^2(1-\frac{v^2}{c^2})}}$$

$$T_t = \frac{2L}{c}\frac{1}{\sqrt{1-\frac{v^2}{c^2}}}$$

$$T_l = \frac{L}{c-v} + \frac{L}{c+v} = \frac{L(c+v)+L(c-v)}{(c-v)(c+v)}$$

$$T_l = \frac{2Lc}{c^2-v^2}$$

$$T_l = \frac{2L}{c}\frac{1}{1-\frac{v^2}{c^2}}$$

9.2

$$T_l - T_t = \frac{2L}{c}\left(\frac{1}{1-\frac{v^2}{c^2}} - \frac{1}{\sqrt{1-\frac{v^2}{c^2}}}\right) \tag{82}$$

$$(T_l - T_t)c = k\lambda = 2L\left((1+\frac{v^2}{c^2}) - (1+\frac{1}{2}\frac{v^2}{c^2})\right) \tag{83}$$

$$k\lambda = 2L\frac{1}{2}\frac{v^2}{c^2} = L\frac{v^2}{c^2} \tag{84}$$

9.3

Če interferometer zavrtimo za 90° lahko zapišemo $k\lambda = -L\frac{v^2}{c^2}$

$$n = \frac{k_1\lambda - k_2\lambda}{\lambda} = \frac{L\frac{v^2}{c^2} + L\frac{v^2}{c^2}}{\lambda} = \frac{2L}{\lambda}\frac{v^2}{c^2} \tag{85}$$

$$\tag{86}$$

Žal se teoretični izračun ne ujema z eksperimentom

9.4

Če upoštevamo Lorentzovo transformacijo 20.5 lahko zapišemo

$$T_l = \frac{2L\sqrt{1-\frac{v^2}{c^2}}}{c}\frac{1}{1-\frac{v^2}{c^2}} = \frac{2L}{c}\frac{1}{\sqrt{1-\frac{v^2}{c^2}}} = T_t \tag{87}$$

10 Stefanov zakon

Lahko ga izpeljemo z integriranjem Planckovega zakona 20.5

$$j = \int_0^\infty \frac{dj}{d\lambda} d\lambda = \int_0^\infty \frac{2\pi h c_0^2}{\lambda^5 \left(e^{\frac{hc_0}{\lambda k_B T}} - 1\right)} d\lambda \tag{88}$$

10.1

$x = \frac{hc_0}{\lambda k_B T} \Rightarrow d\lambda = -\frac{hc_0}{k_B T x^2} dx$ in $\lambda \to 0 \Rightarrow x \to \infty, \lambda \to \infty \Rightarrow x \to 0$

$$j = \int_\infty^0 \frac{2\pi h c_0^2}{\left(\frac{hc_0}{k_B T x}\right)^5 (e^x - 1)} \left(-\frac{hc_0}{k_B T x^2}\right) dx \tag{89}$$

$$j = \frac{2\pi (k_B T)^4}{h^3 c_0^3} \int_0^\infty \frac{x^3}{e^x - 1} dx \tag{90}$$

$$j = \frac{2\pi (k_B T)^4}{h^3 c_0^3} \cdot \frac{\pi^4}{15} = \frac{2\pi^5 k_B^4 T^4}{15 h^3 c_0^3} \tag{91}$$

$$j = \sigma T^4; \sigma = \frac{2\pi^5 k_B^4}{15 h^3 c_0^3} = 5,67 \cdot 10^{-8} \frac{\mathrm{W}}{\mathrm{m^2 K^4}} \tag{92}$$

11 Wienov zakon

Lahko ga izpeljemo z odvajanjem Planckovega zakona 20.5

$$\frac{dj}{d\lambda} = \frac{2\pi h c_0^2}{\lambda^5\left(e^{\frac{hc_0}{\lambda k_B T}} - 1\right)} \tag{93}$$

$$\frac{dj}{dx} = \frac{2\pi k_B^5 T^5}{h^4 c_0^3}\frac{x^5}{e^x - 1}; x = \frac{hc_0}{\lambda k_B T} \tag{94}$$

11.1

$$\frac{dj}{dx} = A\frac{x^5}{e^x - 1} = 0 \tag{95}$$

$$\frac{5x^4(e^x - 1) - x^5 e^x}{(e^x - 1)^2} = 0 \tag{96}$$

$$5x^4(e^x - 1) - x^5 e^x = 0 \tag{97}$$

$$5(e^x - 1) = xe^x \tag{98}$$

$$5 = x\frac{e^x}{e^x - 1} \tag{99}$$

$$x \approx 4.9651 \tag{100}$$

$$\tag{101}$$

11.2

$$\lambda_{max} = \frac{hc_0}{k_B T x} = \frac{hc_0}{4.9651 k_B T} \tag{102}$$

$$\lambda_{max} T = k_W = 2.898 \cdot 10^{-3}\text{m K} \tag{103}$$

12 Gostota energijskega toka

12.1

-
- $$\overline{j} = \overline{w} c_0$$
- $$w_E = \frac{1}{2}\epsilon_0 E^2$$
- $$w_B = \frac{1}{2}\mu_0 H^2 = \frac{1}{2}\frac{B^2}{\mu_0}$$
- $$w = w_E + w_B = \frac{1}{2}\epsilon_0 E^2 + \frac{1}{2}\frac{B^2}{\mu_0}$$
- $$\vec{E} = \vec{B} \times \vec{c}_0$$
- $$c_0^2 = \frac{1}{\epsilon_0 \mu_0}$$

$$E = E_0 \cos(\omega t - kx) \tag{104}$$

$$B = B_0 \cos(\omega t - kx) \tag{105}$$

12.2

$$\overline{w} = \frac{1}{2}\epsilon_0 E_0^2 \overline{\cos(\omega t - kx)} + \frac{1}{2}\frac{B^2}{\mu_0}\overline{\cos(\omega t - kx)} \tag{106}$$

$$\overline{w} = \frac{1}{4}\epsilon_0 E_0^2 + \frac{1}{4}\frac{B^2}{\mu_0} \tag{107}$$

$$\overline{w} = \frac{1}{4}\epsilon_0 E_0^2 + \frac{1}{4}\frac{B^2}{\mu_0} \tag{108}$$

$$\overline{w} = \frac{1}{4}\epsilon_0 E_0^2 + \frac{1}{4}\frac{E_0^2}{\mu_0 c_0^2} \tag{109}$$

$$\overline{w} = \frac{1}{4}\epsilon_0 E_0^2 + \frac{1}{4}\epsilon_0 E_0^2 \tag{110}$$

$$\overline{w} = \frac{1}{2}\epsilon_0 E_0^2 = \frac{1}{2}\frac{B_0^2}{\mu_0} \tag{111}$$

$$\tag{112}$$

12.3

$$\overline{j} = \overline{w} c_0 = \frac{1}{2}\epsilon_0 E_0^2 c_0 = \frac{1}{2}\frac{B_0^2}{\mu_0} c_0 \tag{113}$$

13 Absorpcija svetlobe

13.1

$$dj = -\mu j dx \tag{114}$$

$$\frac{1}{j} dj = -\mu dx \tag{115}$$

$$\int_{j_0}^{j(x)} \frac{1}{j} dj = -\mu \int_0^x dx \tag{116}$$

$$\ln(j(x)) - \ln(j_0) = -\mu x \tag{117}$$

$$\ln\left(\frac{j(x)}{j_0}\right) = -\mu x \tag{118}$$

$$j(x) = j_0 e^{-\mu x} \tag{119}$$

$$\tag{120}$$

13.2

$$\frac{j_0}{2} = j_0 e^{-\mu x} \tag{121}$$

$$\frac{1}{2} = e^{-\mu x} \tag{122}$$

$$\ln\left(\frac{1}{2}\right) = -\mu x \tag{123}$$

$$-\ln(2) = -\mu x \tag{124}$$

$$x = \frac{\ln(2)}{\mu} \tag{125}$$

14 Polarizacija

14.1

p je faktor prepustnosti, E_0 amplituda vpadnega električnega polja, E_0' amplituda prepusnega električnega polja

$$E' = E_0 \cos(\varphi) \tag{126}$$

$$j_{vpadni} = \frac{1}{2}\epsilon_0 E_0^2 c_0 \tag{127}$$

$$j_{prepusni} = \frac{1}{2}\epsilon_0 E_0'^2 c_0 = \frac{1}{2}\epsilon_0 (E_0 \cos(\varphi))^2 c_0 = \frac{1}{2}\epsilon_0 E_0^2 c_0 \cos^2(\varphi) \tag{128}$$

$$p = \frac{j_{prepusni}}{j_{vpadni}} = \frac{\frac{1}{2}\epsilon_0 E_0^2 c_0 \cos^2(\varphi)}{\frac{1}{2}\epsilon_0 E_0^2 c_0} \tag{129}$$

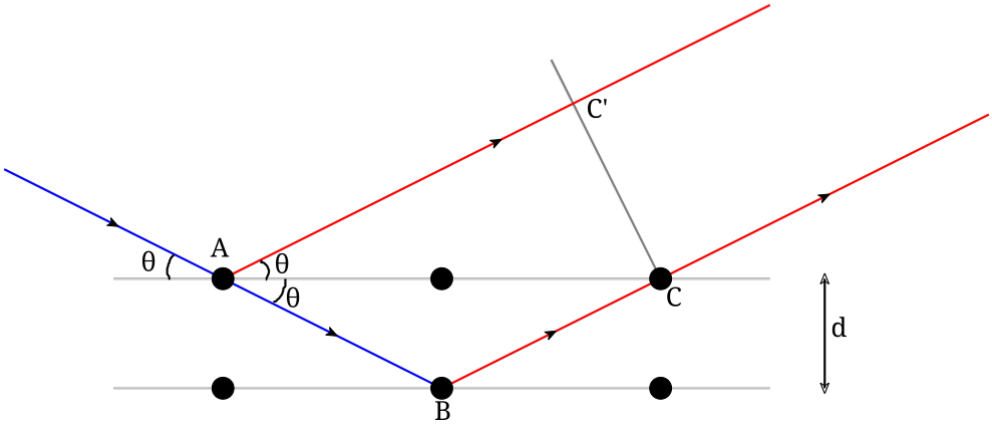
$$p = \cos^2(\varphi) \tag{130}$$

14.2

Pri nepolarizirani svetlobi je $varphi$ enakomerno porazdeljen med 0 in 2π, zato je povprečje $\overline{\cos^2(p)} = \frac{1}{2}$

$$p = \overline{\cos^2(\varphi)} = \frac{1}{2} \tag{131}$$

15 Braggova enačba



Slika 1: https://en.wikipedia.org/wiki/Braggs%27_law

Da pride do konstruktivne interferencije mora biti razlika poti med dvema žarkoma, ki se odbijeta od dveh ploskev kristala, enaka celotnemu številu valovnih dolžin λ

$$N\lambda = |AB| + |BC| - |AC'| \tag{132}$$

$$|AB| = |BC| = \frac{d}{\sin(\theta)} \tag{133}$$

$$|AC| = \frac{2d}{\tan(\theta)} \tag{134}$$

$$|AC'| = |AC|\cos(\theta) = \frac{2d\cos(\theta)}{\sin(\theta)}\cos\theta = \frac{2d\cos^2(\theta)}{\sin(\theta)} \tag{135}$$

$$\tag{136}$$

15.1

$$N\lambda = \frac{d}{\sin(\theta)} + \frac{d}{\sin(\theta)} - \frac{2d\cos^2(\theta)}{\sin(\theta)} \tag{137}$$

$$N\lambda = \frac{2d}{\sin(\theta)}(1 - \cos^2(\theta)) \tag{138}$$

$$N\lambda = \frac{2d}{\sin(\theta)}\sin^2(\theta) \tag{139}$$

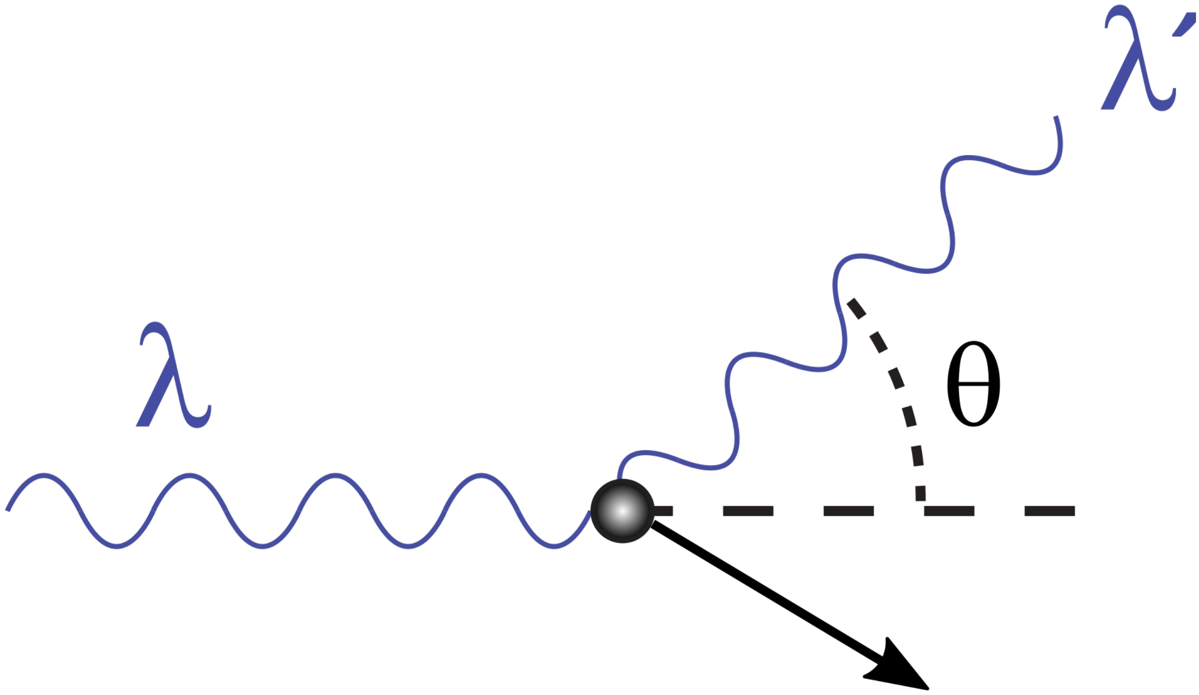
$$N\lambda = 2d\sin(\theta) \tag{140}$$

15.2

Naj bo φ kot med vpadnim žarkom in žarkom sipane svetlobe

$$N\lambda = 2d\sin(\frac{1}{2}\varphi) \tag{141}$$

16 Comptonsko sipanje



Slika 2: https://en.wikipedia.org/wiki/Compton_scattering

- $$\Delta \sum_i E_i = 0$$
- $$\Delta \sum_i P_i = 0$$
- $$E = hf$$
- $$E_e = \sqrt{(p_e c_0)^2 + (m_e c_0^2)^2}$$
- $$E = P c_0$$

16.1

$$E_\gamma + E_e = E'_\gamma + E'_e \tag{142}$$

$$E_\gamma = hf \tag{143}$$

$$E_e = m_e c_0^2; P_e = 0 \tag{144}$$

$$E'_\gamma = hf' \tag{145}$$

$$E'_e = \sqrt{(P'_e c_0)^2 + (m_e c_0^2)^2} \tag{146}$$

$$hf + m_e c_0^2 = hf' + \sqrt{(P'_e c_0)^2 + (m_e c_0^2)^2} \tag{147}$$

$$P_e'^2 c_0^2 = (hf + m_e c_0^2 - hf')^2 - m_e^2 c_0^4 \tag{148}$$

16.2

$$\vec{P}_\gamma + \vec{P}_e = \vec{P'_\gamma} + \vec{P'_e} \tag{149}$$

$$\vec{P'_e} = \vec{P}_\gamma + \vec{P'_\gamma}; P_e = 0 \tag{150}$$

$$P_e'^2 = \vec{P'_e} \cdot \vec{P'_e} = (\vec{P}_\gamma + \vec{P'_\gamma}) \cdot (\vec{P}_\gamma + \vec{P'_\gamma}) \tag{151}$$

$$P_e'^2 = P_\gamma^2 + P_\gamma'^2 - 2P_\gamma \cdot P'_\gamma \cos(\varphi) \tag{152}$$

$$P_e'^2 c_0^2 = P_\gamma^2 c_0^2 + P_\gamma'^2 c_0^2 - 2P_\gamma \cdot P'_\gamma \cos(\varphi) c_0^2 \tag{153}$$

$$P_e'^2 c_0^2 = (hf)^2 + (hf')^2 - 2hfhf' \cos(\varphi) \tag{154}$$

$$(hf + m_e c_0^2 - hf')^2 - m_e^2 c_0^4 = (hf)^2 + (hf')^2 - 2hfhf' \cos(\varphi) \tag{155}$$

$$\begin{aligned} &((hf)^2 + (m_e c_0^2)^2 + (hf')^2 + 2(hf)(m_e c_0^2) - 2(hf')(m_e c_0^2) - 2(hf)(hf'))+ \\ &-m_e^2 c_0^4 = (hf)^2 + (hf')^2 - 2(hf)(hf') \cos(\varphi) \end{aligned} \tag{156}$$

$$\begin{aligned} &(hf)^2 + (hf')^2 + 2(hf)(m_e c_0^2) - 2(hf')(m_e c_0^2) - 2(hf)(hf') = \\ &= (hf)^2 + (hf')^2 - 2(hf)(hf') \cos(\varphi) \end{aligned} \tag{157}$$

$$2(hf)(m_e c_0^2) - 2(hf')(m_e c_0^2) = -2(hf)(hf') \cos(\varphi) \tag{158}$$

$$f m_e c_0^2 - f' m_e c_0^2 = -hff' \cos(\varphi) \tag{159}$$

$$f c_0^2 - f' c_0^2 = -\frac{hff'}{m_e} \cos(\varphi) \tag{160}$$

$$\frac{c_0^2}{f'} - \frac{c_0^2}{f} = -\frac{h}{m_e} \cos(\varphi) \tag{161}$$

$$\frac{c_0}{f'} - \frac{c_0}{f} = -\frac{h}{m_e c^2} \cos(\varphi) \tag{162}$$

$$\lambda' - \lambda = -\frac{h}{m_e c_0^2} \cos(\varphi) \tag{163}$$

17 Ciklotron - klasično

17.1

$$\vec{F_e} = \vec{F_{centripetalna}} \tag{164}$$

$$Q\vec{v} \times \vec{B} = m\frac{v^2}{R_C} \tag{165}$$

$$QvB = m\frac{v^2}{R_C} \tag{166}$$

$$R_C = \frac{mv}{QB} \tag{167}$$

17.2

$$t_0 = \frac{2\pi R_C}{v} = \frac{2\pi m}{QB} \tag{168}$$

$$f_c = \frac{1}{t_0} \tag{169}$$

$$f_c = \frac{QB}{2\pi m} \tag{170}$$

18 Ciklotron - relativistično

18.1

$$m_0 a = QvB \tag{171}$$

$$m_0\frac{dv'}{dt} = QvB \tag{172}$$

$$m_0\frac{\gamma dv}{vt} = QvB \tag{173}$$

$$\gamma m_0 a_r = QvB \tag{174}$$

$$\gamma m_0\frac{v^2}{R_C} = QvB \tag{175}$$

$$\gamma m_0 v = QBR_C \tag{176}$$

$$R_C = \frac{\gamma m_0 v}{QB} \tag{177}$$

18.2

$$t_0 = \frac{2\pi R_C}{v} = \frac{2\pi\gamma m}{QB} \tag{178}$$

$$f_c = \frac{1}{t_0} \tag{179}$$

$$f_c = \frac{QB}{2\pi\gamma m} \tag{180}$$

19 Bohrov model atoma

20 Uporabljene enačbe

20.1 Matematika

Gradient

$$\vec{\nabla} f = \left(\frac{\partial f}{\partial x}, \frac{\partial f}{\partial y}, \frac{\partial f}{\partial z}\right) \tag{181}$$

Divergenca

$$\vec{\nabla} \cdot \vec{F} = \frac{\partial F_x}{\partial x} + \frac{\partial F_y}{\partial y} + \frac{\partial F_z}{\partial z} \tag{182}$$

Rotacija

$$\vec{\nabla} \times \vec{F} = \begin{vmatrix} \vec{i} & \vec{j} & \vec{k} \\ \frac{\partial}{\partial x} & \frac{\partial}{\partial y} & \frac{\partial}{\partial z} \\ F_x & F_y & F_z \end{vmatrix} \tag{183}$$

20.2 Maxwellove enačbe

Faradejev zakon v integralni obliki

$$\oint \vec{E} \cdot d\vec{l} = -\frac{\partial}{\partial t} \int \vec{B} \cdot d\vec{S} \tag{184}$$

Faradejev zakon v diferencialni obliki

$$\vec{\nabla} \times \vec{E} = -\frac{\partial \vec{B}}{\partial t} \tag{185}$$

Amperov zakon v integralni obliki

$$\int \vec{H} \cdot d\vec{s} = \int J d\vec{S} + \int \frac{\partial \vec{D}}{\partial t} \cdot d\vec{S} \tag{186}$$

Amperov zakon v diferencialni obliki

$$\vec{\nabla} \times \vec{H} = \vec{J} + \frac{\partial \vec{D}}{\partial t} \tag{187}$$

20.3 Optika

Enačba preslikave

$$\frac{1}{f} = \frac{1}{a} + \frac{1}{b} \tag{188}$$

Enačba leče

$$\frac{1}{f} = (\frac{n_2}{n_1} - 1)(\frac{1}{R_1} + \frac{1}{R_2}); \tag{189}$$

$R > 0$, če je središče krivulje na nasprotni strani leče, kot površina, ki jo opisuje

Skupek leč

$$\frac{1}{f} = \frac{1}{f_1} + \frac{1}{f_2} - \frac{d}{f_1 f_2} \tag{190}$$

Lomni zakon (3)

$$n_1 \sin(\alpha) = n_2 \sin(\beta) \tag{191}$$

Mikroskop (5)

$$M = \frac{e x_0}{f_{ok} f_{ob}} \tag{192}$$

Daljnogled (6)

$$M = \frac{a f_{ob}}{f_{ok}(a - f_{ob})} \tag{193}$$

20.4 Interferenca

$n_0 > n_1 > n_2$ $\qquad$ $n_0 > n_1 < n_2$

$n_0 < n_1 < n_2$ $\qquad$ $n_0 < n_1 > n_2$

$$2dn\,\text{cos}(\beta) =$$

$$\begin{cases} 2N\lambda & \text{za konstruktivno interferenco} \\ \frac{(2N+1)}{2}\lambda & \text{za destruktivno interferenco} \end{cases} \qquad \begin{cases} \frac{(2N+1)}{2}\lambda & \text{za konstruktivno interferenco} \\ 2N\lambda & \text{za destruktivno interferenco} \end{cases}$$

20.5 Moderna fizika

Lorentzova transformacija

$$x' = \gamma(x - vt) \qquad x = \gamma(x' + vt') \tag{194}$$

$$y' = y \qquad y = y' \tag{195}$$

$$z' = z \qquad z = z' \tag{196}$$

$$t' = \gamma(t - \frac{v}{c^2}x) \qquad t = \gamma(t' + \frac{v}{c^2}x') \tag{197}$$

Lorentzov faktor

$$\gamma = \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}} \tag{198}$$

Galilejeva transformacija

$$x' = x - vt \qquad x = x' + vt' \tag{199}$$

$$y' = y \qquad y = y' \tag{200}$$

$$z' = z \qquad z = z' \tag{201}$$

$$t' = t \qquad t = t' \tag{202}$$

Planckov zakon

$$\frac{dj}{d\lambda} = \frac{2\pi hc^2}{\lambda^5\left(e^{\frac{hc}{\lambda k_B T}} - 1\right)} \tag{203}$$