Optoelectronică, structuri şi tehnologii

Curs 2

2013/2014

Orar

- Curs
  - marti, 17-20, P4
  - 2C ⇨ 3C
    - 14*2/3≈9.33
    - 9÷10 C

Lumina ca undă electromagnetică

Capitolul 2

Ecuatiile lui Maxwell

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

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

$$\nabla \cdot D = \rho$$

$$\nabla \cdot B = 0$$

$$\nabla \cdot J = -\frac{\partial \rho}{\partial t}$$

- Ecuatii constitutive

$$D = \varepsilon \cdot E$$

$$B = \mu \cdot H$$

$$J = \sigma \cdot E$$

- In vid

$$\mu_0 = 4\pi \times 10^{-7} \; H/m$$

$$\varepsilon_0 = 8{,}854 \times 10^{-12} \; F/m$$

$$c_0 = \frac{1}{\sqrt{\varepsilon_0 \cdot \mu_0}} = 2{,}99790 \cdot 10^8 \; m/s$$

Câmpuri electromagnetic cu variaţie armonică în timp

$$X = X_0 e^{j\cdot\omega\cdot t} \quad \frac{\partial X}{\partial t} = j\cdot\omega\cdot X \quad g(\omega) = \int_{-\infty}^{\infty} f(t)\cdot e^{-j\omega t}dt \quad f(t) = \int_{-\infty}^{\infty} g(\omega)\cdot e^{j\omega t}d\omega$$

- Simplificarea ecuatiilor lui Maxwell

$$\nabla^2 E + \omega^2 \varepsilon\mu E = j\omega\mu J + \frac{1}{\varepsilon}\nabla\rho$$

$$\nabla^2 H + \omega^2 \varepsilon\mu H = -\nabla\times J$$

$$\nabla\cdot E = \frac{\rho}{\varepsilon}$$

$$\nabla\cdot H = 0$$

- Ecuaţiile Helmoltz sau ecuaţiile de propagare

Mediu lipsit de sarcini electrice

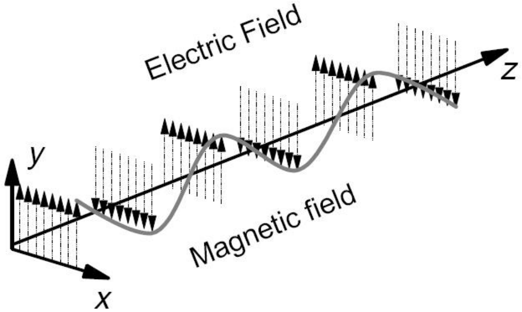
$$\nabla^2 E - \gamma^2 E = 0$$

$$\nabla^2 H - \gamma^2 H = 0$$

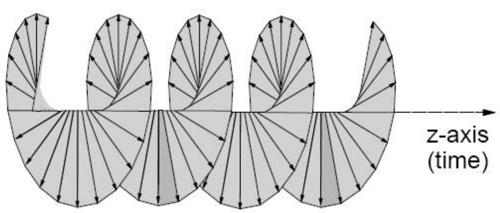
$$\gamma^2 = -\omega^2\varepsilon\mu + j\omega\mu\sigma$$

γ – Constanta de propagare

Solutia ecuatiilor de propagare



Propagare



Polarizare circulara

Camp electric dupa directia Oy, propagare dupa directia Oz

$$E_y = E_+ e^{-\gamma \cdot z} + E_- e^{\gamma \cdot z}$$

$$\gamma = \sqrt{-\omega^2 \varepsilon\mu + j\omega\mu\sigma} = \alpha + j \cdot \beta$$

Exista numai unda progresiva E_+ => A

$$E_y = Ae^{-(\alpha + j \cdot \beta) \cdot z}$$

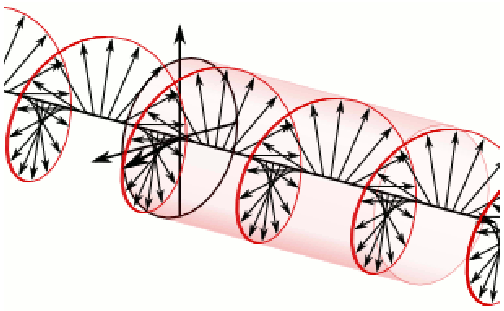
Camp armonic

$$E_y = A \cdot e^{-\alpha \cdot z} \cdot e^{j(\omega \cdot t - \beta \cdot z)}$$

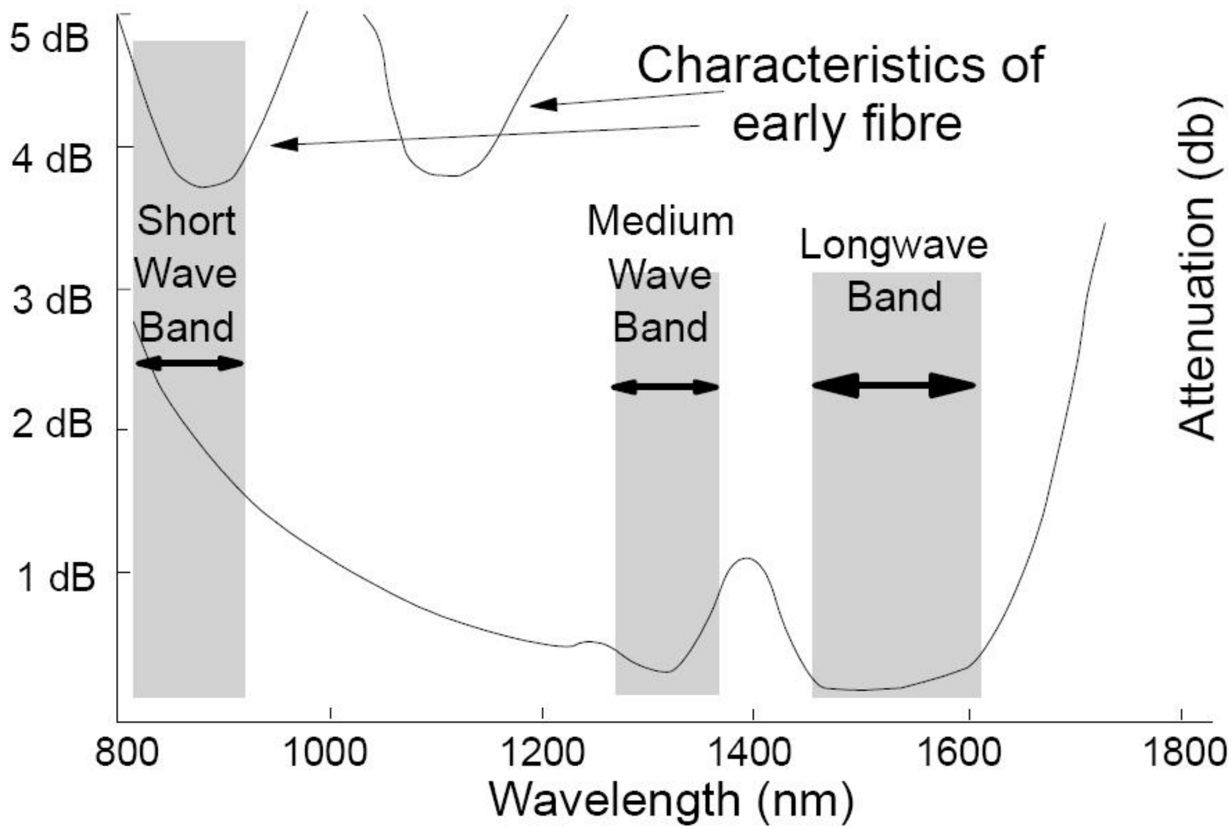
Amplitudine

Atenuare

Propagare (variatie in timp si spatiu)



Atenuarea pe 1 km in SiO_2



Atenuare

$$E_y(z_1) = Ct \cdot e^{-\alpha \cdot z_1} \cdot e^{j(\omega t - \beta \cdot z_1)} \qquad E_y(z_2) = Ct \cdot e^{-\alpha \cdot z_2} \cdot e^{j(\omega t - \beta \cdot z_2)}$$

$$W, P \sim \int E^2$$

$$A = \frac{P_2}{P_1} = \frac{Ct^2 \cdot e^{-2\alpha \cdot z_2}}{Ct^2 \cdot e^{-2\alpha \cdot z_1}} = e^{-2\alpha \cdot (z_2 - z_1)}$$

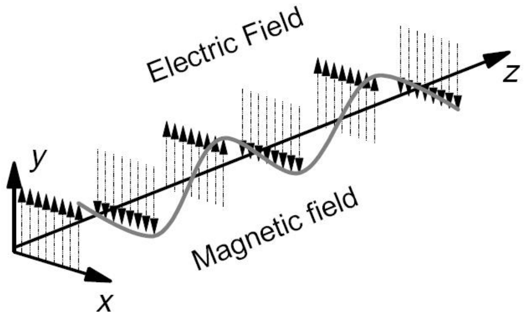
$$A[dB] = 10 \log_{10} \frac{P_2}{P_1} = 10 \log_{10} \left[e^{-2\alpha \cdot (z_2 - z_1)} \right]$$

$$A[dB] = -20 \cdot \alpha \cdot (z_2 - z_1) \log_{10} e = -8.686 \cdot \alpha \cdot (z_2 - z_1)$$

$$A / L[dB/km] = -8.686 \cdot \alpha < 0$$

- Atenuarea se exprima de obicei in **dB/km**
  - de obicei valori pozitive
  - semnul = **implicit**

Parametri de propagare



$$\nabla \times E = -j\omega\mu \cdot H$$

$$H_x = \frac{j\gamma \cdot E_y}{\omega\mu}$$

Mediu fara pierderi, $\sigma = 0$ $\quad \gamma = j\omega \cdot \sqrt{\varepsilon\mu}$

$$\eta = \frac{E_y}{H_x} = \sqrt{\frac{\mu}{\varepsilon}}$$ Impedanta intrinseca a mediului

$E_y = A \cdot e^{-\alpha \cdot z} \cdot e^{j(\omega \cdot t - \beta \cdot z)}$ punctele de faza constanta: $(\omega \cdot t - \beta \cdot z) = \text{const}$

Viteza de faza $\quad v = \frac{dz}{dt} = \frac{\omega}{\beta} = \frac{1}{\sqrt{\varepsilon\mu}}$

Viteza de grup $\quad v_g = \frac{dz}{dt} = \frac{d\omega}{d\beta}$ in medii dispersive unde $\beta = \beta(\omega)$

Parametri de propagare

- In vid

$$\eta_0 = \sqrt{\frac{\mu_0}{\varepsilon_0}} = 377\Omega \qquad v = v_g = c_0 \qquad c_0 = \frac{1}{\sqrt{\varepsilon_0 \cdot \mu_0}} = 2{,}99790 \cdot 10^8\ m/s$$

$$\lambda_0 = \frac{2\pi}{\beta} = \frac{c_0}{f} \qquad T = \frac{2\pi}{\omega} = \frac{1}{f}$$

Periodicitate in spatiu   Periodicitate in timp

- In mediu nedispersiv ε_r

$$c = \frac{1}{\sqrt{\varepsilon \cdot \mu_0}} = \frac{1}{\sqrt{\varepsilon_0 \varepsilon_r \cdot \mu_0}} = \frac{c_0}{\sqrt{\varepsilon_r}}$$

$n = \sqrt{\varepsilon_r}$ Indice de refractie al mediului $c = \frac{c_0}{n}$

$$T = \frac{2\pi}{\omega} = \frac{1}{f} \qquad \lambda = \frac{2\pi}{\beta} = \frac{c}{f} \qquad \lambda = \frac{c_0}{n \cdot f} = \frac{\lambda_0}{n}$$

Parametri, dependenta de mediu

$$\eta_0 = \sqrt{\frac{\mu_0}{\varepsilon_0}} = 377\Omega$$

$$c_0 = \frac{1}{\sqrt{\varepsilon_0 \cdot \mu_0}} = 2{,}99790 \cdot 10^8 \ m/s$$

$n = 1$

$$T = \frac{2\pi}{\omega} = \frac{1}{f}$$

$$\lambda_0 = \frac{2\pi}{\beta} = \frac{c_0}{f}$$

$$\eta = \frac{\eta_0}{n}$$

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

$n = \sqrt{\varepsilon_r}$

$$T = \frac{2\pi}{\omega} = \frac{1}{f}$$

$$\lambda = \frac{c_0}{n \cdot f} = \frac{\lambda_0}{n}$$

ITU G.692

"the allowed channel frequencies are based on a 50 GHz grid with the reference frequency at 193.10 THz"

SI

"a source that emits monochromatic radiation of frequency $540 \cdot 10^{12}$ Hz"

Dispersia

- In medii dispersive β = β(ω), n = n(ω)

$$\frac{d\beta}{d\omega}=\frac{d}{d\omega}\left(\frac{\omega\cdot n}{c}\right)=\frac{1}{c}\left(n+\omega\frac{dn}{d\omega}\right)$$

$$\frac{d\beta}{d\omega}=-\frac{\lambda}{\omega}\cdot\frac{d\beta}{d\lambda}=\frac{1}{c}\left(n-\lambda\frac{dn}{d\lambda}\right)=\tau \quad (s/m)$$

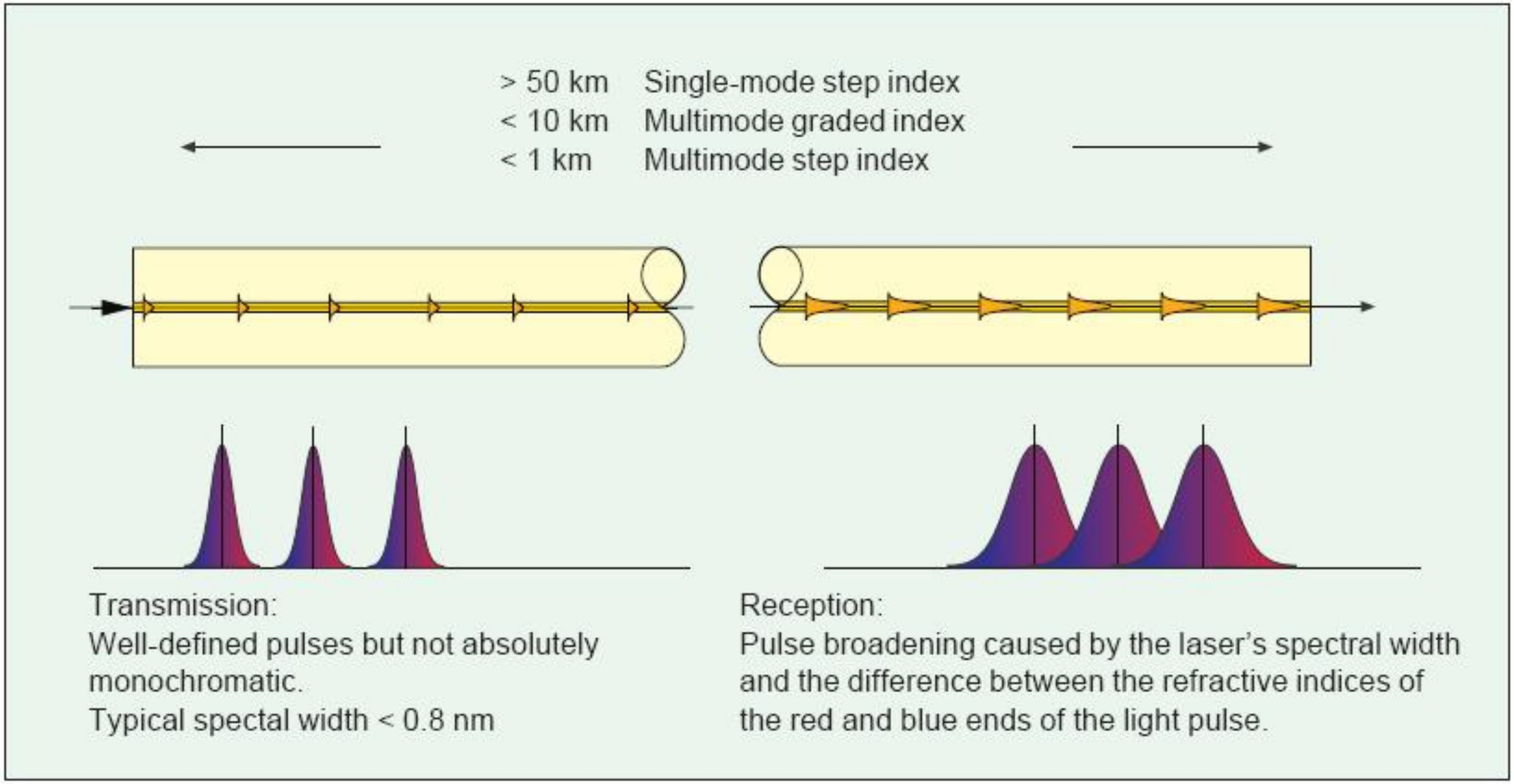
$$D=\frac{d\tau}{d\lambda}=\frac{1}{c}\left(\frac{dn}{d\lambda}-\lambda\frac{d^2n}{d\lambda^2}-\frac{dn}{d\lambda}\right)=-\frac{\lambda}{c}\frac{d^2n}{d\lambda^2} \quad (s/m^2)$$

- Dispersia se exprima de obicei in **ps/nm/km** si permite aflarea intarzierilor aparute intre "moduri" (latirea impulsurilor) pentru o anumita latime spectrala si o anumita distanta parcursa

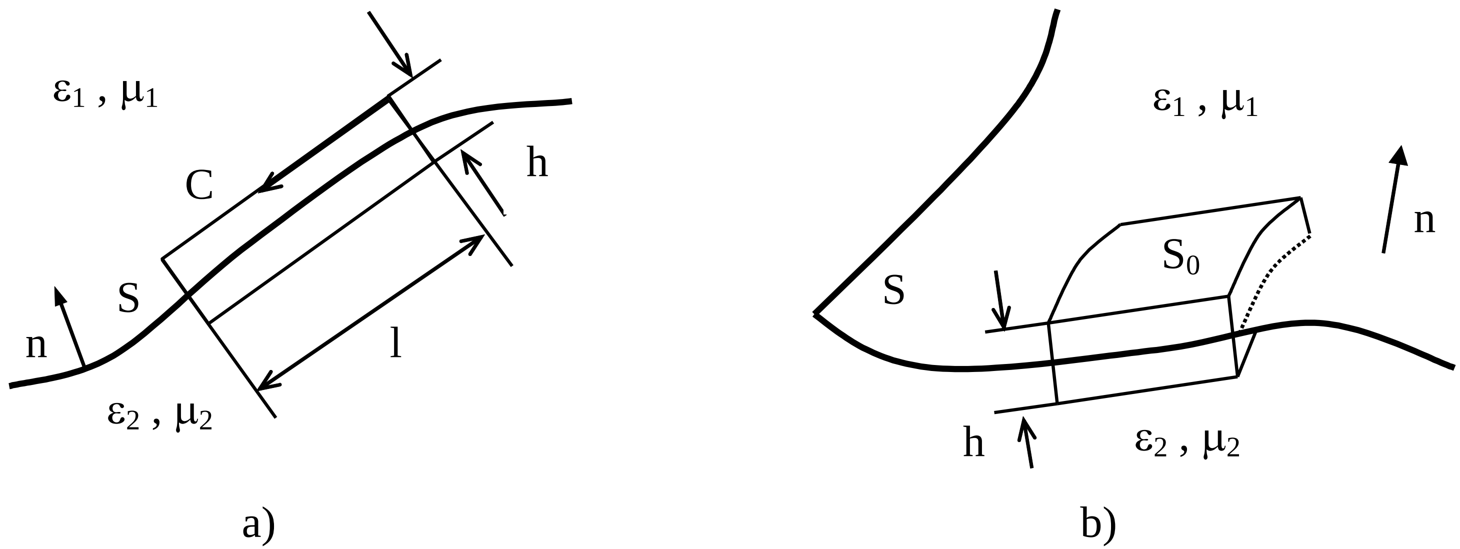
$$\Delta\tau = D\cdot\Delta\lambda\cdot L$$

Dispersie

$$n = n(\omega) \rightarrow \mathbf{c = c(\omega)}$$



Condiţii la limita de separaţie între două medii

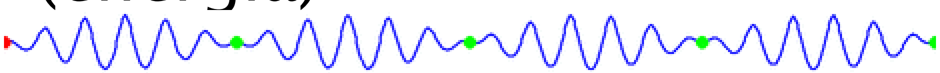


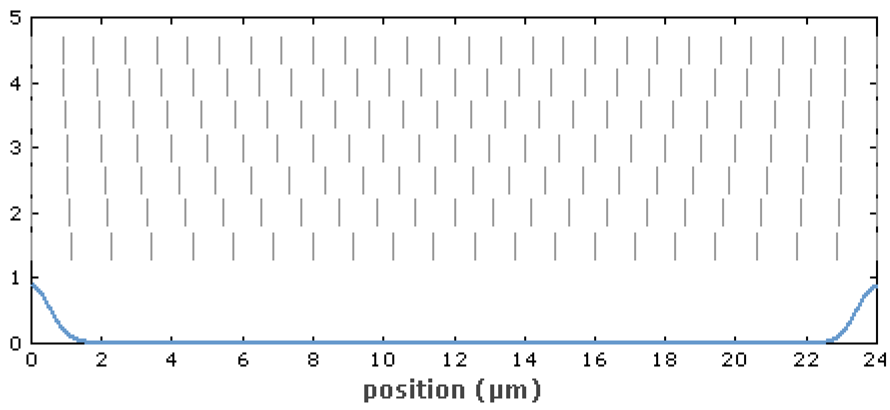
$$n \times (E_1 - E_2) = 0 \qquad n \cdot (D_1 - D_2) = \rho_S$$

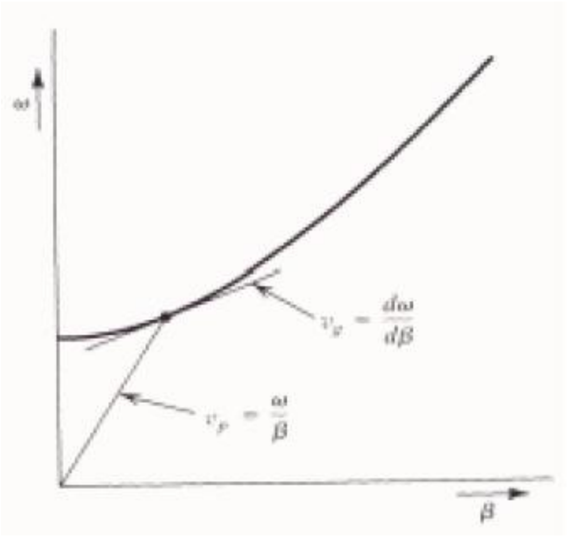
$$n \times (H_1 - H_2) = J_S \qquad n \cdot (B_1 - B_2) = 0$$

Viteze de grup si faza

- Viteza de faza – viteza virtuala cu care circula punctul cu o anumita faza
- Viteza de grup – viteza cu care circula informatia (energia)



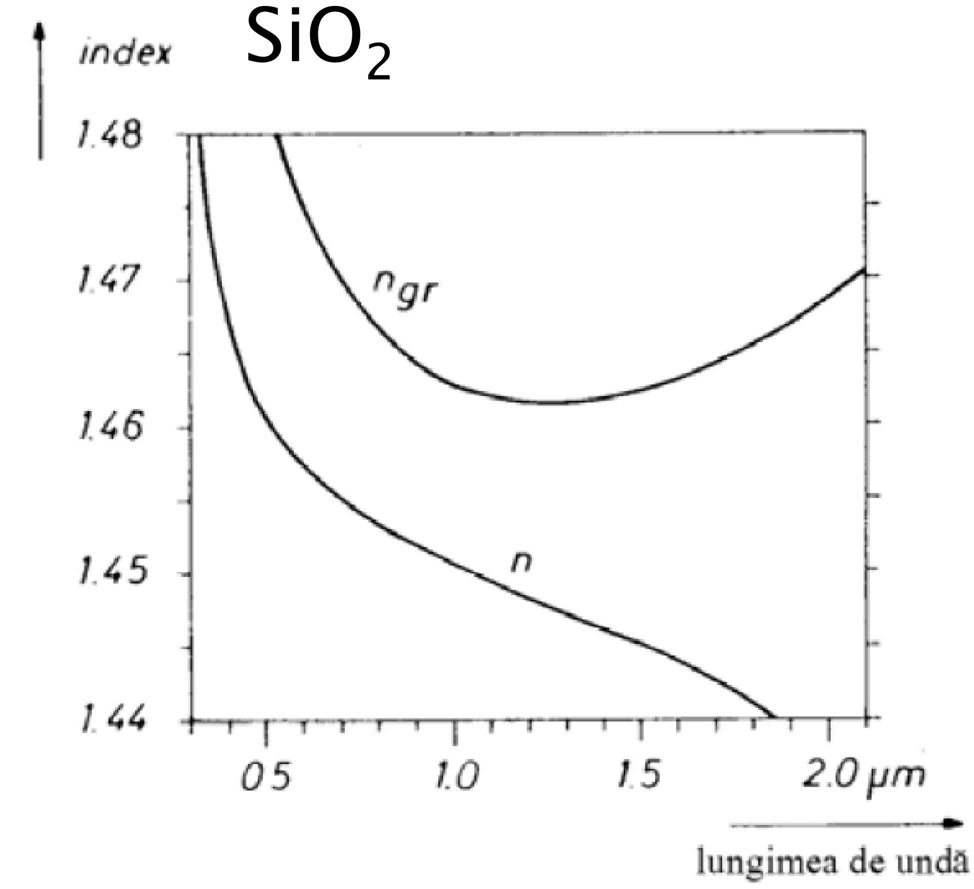




Dispersie normala

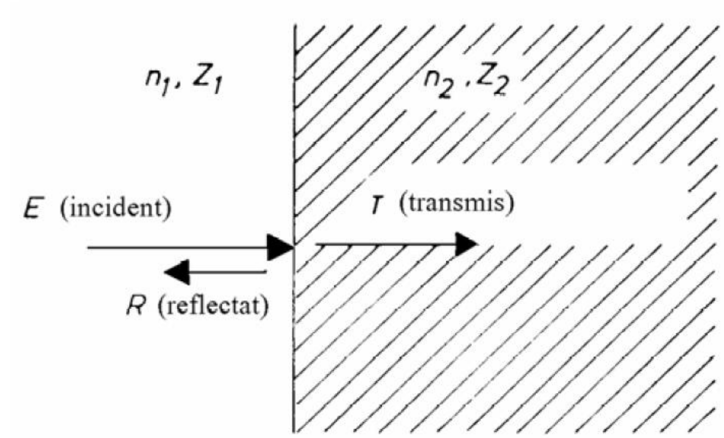
$$n_{gr} = n - \lambda \frac{dn}{d\lambda}$$

$$D = \frac{d\tau}{d\lambda} = \frac{1}{c} \cdot \frac{d n_{gr}}{d\lambda}$$



Transmisia puterii intre medii

- incidenta normala
- reflexia in amplitudine



$$Z = \frac{Z_0}{n} \qquad \Gamma = \frac{Z_2 - Z_1}{Z_2 + Z_1} = \frac{n_1 - n_2}{n_1 + n_2}$$

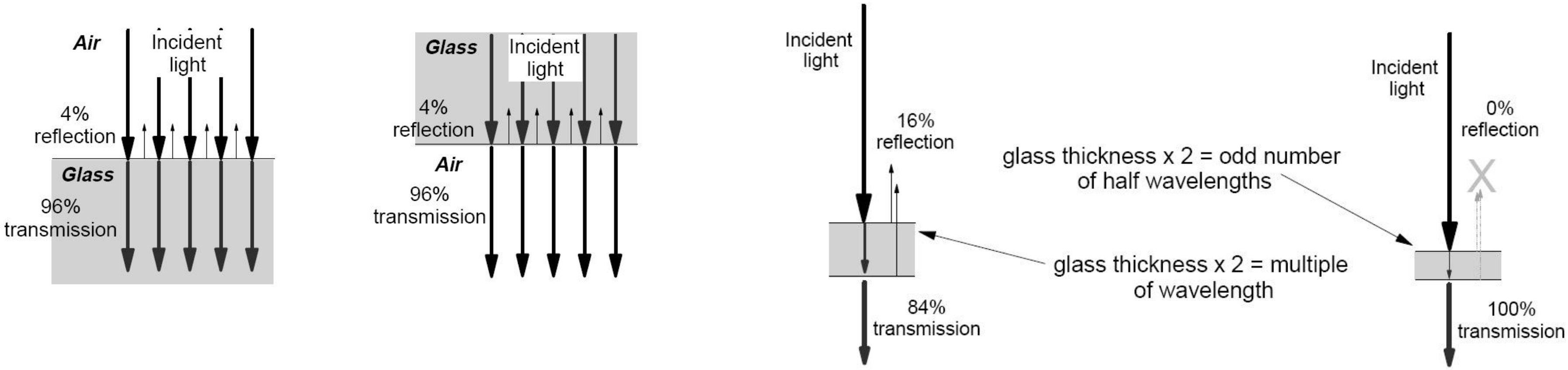
- densitatea de putere proportionala cu patratul amplitudinii câmpului

$$r = \left(\frac{n_1 - n_2}{n_1 + n_2}\right)^2 \qquad t = \left(\frac{2n_1}{n_1 + n_2}\right)^2$$

- interfata aer-sticla ($n_1 = 1$, $n_2 = 1.5$)

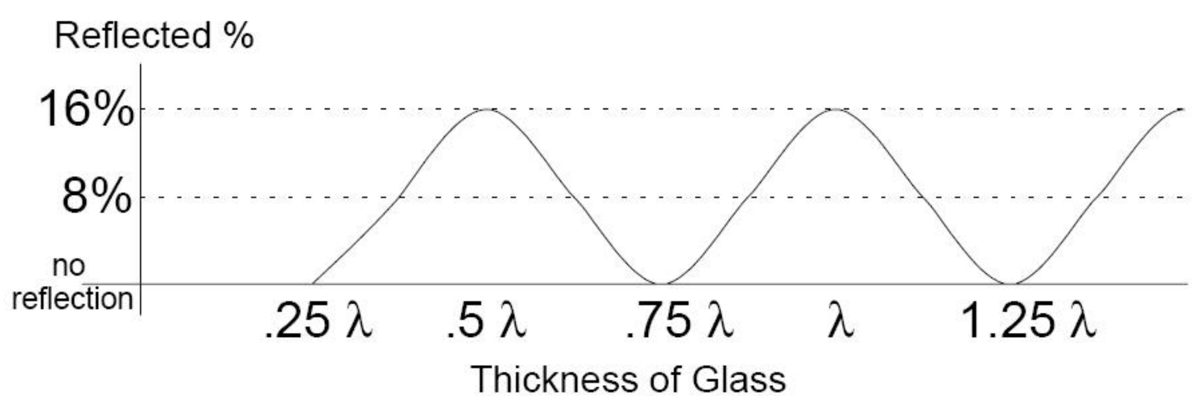
$$r = 0.04 = 4\%$$

Transmisia printr-o lamela



$$\Gamma = \frac{1.5-1}{1.5+1} = 0.2; \quad r = \Gamma^2 = 0.04 = 4\% \quad \Gamma_{max} = 0.2 + 0.2; \quad r_{max} = \Gamma_{max}^2 = 0.16 = 16\%$$

- apare interferenta intre diversele unde reflectate
- se aduna campurile nu puterile
- lamele antireflexive



Transmisia puterii intre medii

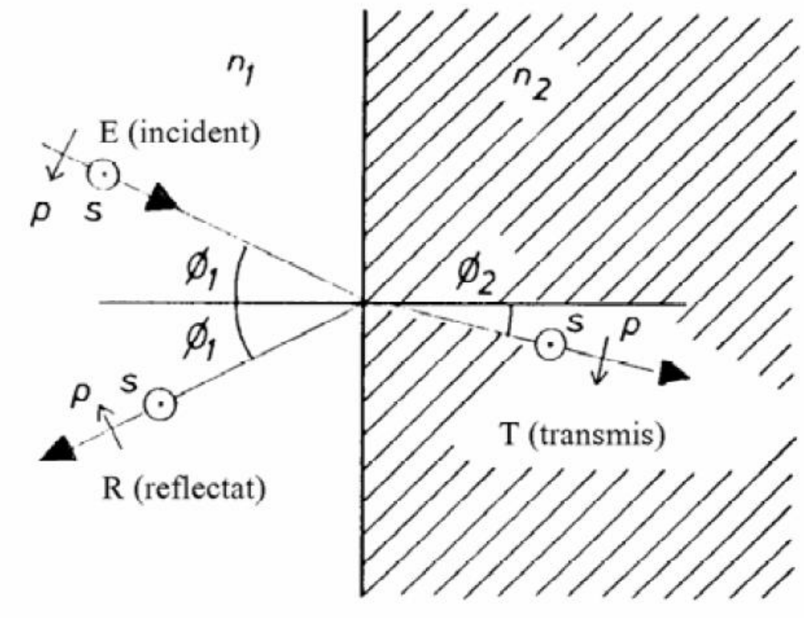
- incidenta oblica
- reflexiile in amplitudine a campului:

$$r_s = -\frac{\sin(\phi_1 - \phi_2)}{\sin(\phi_1 + \phi_2)}$$

$$r_p = \frac{\tan(\phi_1 - \phi_2)}{\tan(\phi_1 + \phi_2)}$$

$$t_s = \frac{2\sin\phi_2 \cos\phi_1}{\sin(\phi_1 + \phi_2)}$$

$$t_p = \frac{2\sin\phi_2 \cos\phi_1}{\sin(\phi_1 + \phi_2)\cos(\phi_1 - \phi_2)}$$



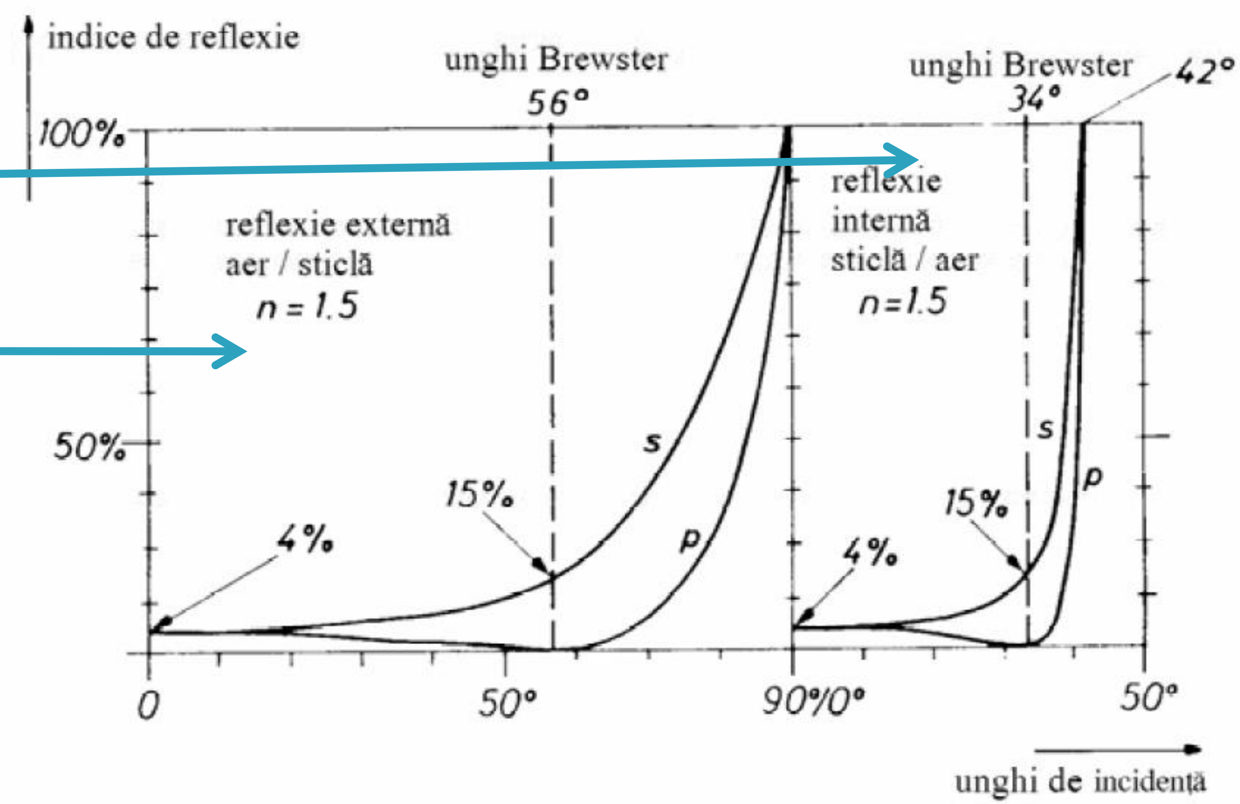
Unghi Brewster

- transmisia totala a polarizarii p
- lumina reflectata este total polarizata (s)

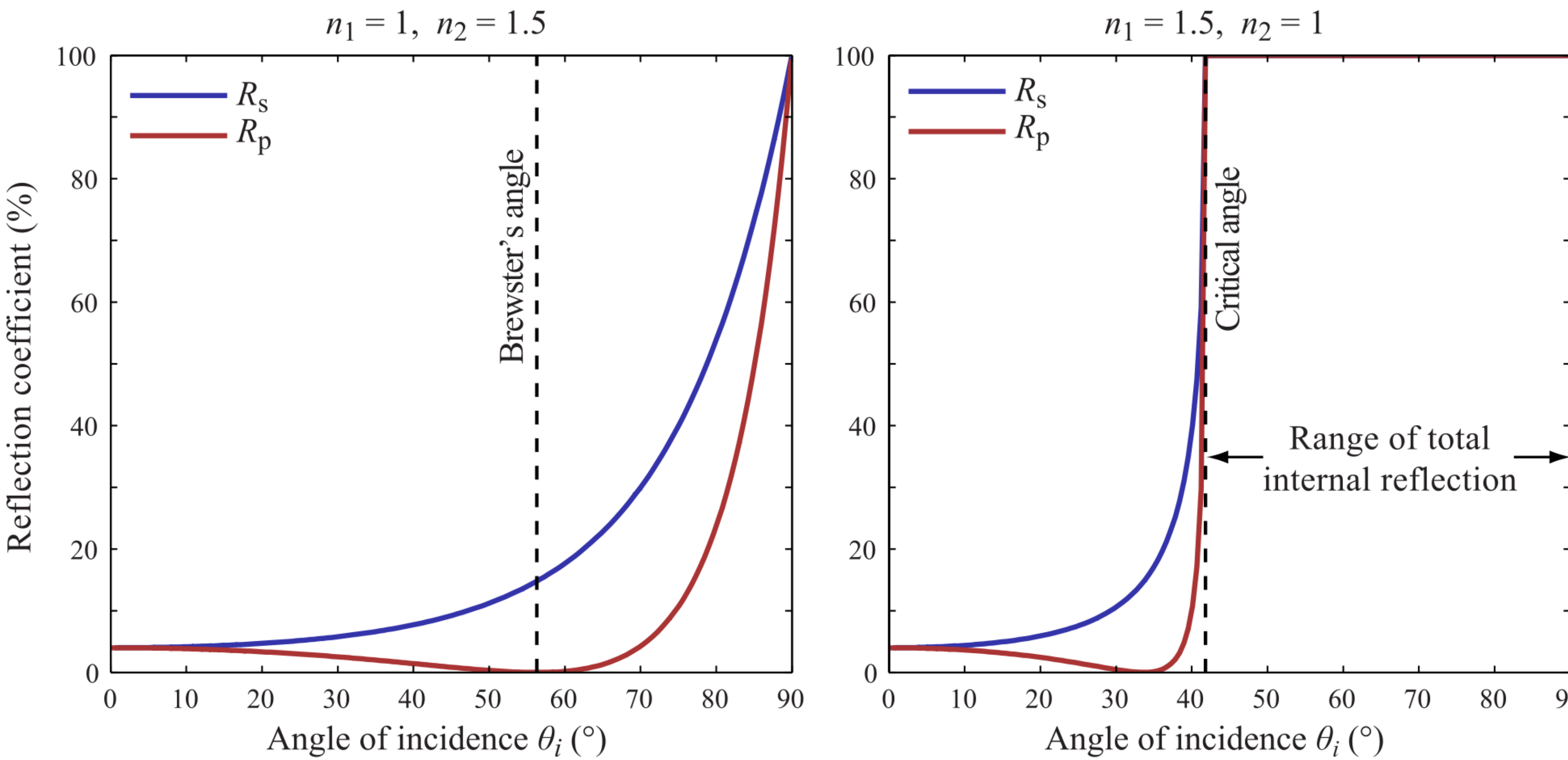
$$\phi_B = \arctan\left(\frac{n_2}{n_1}\right)$$

$$\phi_B = 34^\circ$$

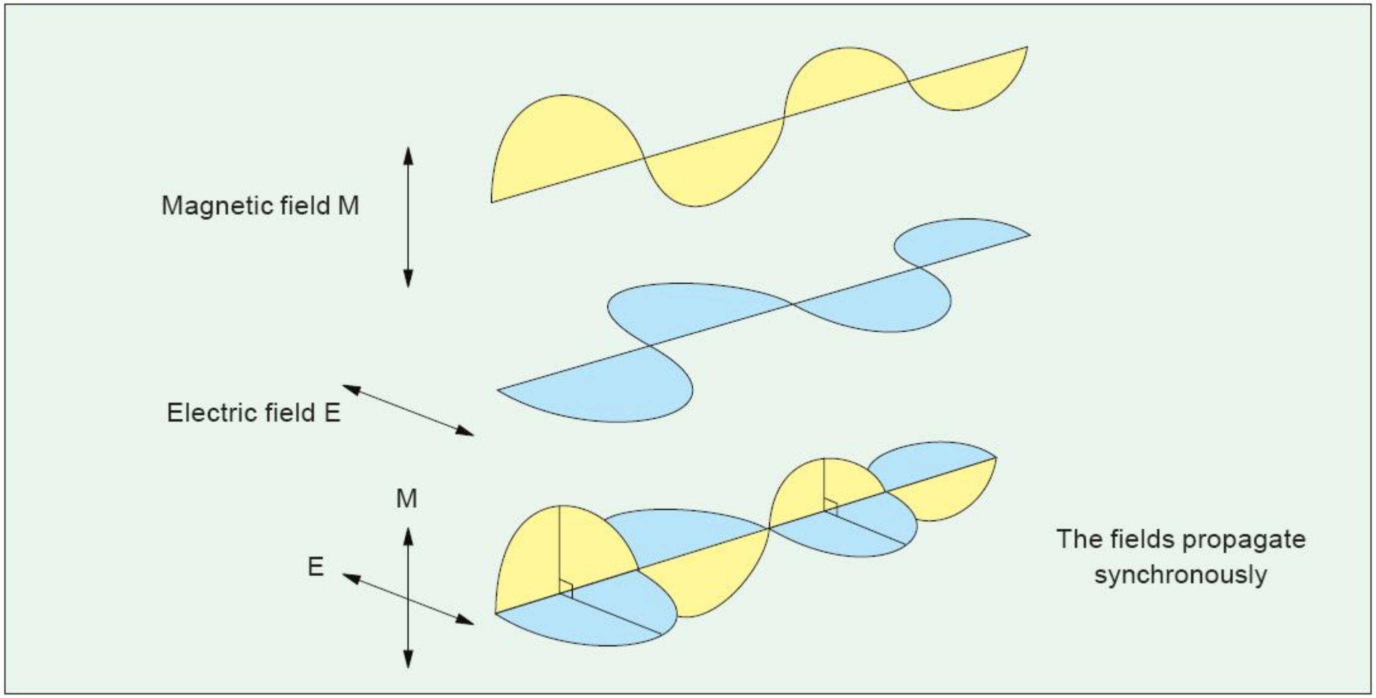
$$\phi_B = 56^\circ$$

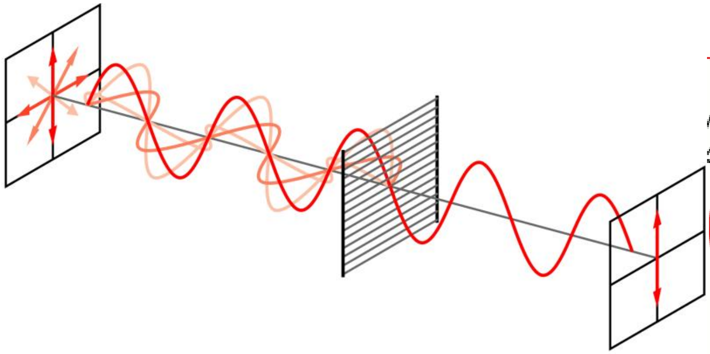


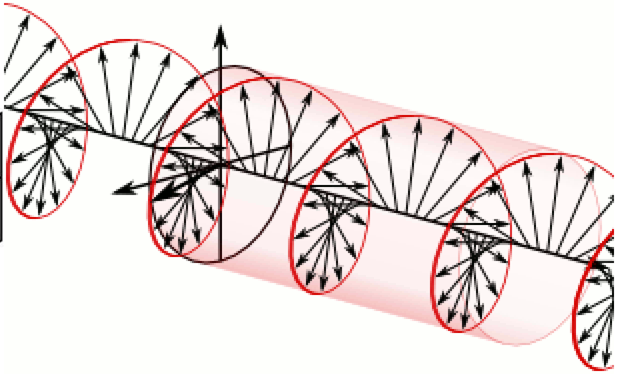
Unghi Brewster



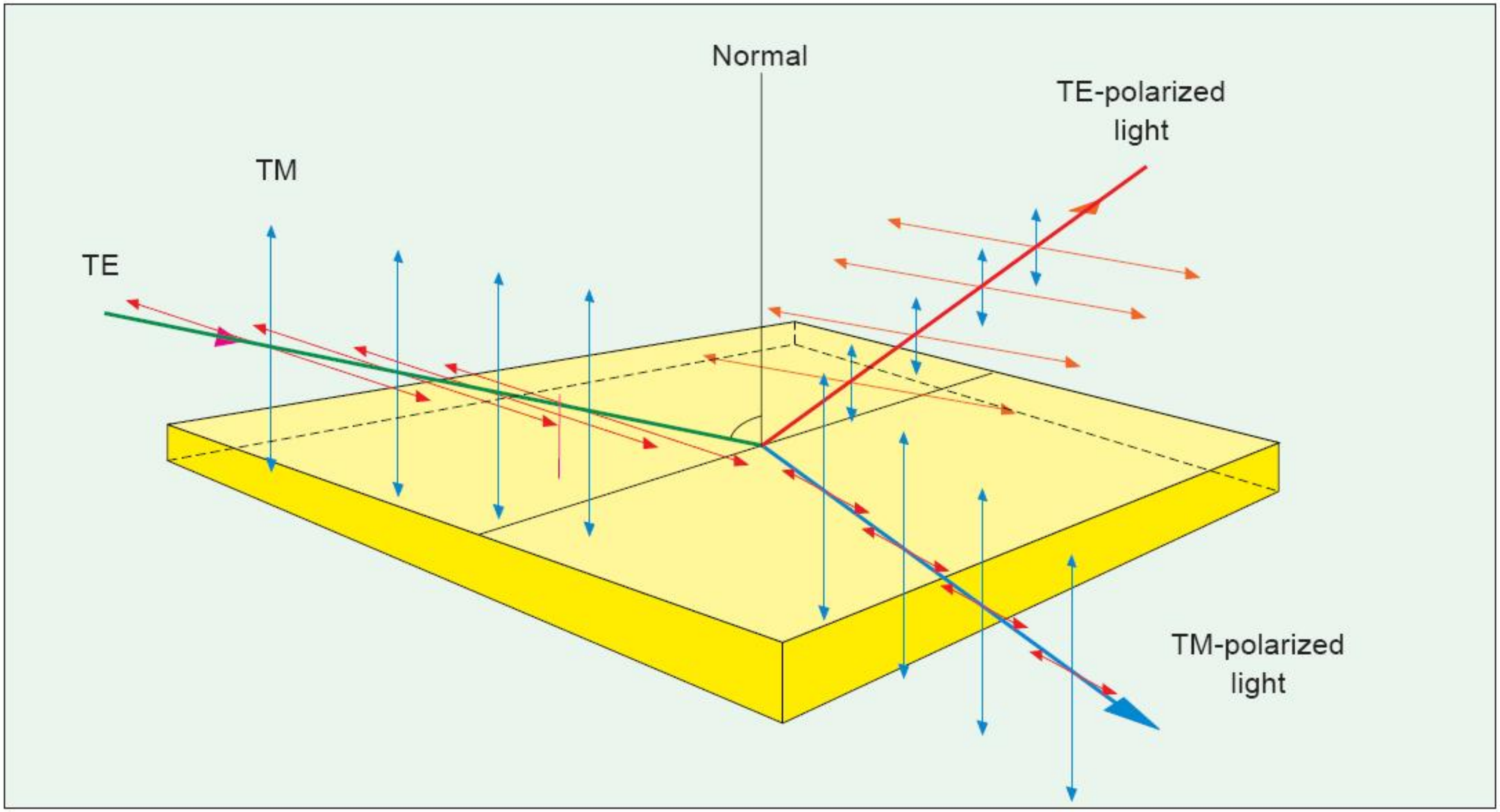
Polarizarea luminii



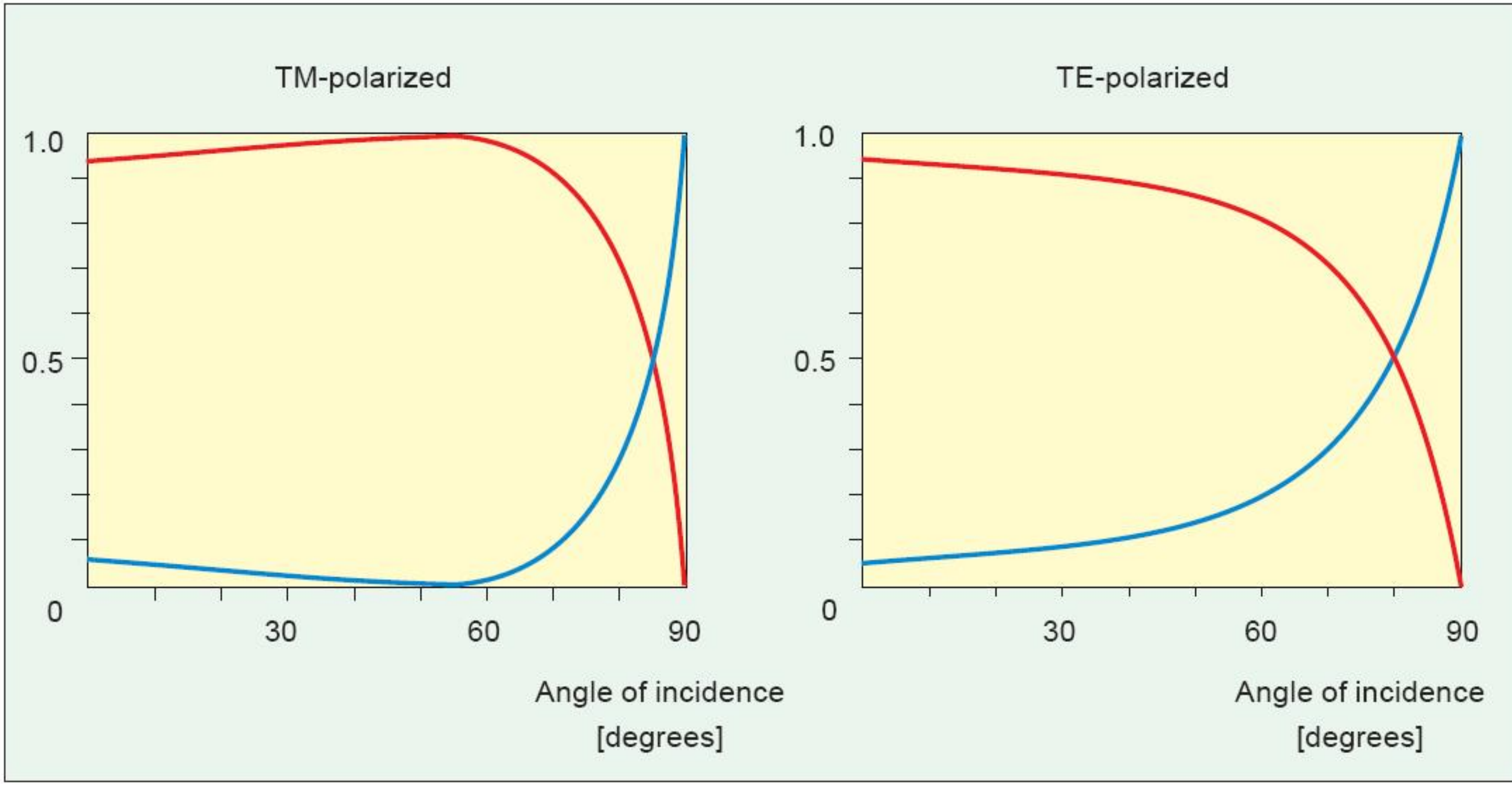




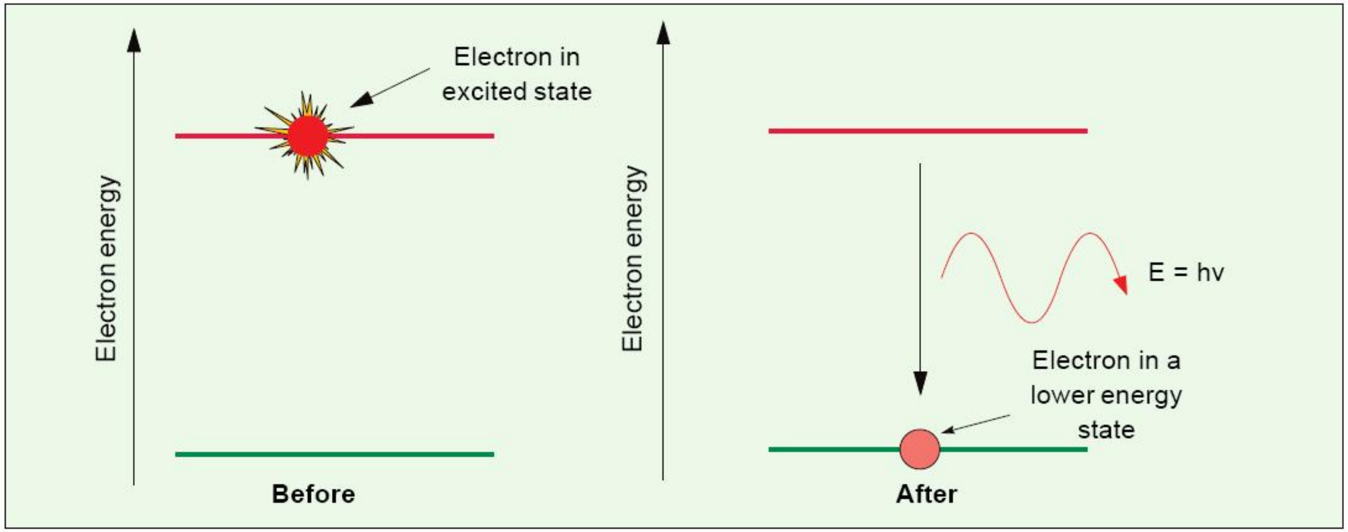
Polarizarea luminii



Polarizarea luminii

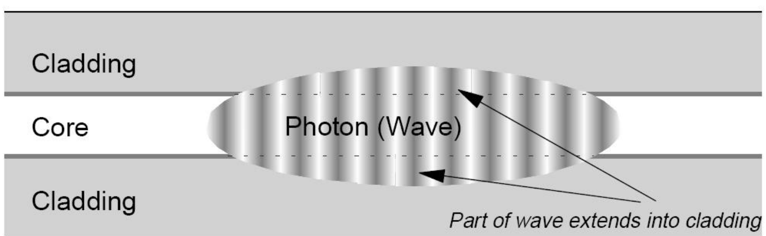


Model cuantic – foton



$$E_g = h\nu; \quad \lambda = \frac{hc}{E_g}; \quad \lambda[\mu m] = \frac{1.240}{E_g[eV]}$$

- h constanta lui Plank $6.62 \cdot 10^{-32}\ Ws^2$
- c viteza luminii in vid $2.998 \cdot 10^{8} m/s$

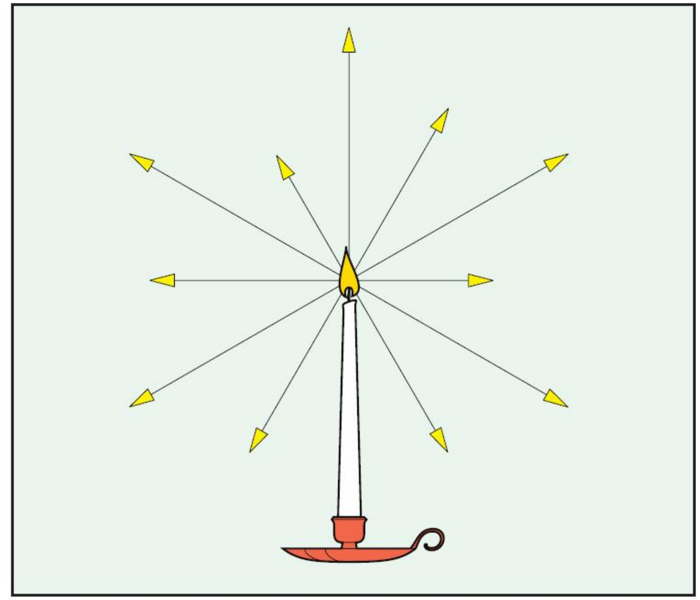


Optică geometrică

Capitolul 3

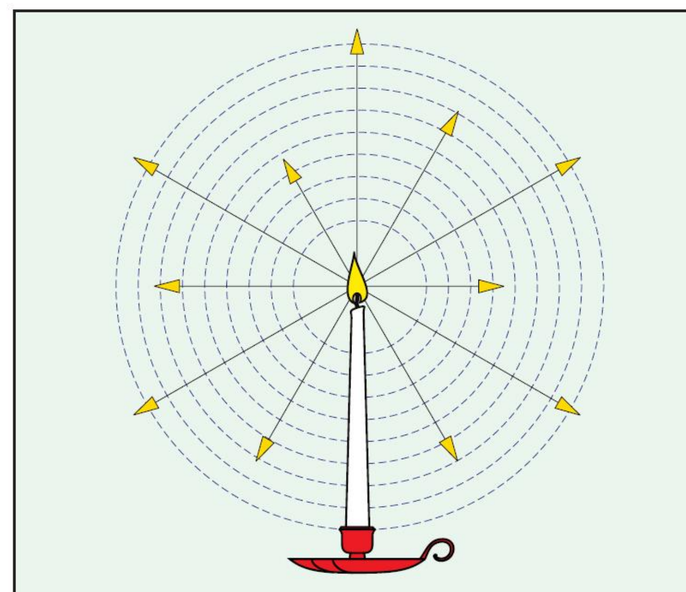
Raze de lumina

- Lumina este constituita din raze care se propaga in linie dreapta in medii omogene
- Sursa omnidirectionala: emite similar in toate directiile



- Energia luminoasa descreste invers proportional cu patratul distantei fata de sursa (energia se imparte uniform pe suprafata intregii sfere)

$$P = \frac{P_0}{r^2}$$

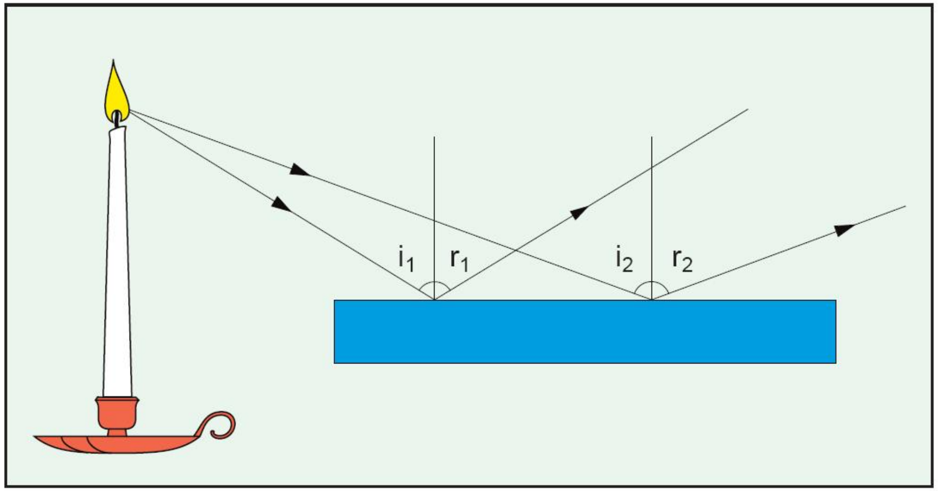


Reflexia luminii

- la suprafata de separatie dintre doua medii, (o parte din) lumina se intoarce in mediul de incidenta
- unghiul facut de raza incidenta cu normala (ϕ_i) este egal cu unghiul facut de raza reflectata cu normala (ϕ_r)

- Legea reflexiei

$$\phi_i = \phi_r$$

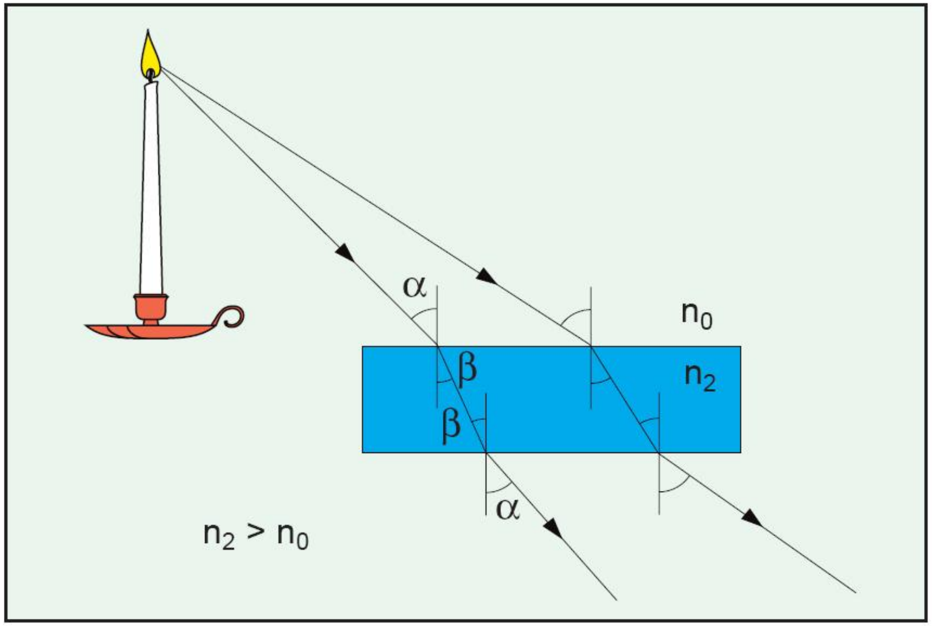


Refractia luminii

- la suprafata de separatie dintre doua medii, (o parte din) lumina se (poate) propaga in mediul de transmisie sub un unghi diferit de unghiul incident
- la trecerea in medii mai “dense” (optic) lumina se apropie de normala
- Legea lui Snell (a refractiei)

$$n_1 \cdot \sin \phi_i = n_2 \cdot \sin \phi_R$$

ϕ_i – unghi incident
ϕ_R – unghi de refractie



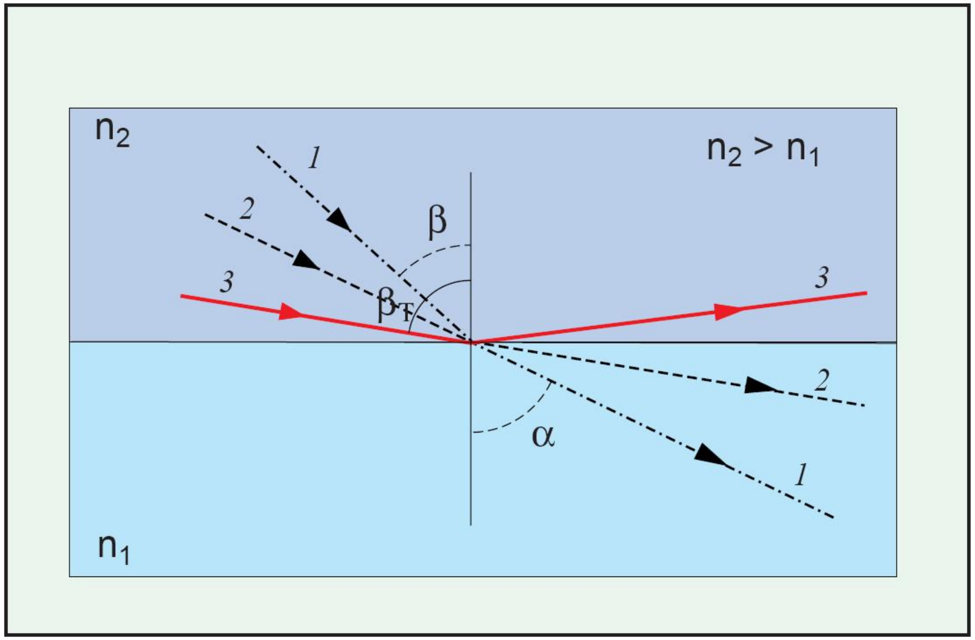
Reflexia totala

- Apare numai când lumina se propaga dintr-un mediu mai dens optic intr-un mediu mai putin dens
- La intersectia luminii cu suprafata de separatie a doua medii se intalnesc in general raze reflectate si raze refractate
- Pentru un unghi de incidenta numit unghi critic, raza refractata se obtine in lungul suprafetei de separatie
- Pentru orice unghi mai mare decât unghiul critic exista numai raza reflectata

$$n_1 > n_2; \quad \phi_R = 90°$$

$$n_1 \cdot \sin \phi_C = n_2$$

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

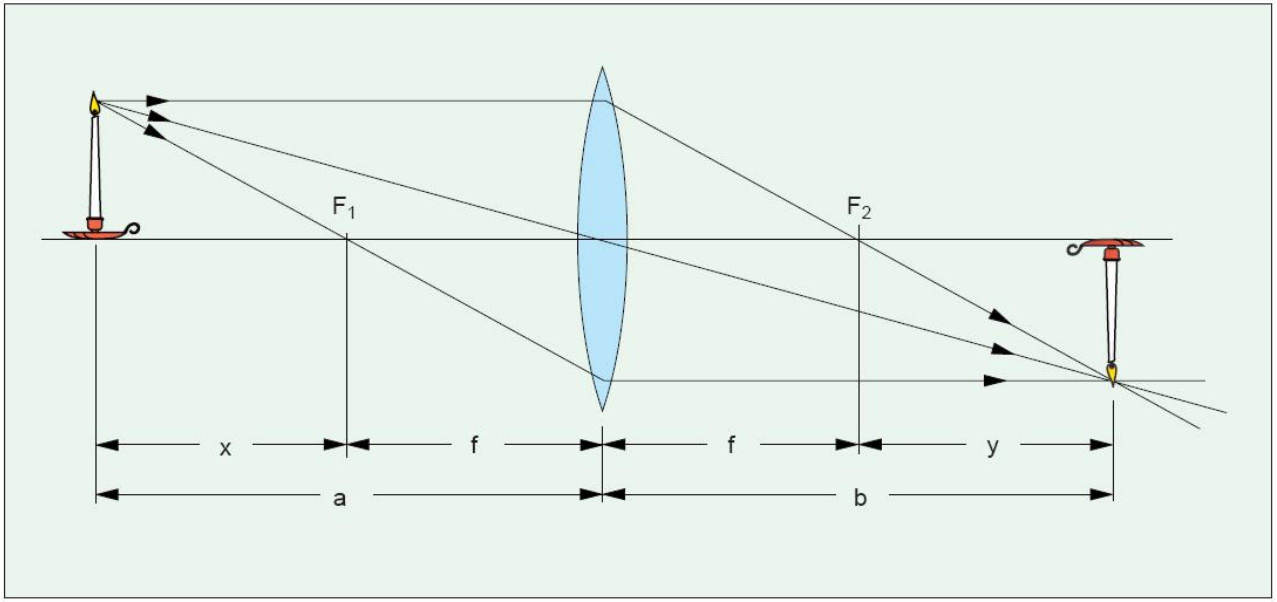


Lentile

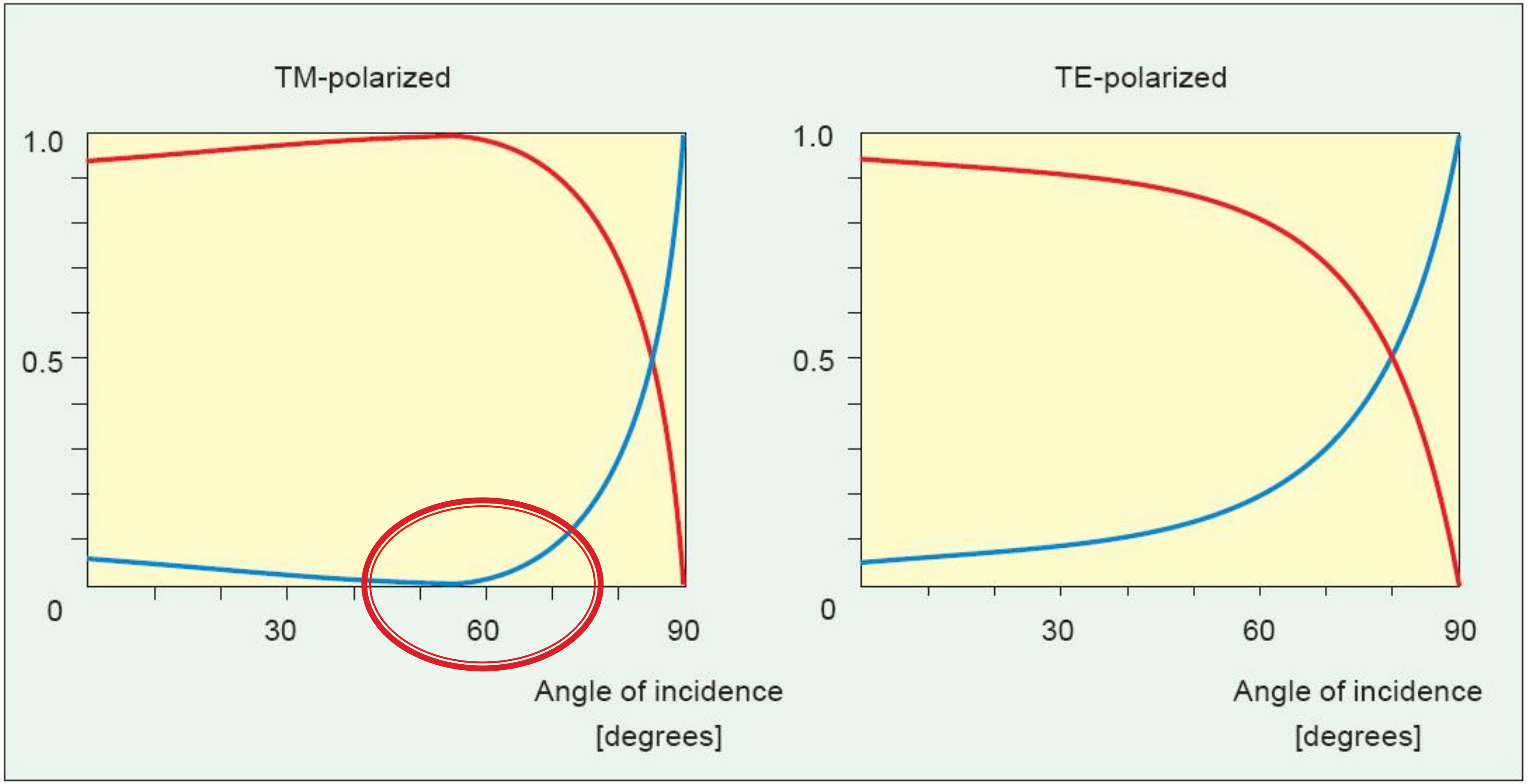
- Razele de lumina paralele sunt concentrate intr-un punct numit focar, aflat la distanta focala de planul lentilei
- O sursa omnidirectionala pozitionata in focar va permite obtinerea unui fascicul paralel

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

$$x \cdot y = f^2$$



Polarizarea luminii



Transmisia puterii intre medii

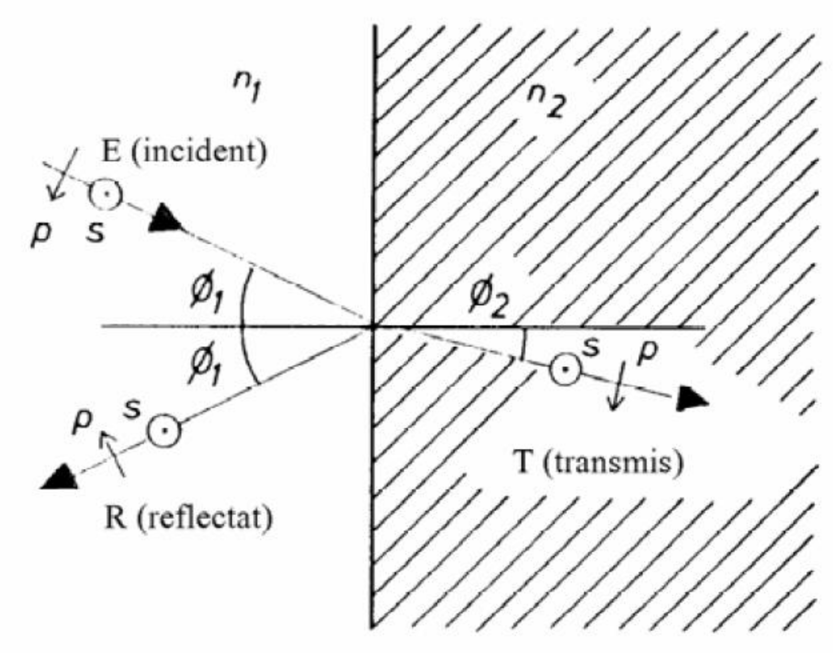
- incidenta oblica
- reflexiile in amplitudine a campului:

$$r_s = -\frac{\sin(\phi_1 - \phi_2)}{\sin(\phi_1 + \phi_2)}$$

$$r_p = \frac{\tan(\phi_1 - \phi_2)}{\tan(\phi_1 + \phi_2)}$$

$$t_s = \frac{2\sin\phi_2 \cos\phi_1}{\sin(\phi_1 + \phi_2)}$$

$$t_p = \frac{2\sin\phi_2 \cos\phi_1}{\sin(\phi_1 + \phi_2)\cos(\phi_1 - \phi_2)}$$



Unghi Brewster

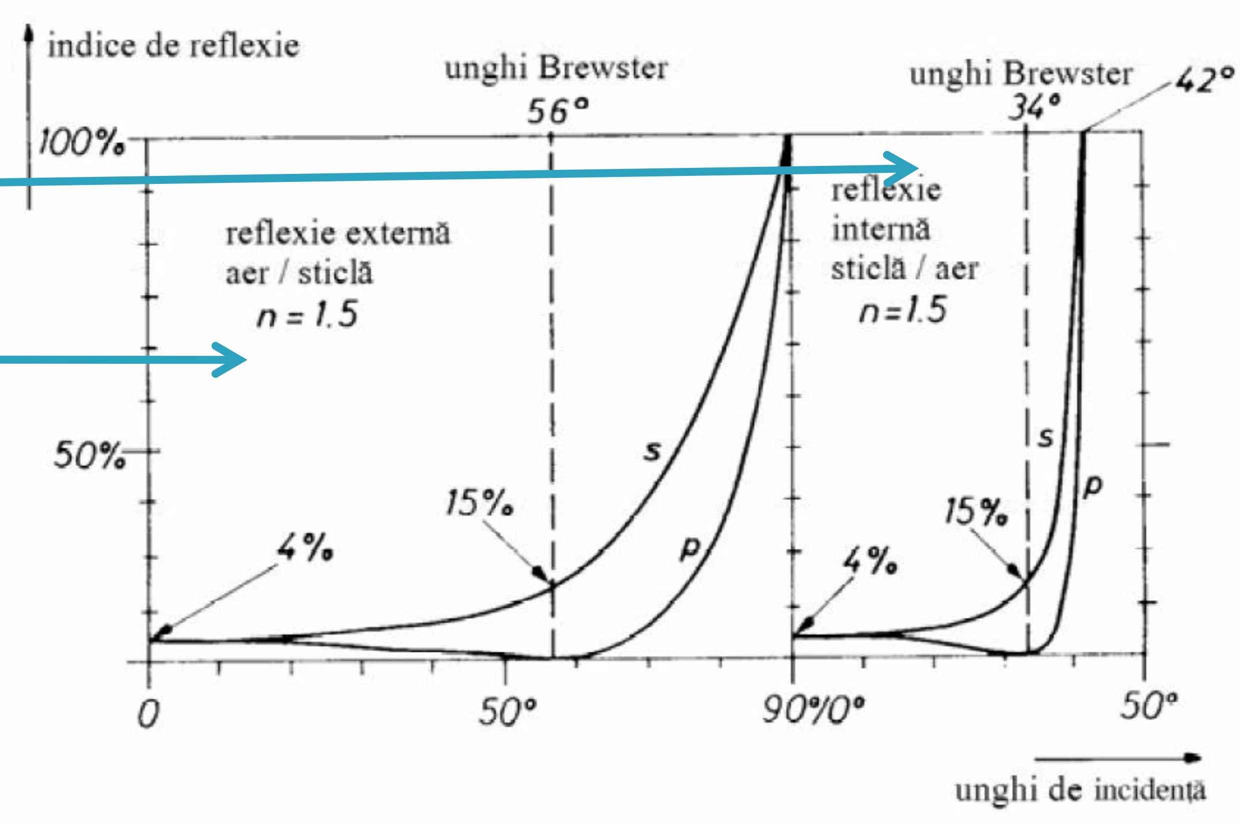
$$r_p = 0 \quad \Rightarrow \quad \tan(\phi_1 + \phi_2) \to \infty \quad \Rightarrow \quad \phi_1 + \phi_2 = \frac{\pi}{2}$$

$$n_1 \cdot \sin\phi_1 = n_2 \cdot \sin\phi_2 = n_2 \cdot \cos\phi_1$$

$$\phi_B = \arctan\left(\frac{n_2}{n_1}\right)$$

$$\phi_B = 34°$$

$$\phi_B = 56°$$



Fotometrie şi radiometrie

Capitolul 4

O alta dualitate

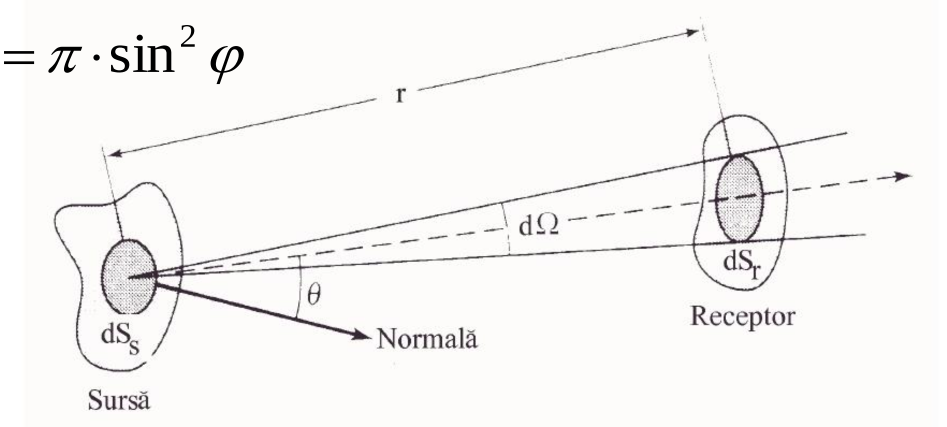
- In optoelectronica lumina poate fi privita din doua puncte de vedere
  - energetic (efect asupra dispozitivului)
  - uman (efect asupra ochiului)
- Dualitatea marimilor implicate
  - energetice
  - luminoase
- Candela (cd) este una din cele 7 marimi fundamentale ale SI
  - Cd = intensitatea luminoasa a unei surse ce emite o radiatie monocromatica cu frecventa $540 \cdot 10^{12}$ Hz (λ = 555nm in vid) si are o intensitate radianta de 1/683 W/sr

Flux energetic

- Flux energetic al luminii
  - viteza cu care energia trece printr-o suprafata
  - energie/unitatea de timp
  - unitatea SI – W

$$\Phi_e = \frac{dE}{dt} \quad [W]$$

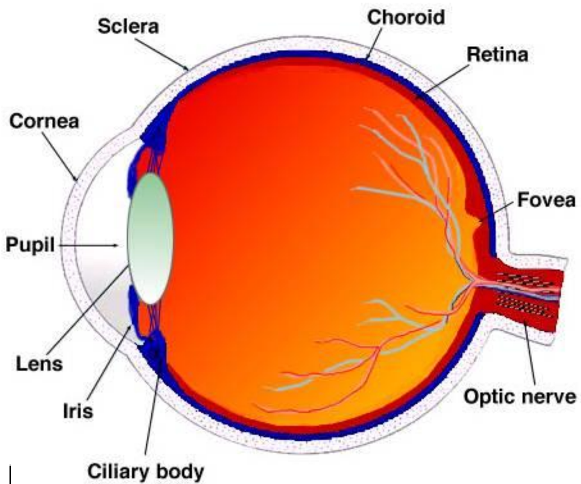
- Unghi solid
  - definitie $\Omega = \frac{A}{r^2} \quad [sr]$
  - valoarea maxima: $\Omega = 4\pi$ sr
  - pentru unghiuri mici $\Omega = \pi \cdot \sin^2 \varphi$

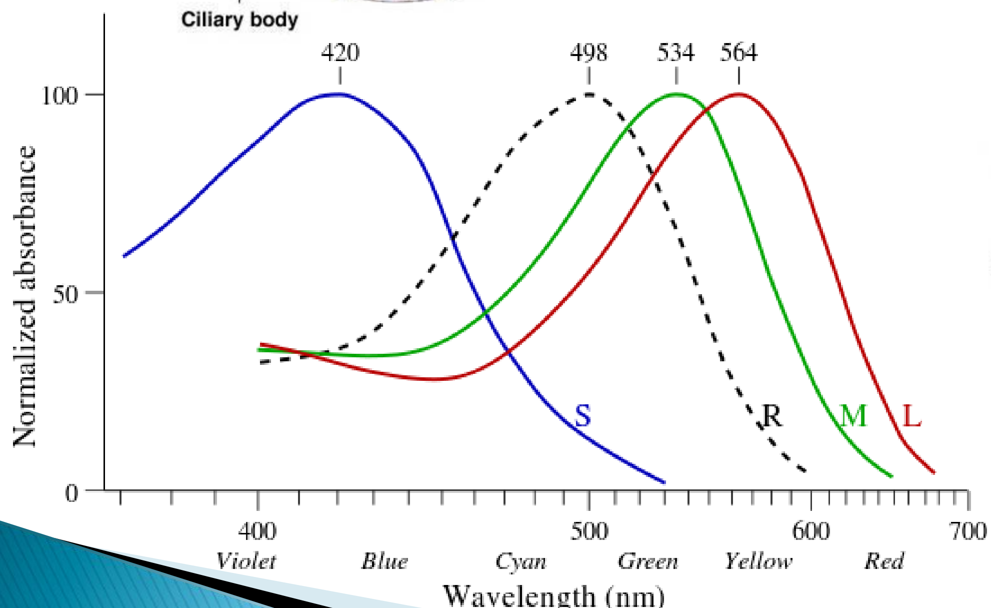


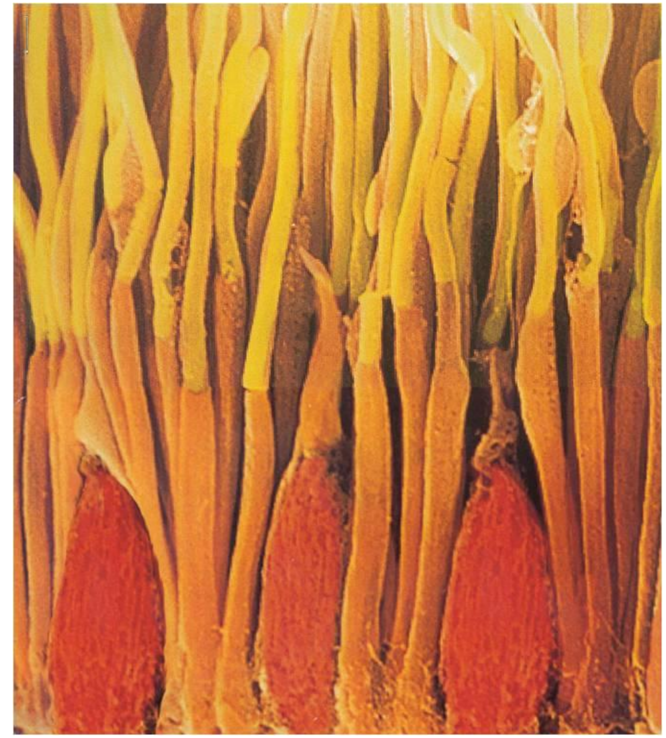
Flux luminos

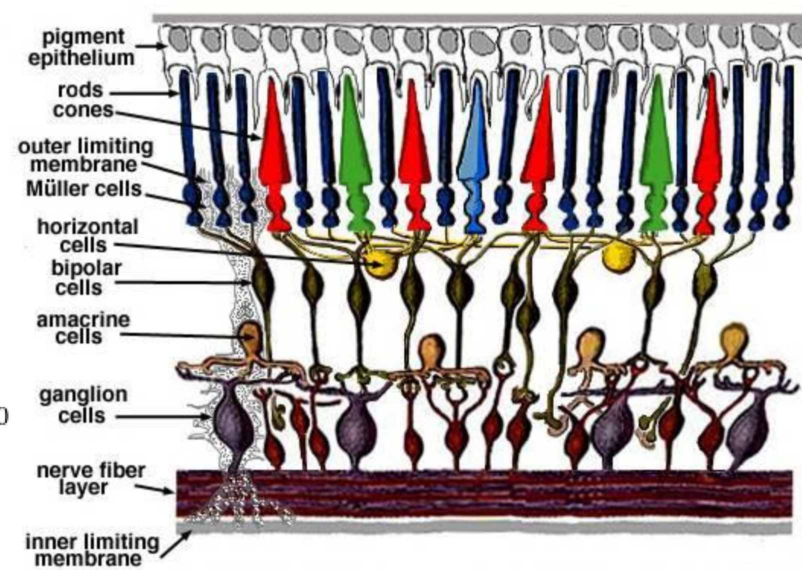
- Flux luminos, definitie
  - o masura a puterii luminoase percepute de om
- Unitate de masura – lm = lumen
  - In SI de unitati **lumenul** este definit ca fluxul luminos al unei surse luminoase punctiforme cu intensitatea luminoasa de o candela intr-un unghi solid egal cu 1 sr.
  - la λ = 555nm $\Phi_e = 1W \Leftrightarrow \Phi_v = 683 lm$
- Dualitate pentru toate marimile implicate
  - radiometrie – indice “e”
  - fotometri – indice “v”
- La alte lungimi de unda se tine cont de sensibilitatea relativa medie a ochiului uman

Ochiul uman


Sclera
Choroid
Retina
Cornea
Fovea
Pupil
Lens
Iris
Optic nerve
Ciliary body


420
498
534
564
100
50
0
Normalized absorbance
S
R
M
L
400
500
600
700
Violet
Blue
Cyan
Green
Yellow
Red
Wavelength (nm)

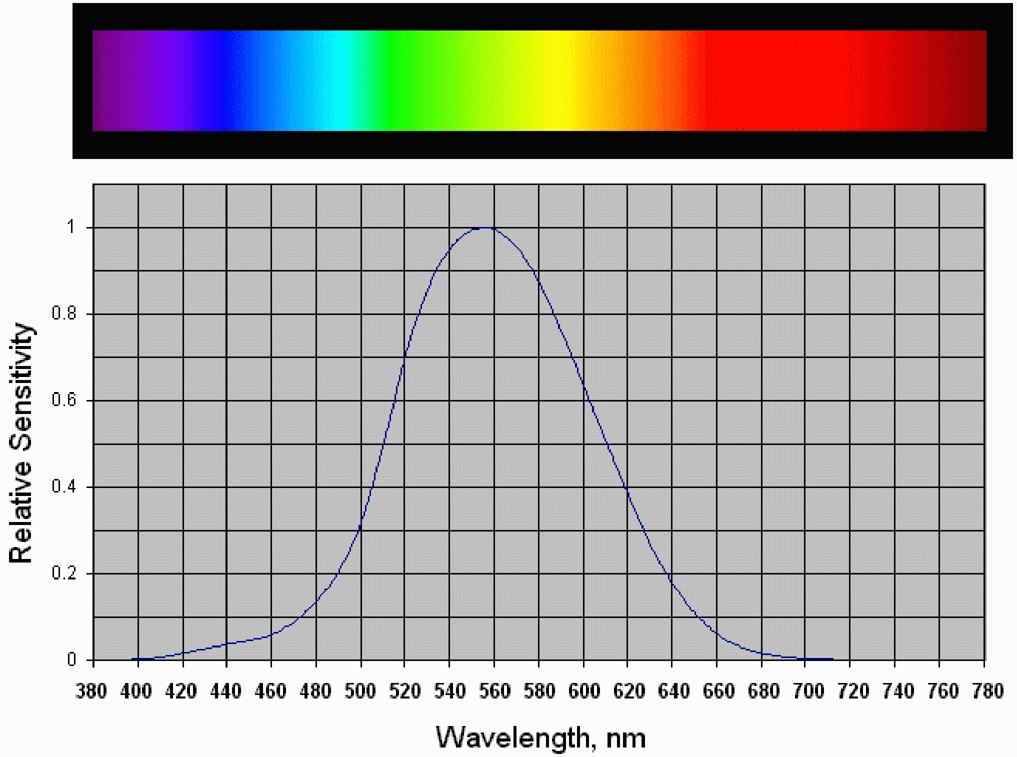



pigment epithelium
rods
cones
outer limiting membrane
Müller cells
horizontal cells
bipolar cells
amacrine cells
ganglion cells
nerve fiber layer
inner limiting membrane

Standarde

- Se incearca definirea omului “standard”
- CIE – Commission Internationale de l'Éclairage
  - 1931 – luminozitatea relativa standard V(λ) – fotopic
  - 1951 – luminozitatea relativa standard V(λ) – scotopic
  - 1978 – Vos
  - 2005 – Sharpe, Stockman, Jagla, Jägle
- Sensibilitatea maxima a ochiului uman
  - vedere diurna (fotopic), $\lambda=555$ nm, $\eta_v = 683$ lm/W
  - vedere nocturna (scotopic), $\lambda=507$ nm , $\eta_v = 1700$ lm/W

CIE V(λ)



Response of Human Eye Versus Wavelength

(Data from the 1988 C.I.E. Photopic Luminous Efficiency Function)

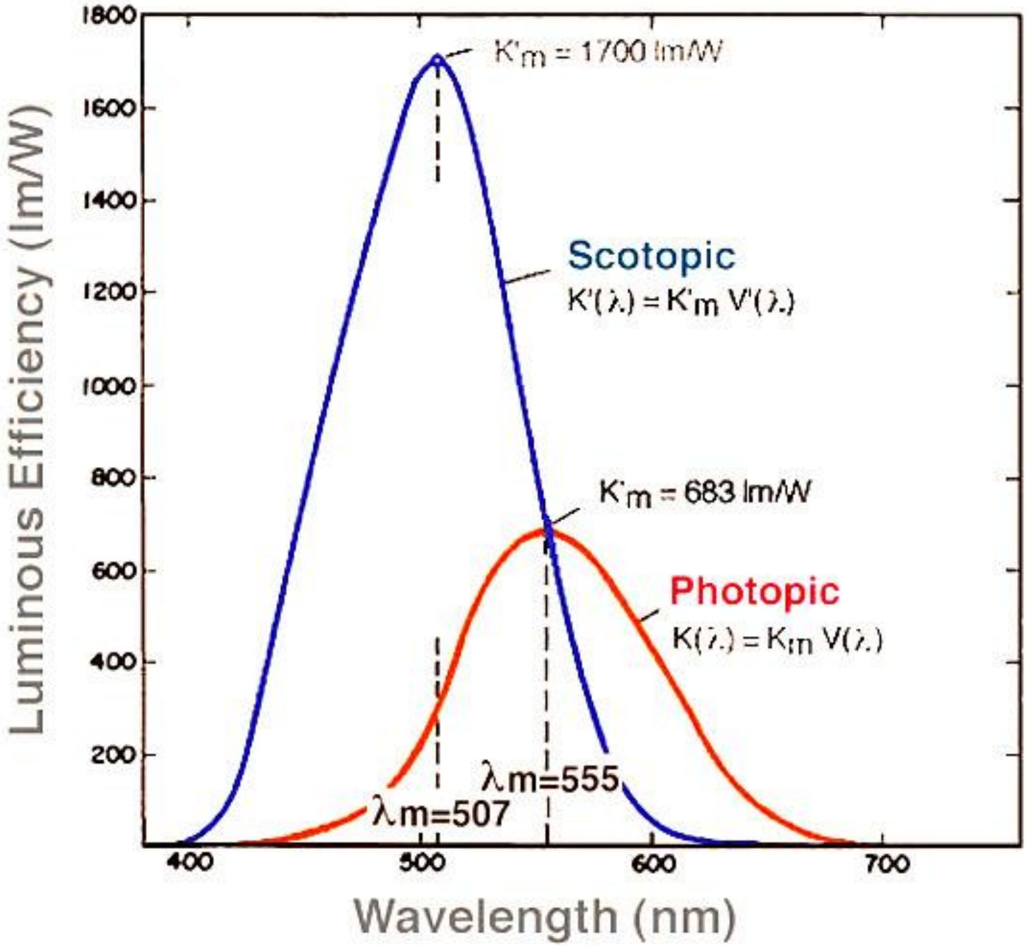


Figure 9. The scotopic and the photopic curves of spectral luminous efficacy (non-normalised values).

efect Purkinje

Contact

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