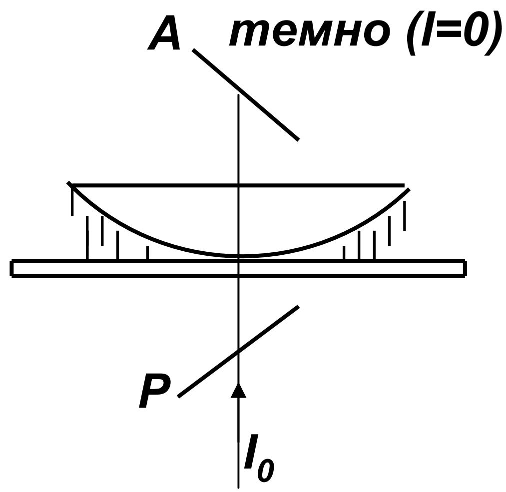
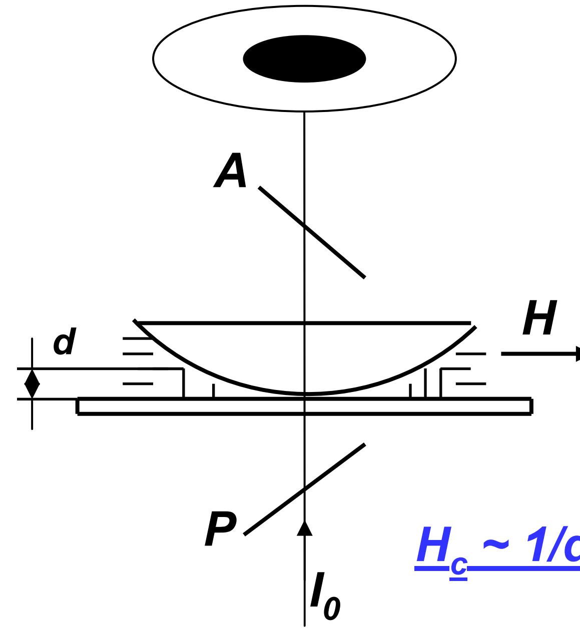
ЛЕКЦИЯ 3. Электрооптика НЖК и композитные материалы

I. Переход Фредерикса

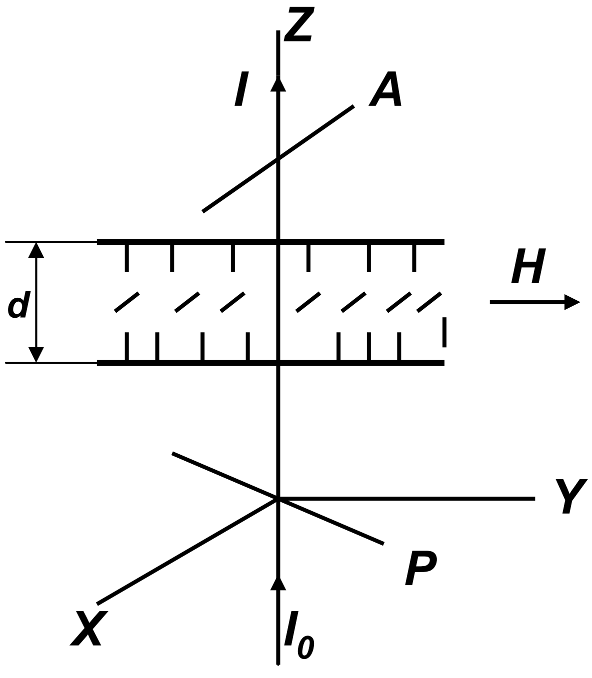
1. Эксперимент.

$$I = I_0 \sin^2 \frac{\Delta\Phi}{2},$$

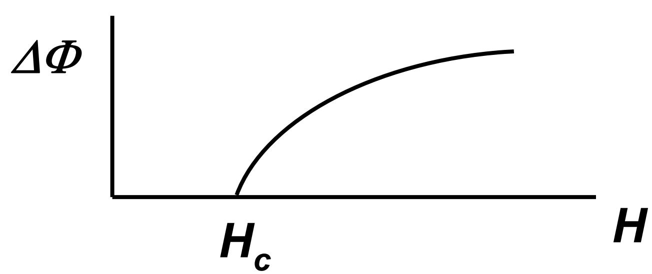




H_c ~ 1/d !



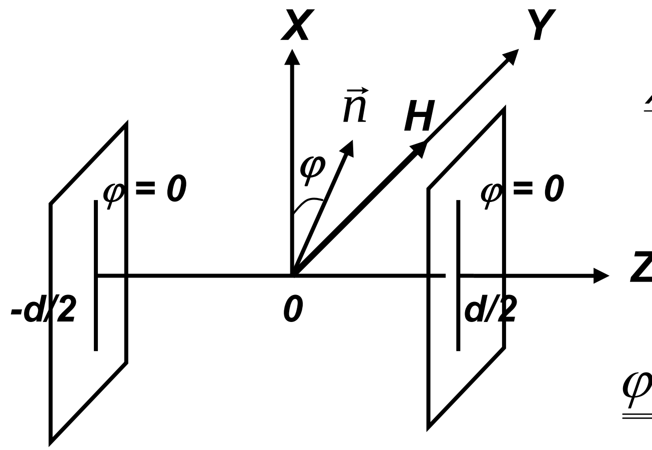
$$\Delta\Phi = \frac{2\pi}{\lambda}\int_0^d \left[n(z) - n_0\right]\cdot dz = \frac{2\pi \cdot d\langle\Delta n\rangle}{\lambda}.$$



2. Теория. Twist деформация.

Постановка задачи.

☞ $= \int_{-d/2}^{d/2} \left[\frac{K_2}{2} \left(\frac{\partial \varphi}{\partial z} \right)^2 - \frac{\chi_a H^2}{2} \sin^2 \varphi \right] \cdot dz.$



$\chi_a > 0,$

δ☞ $= 0!$

$\varphi(z) - ?$

$$K_2 \frac{\partial^2 \varphi}{\partial z^2} + \frac{\chi_a H^2}{2} \sin 2\varphi = 0$$ ***- уравнение равновесия***

$\varphi = 0$ ***при*** $z = \pm d/2$ ***- граничные условия***

Безразмерная форма задачи: $\tilde{z} = \frac{\pi}{d} z, \quad h = \frac{H}{H_F}, \quad H_F = \frac{\pi}{d} \left(\frac{K_2}{\chi_a} \right)^{1/2}$

$$\frac{\partial^2 \varphi}{\partial \tilde{z}^2} + \frac{h^2}{2} \sin 2\varphi = 0, \quad \Rightarrow \quad \varphi(\tilde{z}) = \varphi(-\tilde{z}) \quad \Rightarrow \quad \frac{\partial \varphi}{\partial \tilde{z}} = 0$$ ***при*** $\tilde{z} = 0$

$\varphi = 0$ ***при*** $\tilde{z} = \pm \pi / 2.$

Решение.

$$\left(\frac{\partial\varphi}{\partial\tilde{z}}\right)^2+h^2\sin^2\varphi=C;\qquad C=h^2\sin^2\varphi_m,\qquad (\varphi_m=\varphi(0)).$$

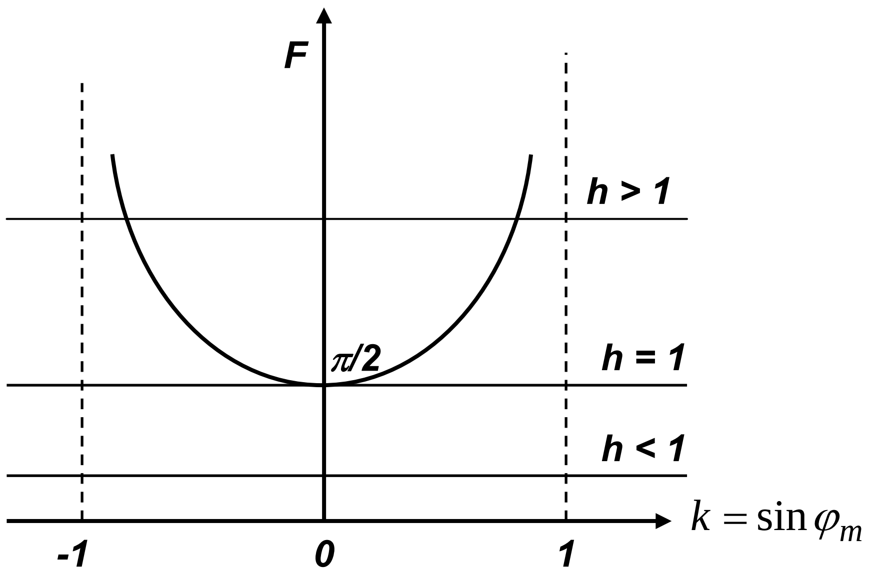
$$\frac{\partial\varphi}{\partial\tilde{z}}=\pm h\cdot(\sin^2\varphi_m-\sin^2\varphi)^{1/2}.$$

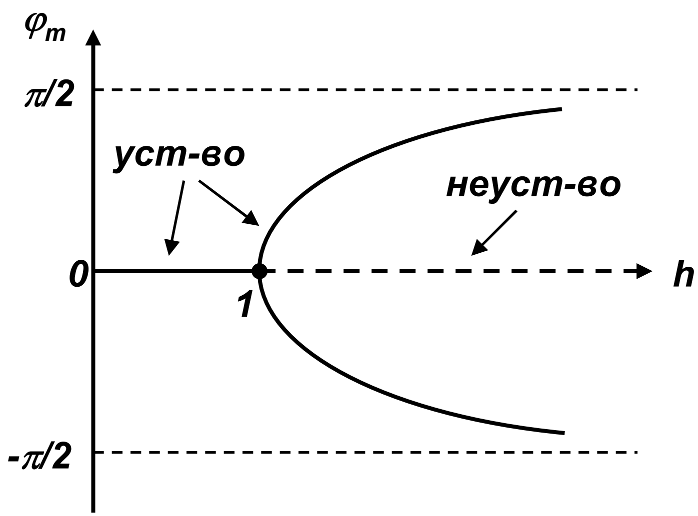
$$\int_{\varphi_m}^{\varphi}\frac{d\varphi'}{(\sin^2\varphi_m-\sin^2\varphi')^{1/2}}=\pm h\cdot\tilde{z};\qquad \int_{\varphi_m}^{0}\frac{d\varphi'}{(\sin^2\varphi_m-\sin^2\varphi')^{1/2}}=\pm h\cdot\frac{\pi}{2}.$$

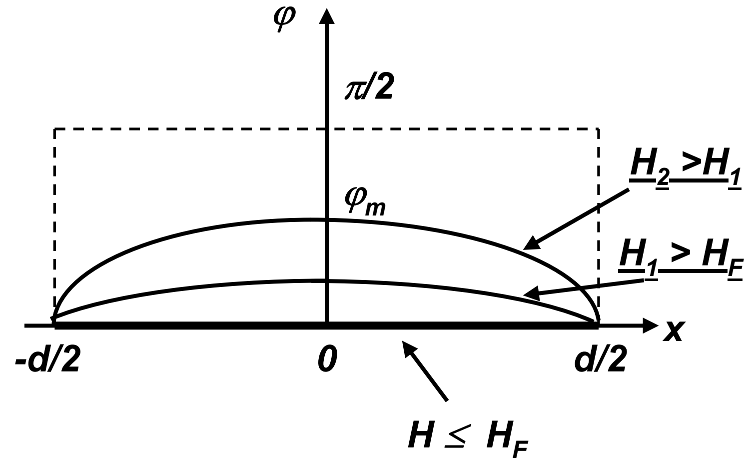
$$\varphi(\tilde{z};\varphi_m(h))\qquad\qquad \varphi_m(h)$$

Анализ. $\sin\xi=\dfrac{\sin\varphi'}{\sin\varphi_m};\quad k=\sin\varphi_m$

$$F(k)=\int_0^{\pm\pi/2}\frac{dz}{\sqrt{1-k^2\sin^2\xi}}=\pm\frac{\pi}{2}\cdot h.$$







$$h_c = 1 \quad \Rightarrow H_c = H_F = \frac{\pi}{d}\cdot\left(\frac{K_2}{\chi_a}\right)^{1/2}.$$

При H ≥ H_F; $$\varphi = \varphi_m \cos\frac{\pi}{d}x = \varphi_m \cos\tilde{x}.$$

$$\varphi_m \approx 2\left(\frac{H}{H_F} - 1\right)^{1/2}$$

3. Исследование на устойчивость.

$$\text{☞} = \int_{-d/2}^{d/2}\left[\frac{K_2}{2}\left(\frac{\partial\varphi}{\partial z}\right)^2 - \frac{\chi_a H^2}{2}\sin^2\varphi\right]\cdot dz$$

при φ << 1 $\approx$

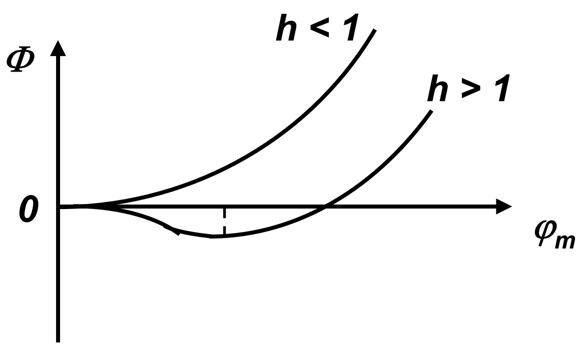
$$\frac{\pi\cdot K_2}{2d}\int_{-\pi/2}^{\pi/2}\left[\left(\frac{\partial\varphi}{\partial\tilde{z}}\right)^2 - h^2\varphi^2 + \frac{h^2}{3}\varphi^4\right]\cdot d\tilde{z} =$$

$$= \frac{\pi^2 K_2}{4d}\left[(1-h^2)\varphi_m^2 + \frac{h^2}{4}\varphi_m^4\right].$$

$$\sin^2\varphi \approx \varphi^2 - \frac{\varphi^4}{3},$$

$$\varphi \approx \varphi_m \cos\tilde{z}.$$

$$\frac{\partial\text{☞}}{\partial\varphi_m} = 0 = \frac{\pi^2 K_2}{4d}\left[2(1-h^2) + h^2\varphi_m^2\right]\varphi_m.$$

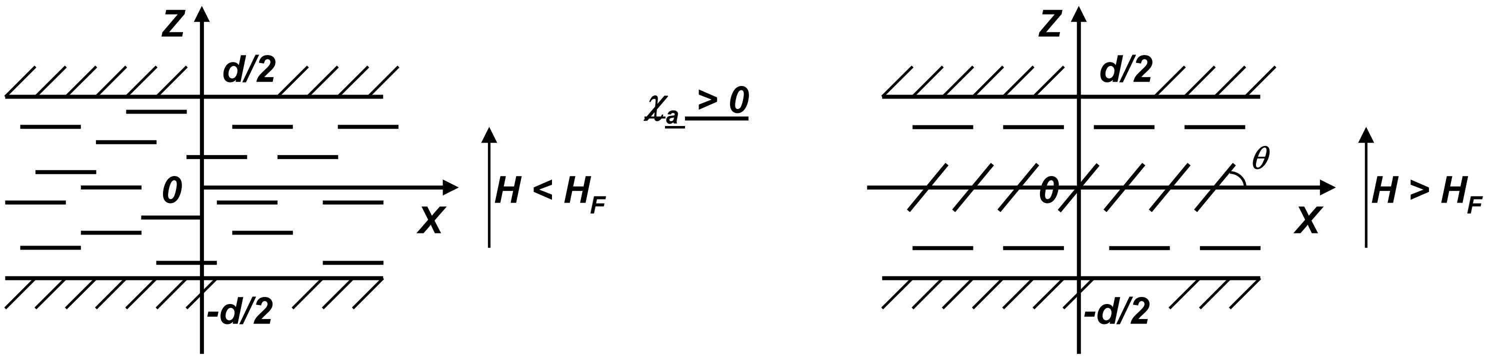


(1) $\varphi_m = 0.$

(2) $$\varphi_m^2 = 2\frac{h^2-1}{h^2} \approx 2(h-1)(h+1) \approx 4(h-1),$$

или $$\varphi_m \approx 2\left(\frac{H}{H_F} - 1\right)^{1/2}.$$

II. Магнитооптика НЖК (S – эффект)



1. Расчет поля директора.

$$☞ = \int_{-d/2}^{d/2} \left(F_{el} + F_m\right) \cdot dz = \min$$

$$F_{el} = \frac{K_1}{2}(div\vec{n})^2 + \frac{K_2}{2}(\vec{n} \cdot rot\vec{n})^2 + \frac{K_3}{2}(\vec{n} \times rot\vec{n})^2$$

$$\vec{n} = \left(\cos\theta(z); 0; \sin\theta(z)\right).$$

$$F_{el} = \left(\frac{K_1}{2}\cos^2\theta + \frac{K_3}{2}\sin^2\theta\right) \cdot \left(\frac{\partial\theta}{\partial z}\right)^2 = \frac{K_1}{2}(1 + \delta \cdot \sin^2\theta) \cdot \left(\frac{\partial\theta}{\partial z}\right)^2, \qquad \delta = \frac{K_3 - K_1}{K_1}.$$

$$F_m = -\frac{\chi_a}{2}(\vec{n} \cdot \vec{H})^2 = -\frac{\chi_a H^2}{2}\sin^2\theta.$$

$$\text{☞} = \int\limits_{-d/2}^{d/2} \left[\frac{K_1}{2} (1 + \delta \cdot \sin^2\theta) \cdot \left(\frac{\partial\theta}{\partial z} \right)^2 - \frac{\chi_a H^2}{2} \sin^2\theta \right] \cdot dz.$$

$$\tilde{z} = \frac{\pi \cdot z}{d}, \qquad h = H / H_F, \qquad H_F = \frac{\pi}{d} \left(\frac{K_1}{\chi_a} \right)^{1/2}.$$

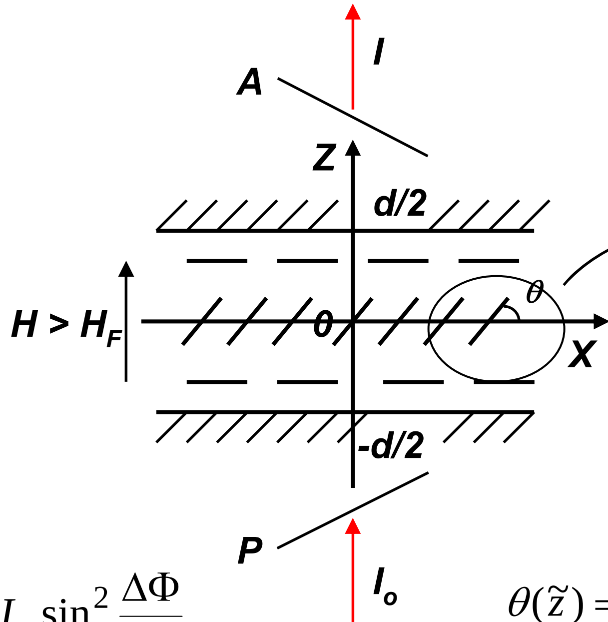
$$\text{☞} = \frac{\pi \cdot K_1}{2d} \int\limits_{-\pi/2}^{\pi/2} \left[(1 + \delta \cdot \sin^2\theta) \cdot \left(\frac{\partial\theta}{\partial\tilde{z}} \right)^2 - h^2 \sin^2\theta \right] \cdot d\tilde{z} \approx \frac{\pi \cdot K_1}{2d} \int\limits_{-\pi/2}^{\pi/2} \left[\left(\frac{\partial\theta}{\partial\tilde{z}} \right)^2 + \delta \cdot \theta^2 \left(\frac{\partial\theta}{\partial\tilde{z}} \right)^2 - h^2 \left(\theta^2 - \frac{\theta^4}{3} \right) \right] \cdot d\tilde{z}.$$

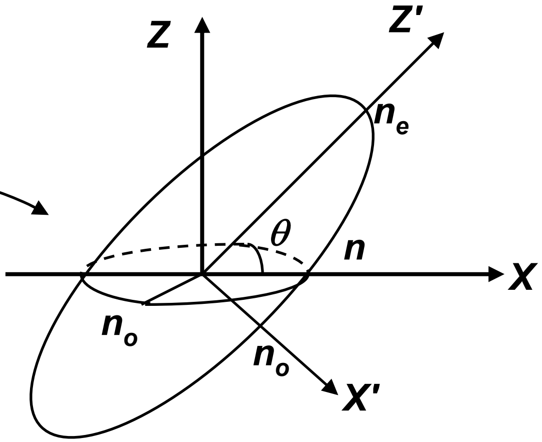
$$\theta = \theta_m \cos\tilde{z}.$$

Тогда $$\tilde{\text{☞}} = \frac{\text{☞} \cdot 2d}{\pi \cdot K_1} = \frac{\pi}{2} (1 - h^2) \cdot \theta_m^2 + \frac{\pi}{8} (\delta + h^2) \cdot \theta_m^4.$$

$$\frac{\partial\tilde{\text{☞}}}{\partial\theta_m} = \frac{\pi}{2} \theta_m \left[2(1 - h^2) + (\delta + h^2) \cdot \theta_m^2 \right] = 0 \quad \Rightarrow \theta_m^2 = \frac{2(h^2 - 1)}{h^2 + \delta} \approx \frac{4(h-1)}{1+\delta} = 4 \frac{K_1}{K_3} (h - 1).$$

2. Расчет оптики слоя.





$$I = I_o \sin^2 \frac{\Delta\Phi}{2},$$

$$\theta(\tilde{z}) = \theta_m \cos\tilde{z}, \qquad \theta_m^2 = 4\frac{K_1}{K_3}(h-1).$$

$$\Delta\Phi = \frac{2\pi}{\lambda}\cdot\Delta l = \frac{2\pi}{\lambda}\int_{-d/2}^{d/2}\Delta n(z)\cdot dz.$$

$$\Delta n(z) = n(z) - n_o$$

$$\frac{x'^2}{n_o^2} + \frac{z'^2}{n_e^2} = 1 \qquad \begin{cases} x' = x\cdot\sin\theta - z\cdot\cos\theta \\ z' = x\cdot\cos\theta + z\cdot\sin\theta \end{cases}$$

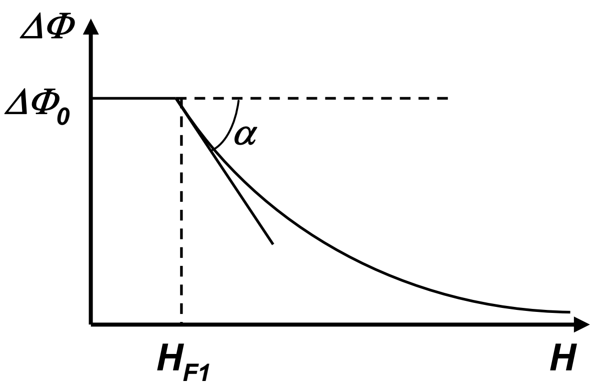
При z = 0 x = n.   ***Тогда*** $n^2\left(\frac{\sin^2\theta}{n_o^2} + \frac{\cos^2\theta}{n_e^2}\right) = 1.$

$$n = \frac{n_o n_e}{\sqrt{n_e^2\sin^2\theta + n_o^2\cos^2\theta}} = \frac{n_e}{\sqrt{1+\frac{n_e^2-n_o^2}{n_o^2}\sin^2\theta}} \approx n_e\left(1 - \frac{n_e^2-n_o^2}{2n_o^2}\theta^2\right).$$

$$\Delta n(z) = n(z) - n_o \approx (n_e - n_o) - \frac{n_e}{n_o}\cdot\frac{n_e^2 - n_o^2}{2n_o}\theta^2 \approx (n_e - n_o) - (n_e - n_o)\theta^2.$$

$$\Delta\Phi \approx \underbrace{\frac{2\pi}{\lambda}(n_e - n_o)\cdot d}_{\Delta\Phi_0} - \frac{2\pi}{\lambda}(n_e - n_o)\theta_m^2 \underbrace{\int_{-d/2}^{d/2}\cos^2\frac{\pi\cdot z}{d}\cdot dz}_{= d/2}.$$

$$\Delta\Phi \approx \Delta\Phi_0 - \frac{\pi}{\lambda}\cdot\Delta n\cdot d\,4\frac{K_1}{K_3}\left(\frac{H}{H_{F_1}} - 1\right),$$ ***где*** $$\Delta n = n_e - n_o,\quad H \ge H_{F_1}$$



$$H_{F_1} = \frac{\pi}{d}\left(\frac{K_1}{\chi_a}\right)^{1/2}$$

$$\Delta\Phi_0 = \frac{2\pi}{\lambda}\Delta n\cdot d \quad\Rightarrow \Delta n\cdot d = \frac{\Delta\Phi_0\lambda}{2\pi}.$$

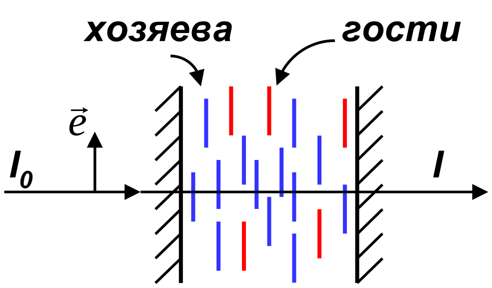
$$tg\alpha = \frac{\pi}{\lambda}(\Delta n\cdot d)4\frac{K_1}{K_3}\cdot\frac{1}{H_{F_1}}$$ ***или*** $$tg\alpha = 2\Delta\Phi_0\frac{K_1}{K_3}\cdot\frac{1}{H_{F_1}}$$

$$\Downarrow$$

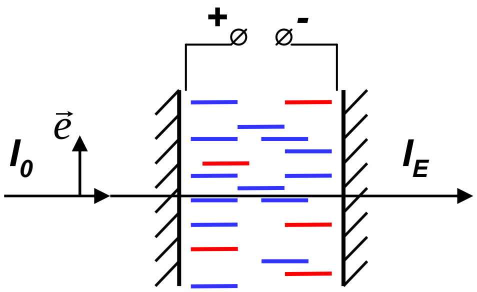
$$\frac{K_3}{K_1} = \frac{2\Delta\Phi_0}{H_{F_1}tg\alpha}.$$

III. Применения

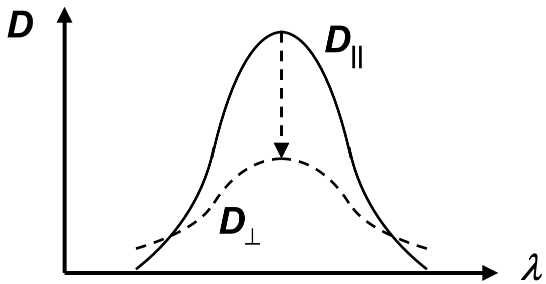
1. Эффект гость - хозяин.



$D_{||} = D(0)$



$D_{\perp} = D(E)$

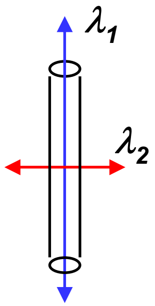


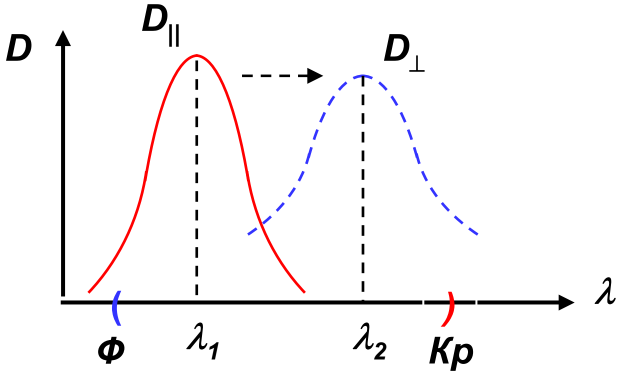
$I = I_0 \exp(-D)$

$I_E / I \sim 30$

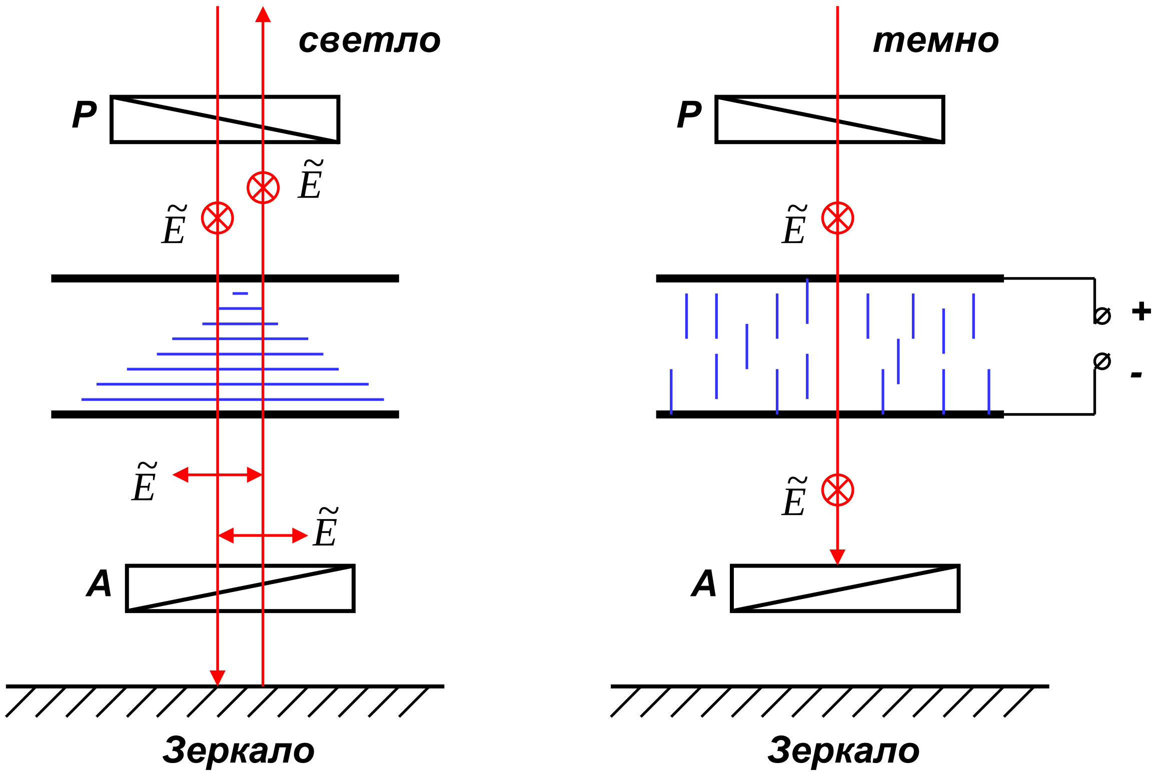
$\Delta D = D_{||} - D_{\perp} \sim 1.5$

2. Переключение цвета.

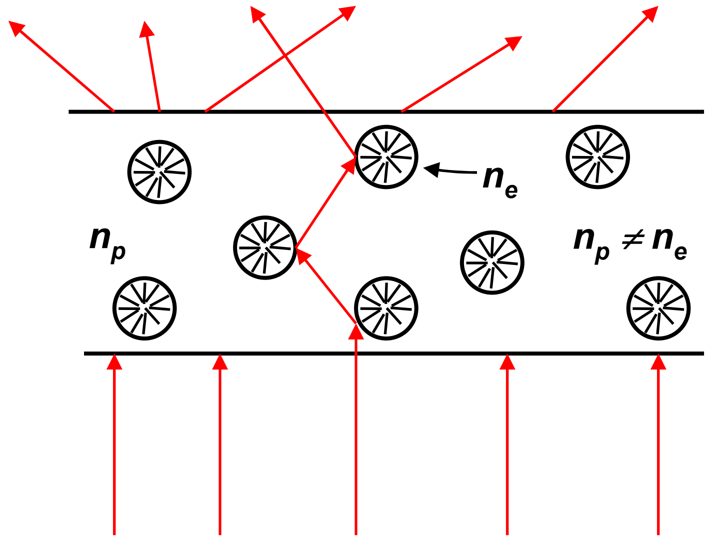


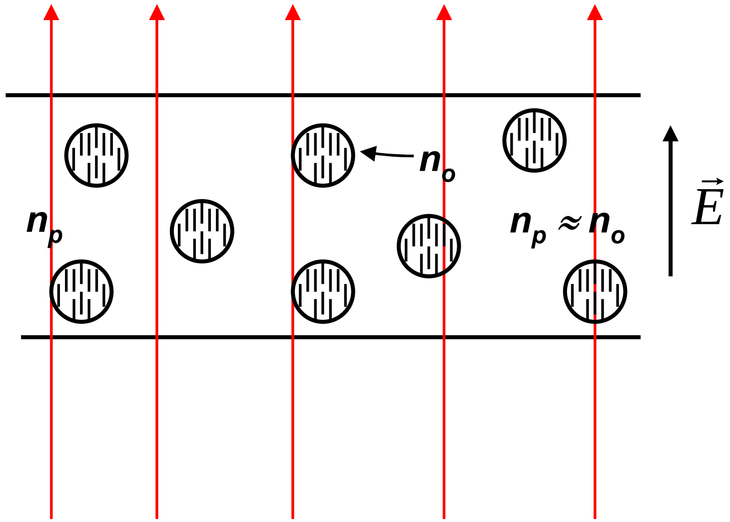


3. Индикаторы на переходе Фредерикса (twist – эффект).



4. Жидкие кристаллы, диспергированные в полимерах (PDLC) .





5. ЖК в полимерных сетках – Polymer Network Liquid Crystal (PNLC)

Получение жидкокристаллических гелей (PNLC)

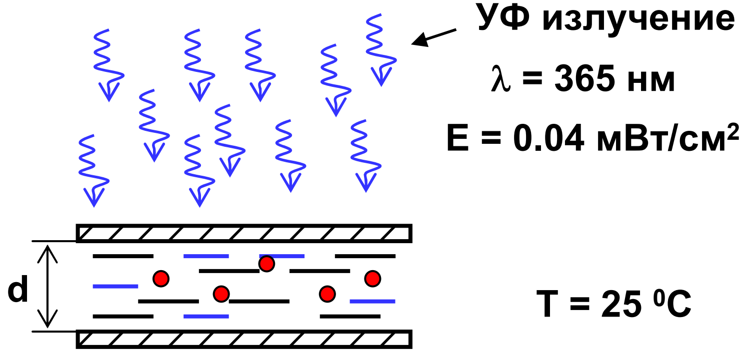


Рис. 1. Схема приготовления PNLC.

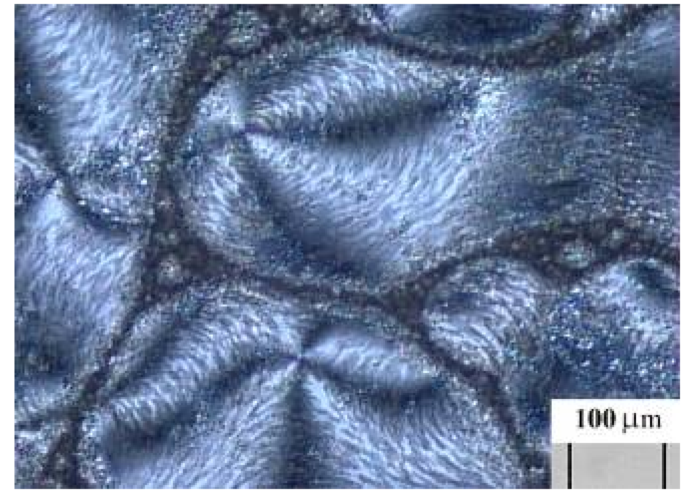


Рис. 2. Текстура неориентированного PNLC.

— ЖК 1277

— Мономер: Бисфенол – А - диметакрилат

● Фотоинициатор: Бензоин метиловый эфир

Ориентант - Паклак

ЖК : Мономер : Фотоинициатор =
= 94.3 : 5.2 : 0.5 мас.%

Особенности полученных ориентированных PNLC.

1. Оптически анизотропны.
2. Рассеивают свет (мутные).
3. Наблюдается анизотропия рассеяния. (Интенсивность рассеянного света зависит от угла между плоскостью поляризации падающего света и направлением директора).