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3rd Lecture

3.0. APPLICATIONS OF LC AND WEAK NLC ANCHORING

3.1. Application of LC to Health Science and to Industry

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3.1.0 Application of LC to mass psycology

***Mood Rings**

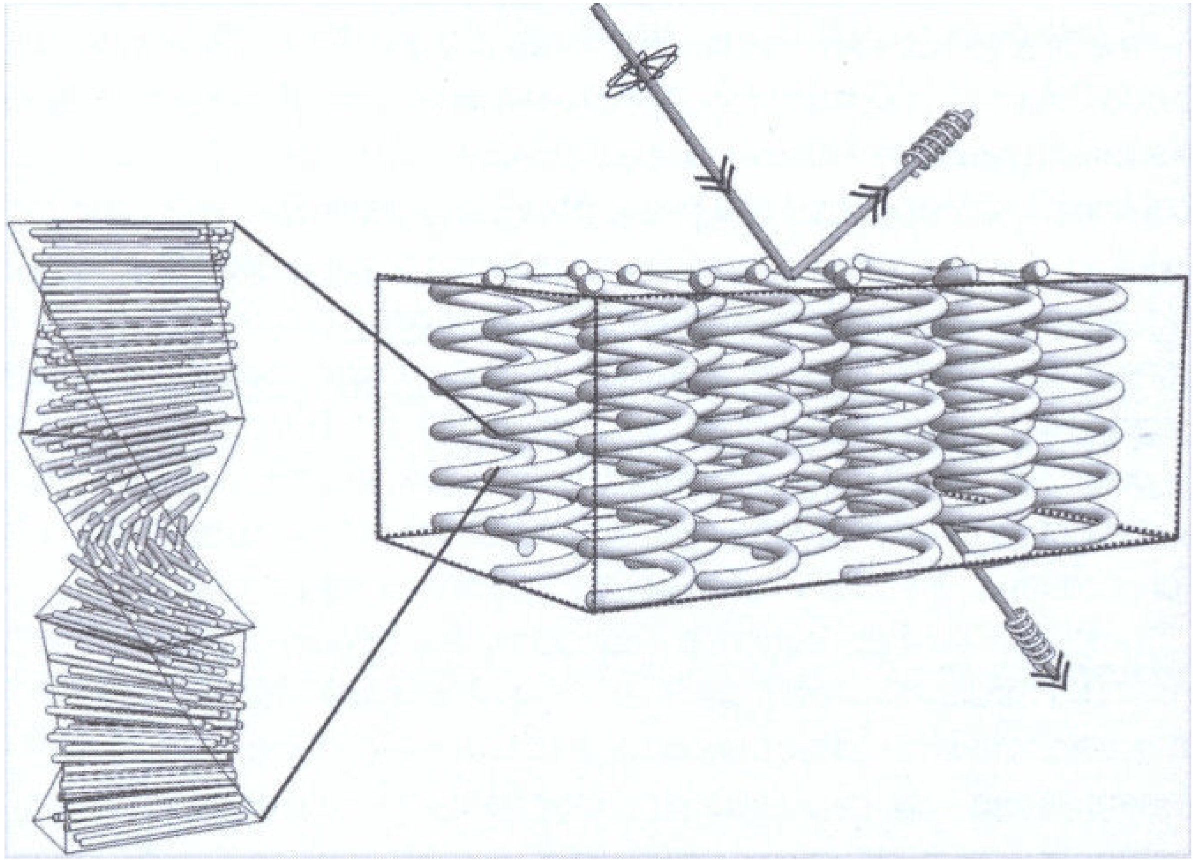
Are you anxious or calm? Find out by gauging
Your mood with a mood ring.

*Adapted from Product Brochure,
Davis Liquid Crystals Inc., San Leandro, CA.

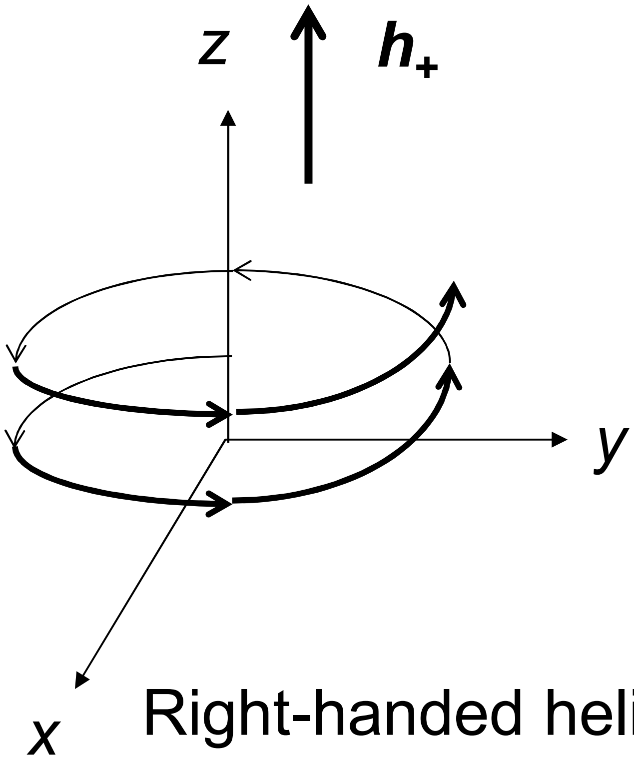
3.1.1. Application of LC to Medicine

The main application to Medicine is relevant to **Cholesteric Liquid Crystals (CLC)** as Thermometer and for Thermography

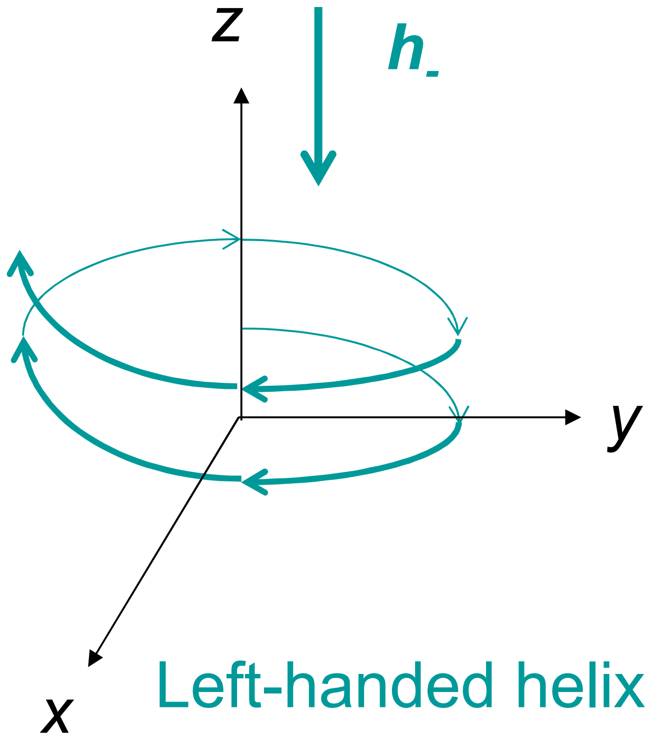
The key is the Bragg-like reflection and refraction occurring to an impinging non polarized light beam



With respect to a right-handed frame of reference



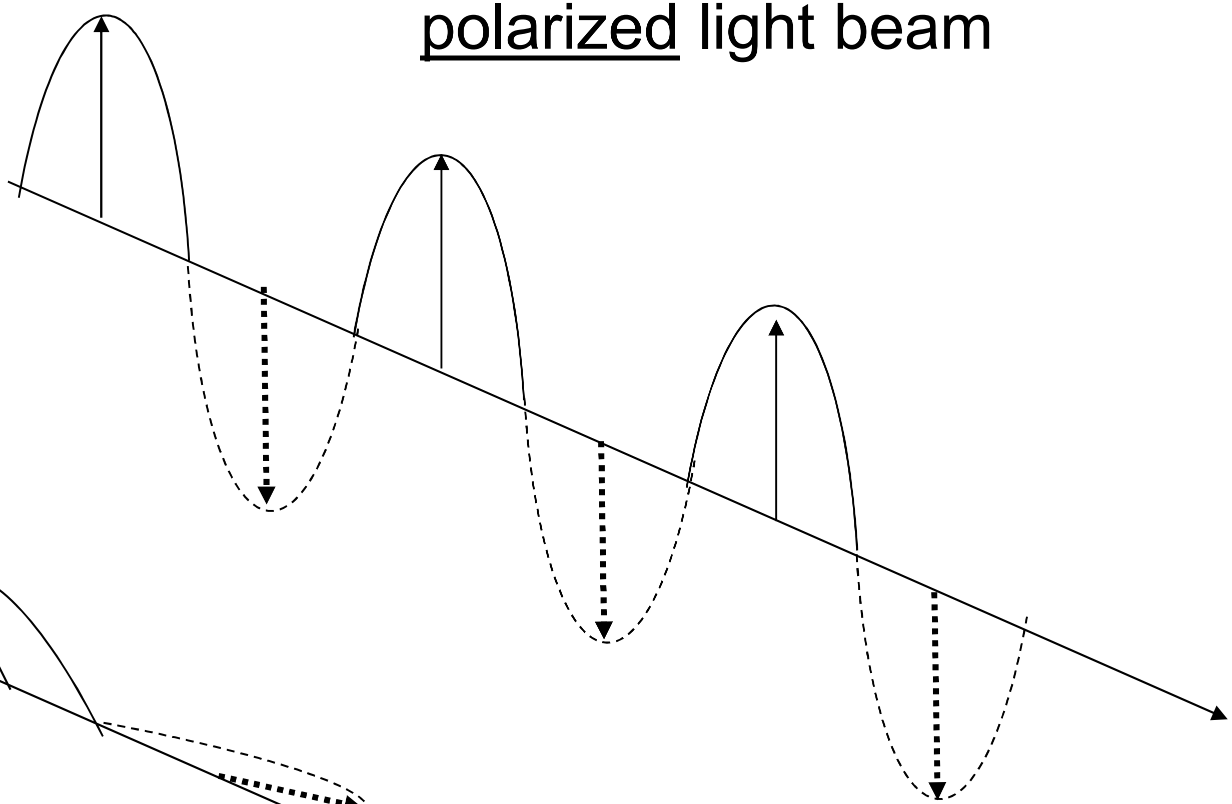
Right-handed helix

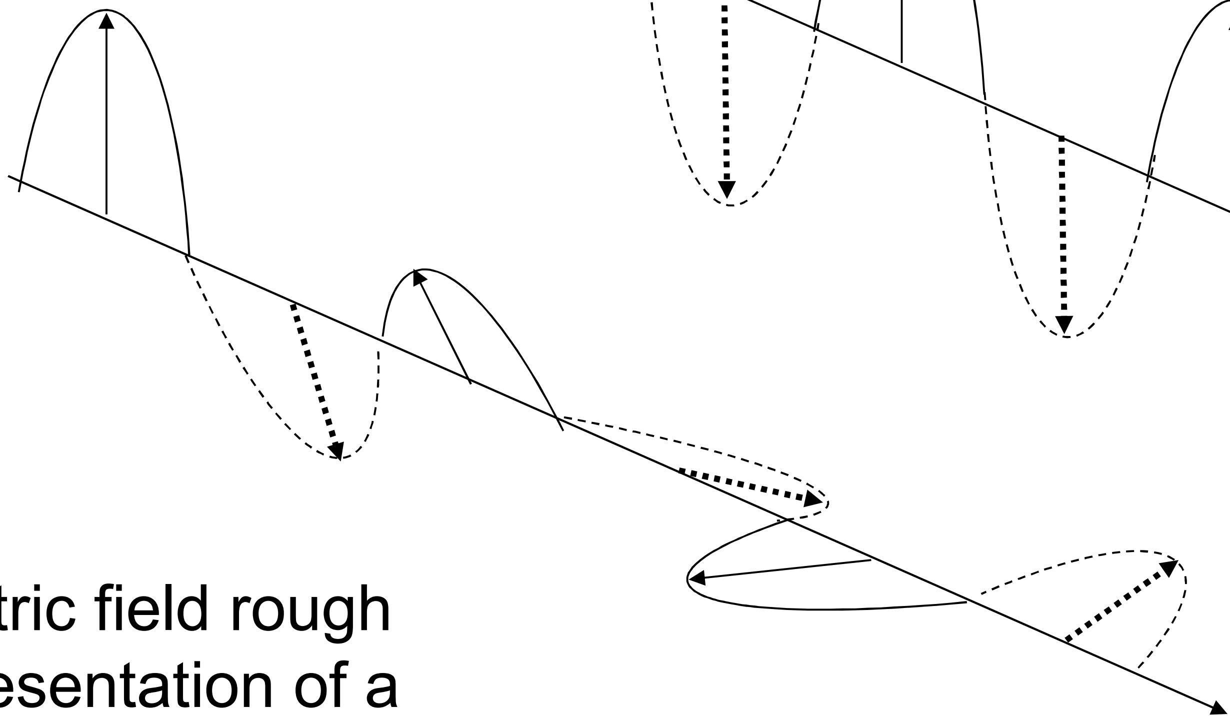


Left-handed helix

each with its handedness *h*

Electric field of a <u>linear polarized</u> light beam





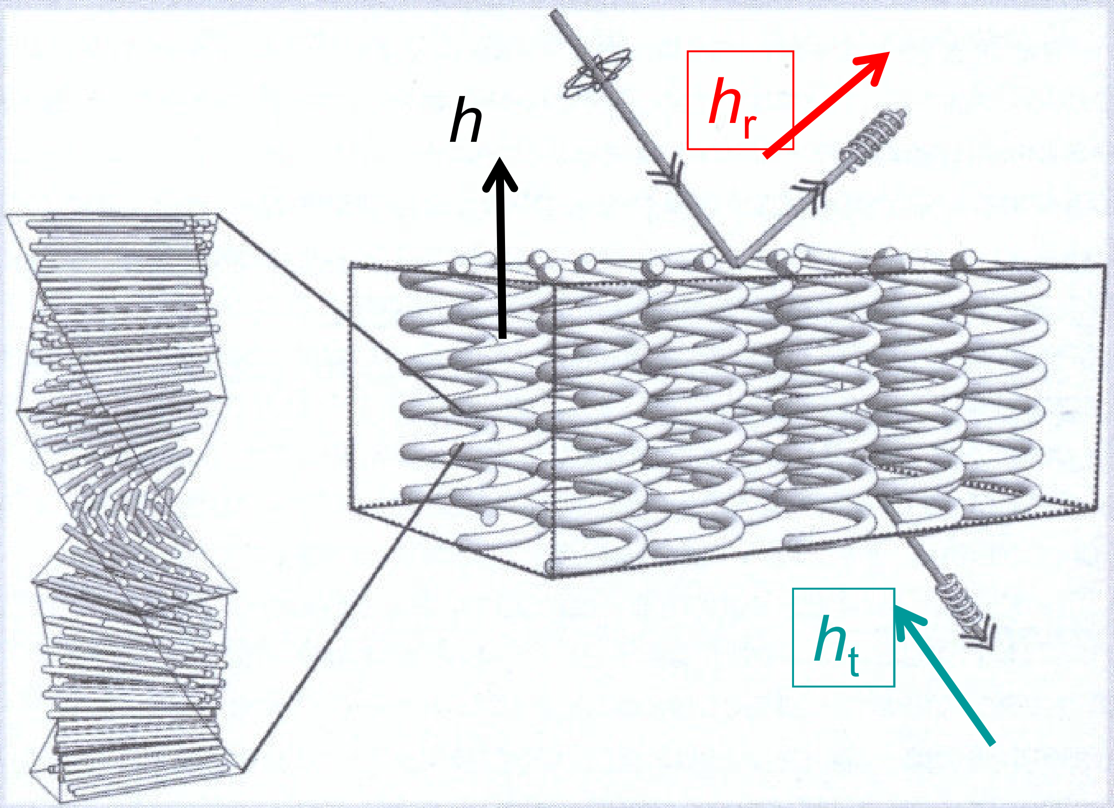
Electric field rough representation of a **<u>circular polarized</u>** light beam

Having a “cell” made by two flexible transparent polyester (Mylar) sheets, packed at distance d = 10 μm from each other, treated in order to favour planar alignment, filled by CLC

If a non polarized <u>**white**</u> light beam is impinging onto the “sheet-cell”, it meets a reflecting and refracting structure

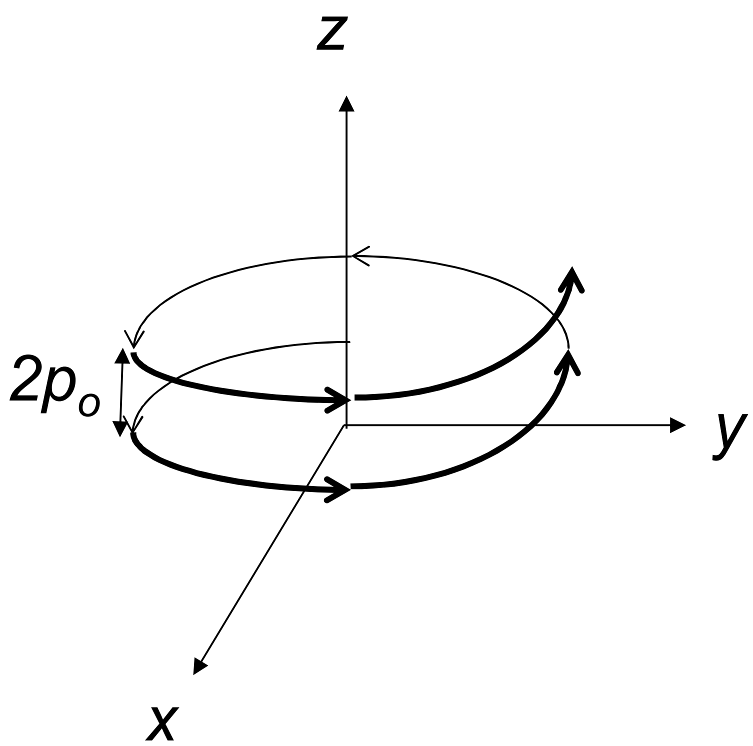
The reflected beam is circularly polarized with the same handedness h_r (right-) as CLC (h)

The transmitted beam too, but with reverse handedness h_t (left-)

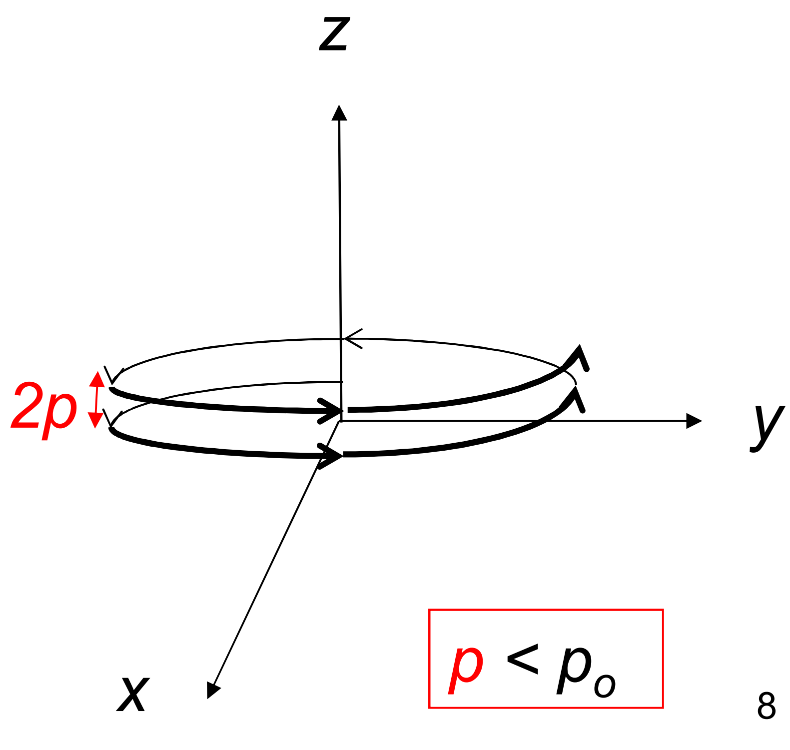


This figure is a representation of the selective reflection of circularly polarized light by a film of planar-aligned cholesteric liquid crystal. The twisted structure of the liquid crystal is represented by springs, all having the same handedness; the springs trace out the orientation of the director or optic axis through the film. The arrangement of molecules within the twisted structure is shown by the exploded view, where the rods represent groups of molecules. The incident light is unpolarized, and the reflected light is circularly polarized with the same handedness as the twist of the liquid crystal. The transmitted light is also circularly polarized, but with the opposite sense.

Let us suppose that the structure is like this (where the structure pitch p_o at room temperature is shown):



Increasing temperature, the twist increases, thus the pitch shortens!



$p < p_o$

This means that the sheet "cell" is ***sensitive to temperature variations***

Putting the sheet at contact with a small part of a body, the sheet works as a thermometer

t_F	t_C
94,6	34,8
96,6	35,9
98,6	37,0
100,6	38,1
102,6	39,2
104,6	40,3

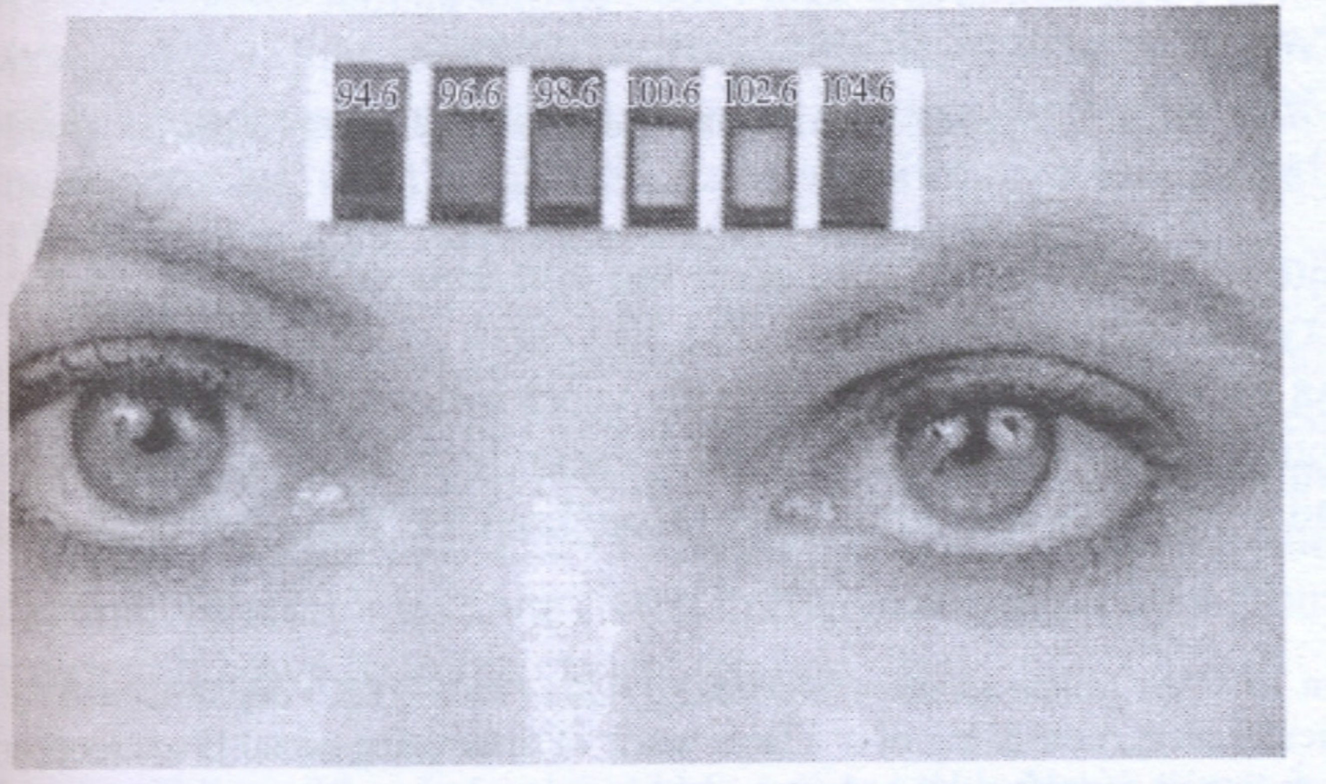


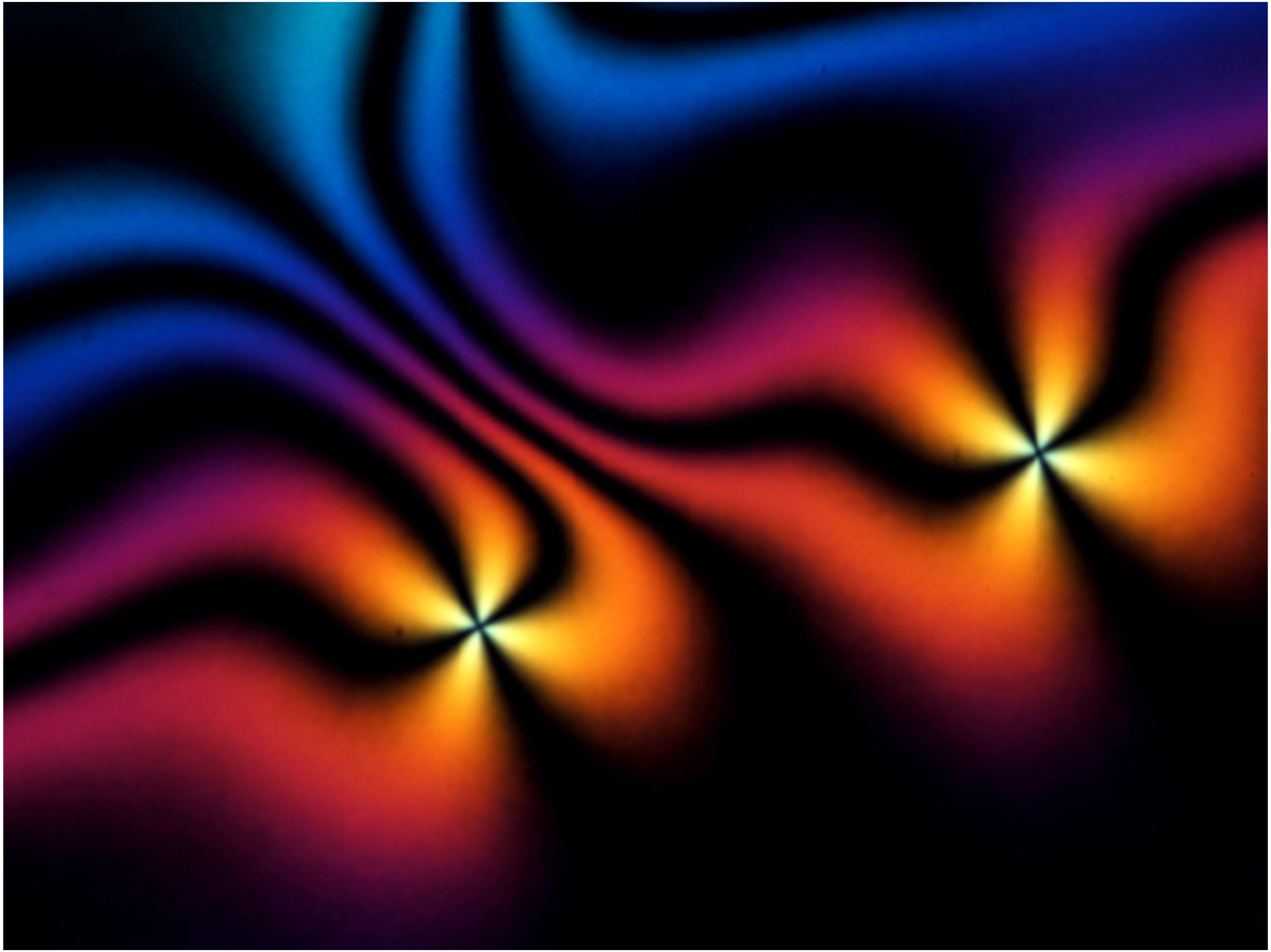
Figure 12.1 A liquid crystal body temperature indicator. LC Hallcrest Inc.

Of course, the range of mesophase must be the proper one (in the previous case, from t = 34.8°C to 40.3°C), and the down sheet in contact with the skin must be **black painted**, since the CLC is *semitransparent*, and we have to observe <u>the reflection by CLC</u>, not by the patient skin!

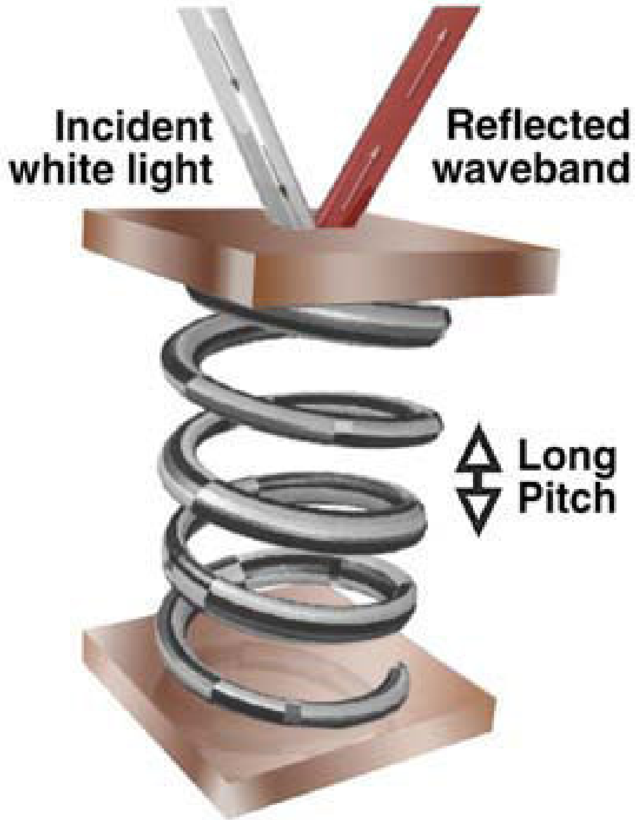
But the most interesting application is for Thermography

If there are surfaces presenting areas with different temperature, it is possible to have **temperature mapping**

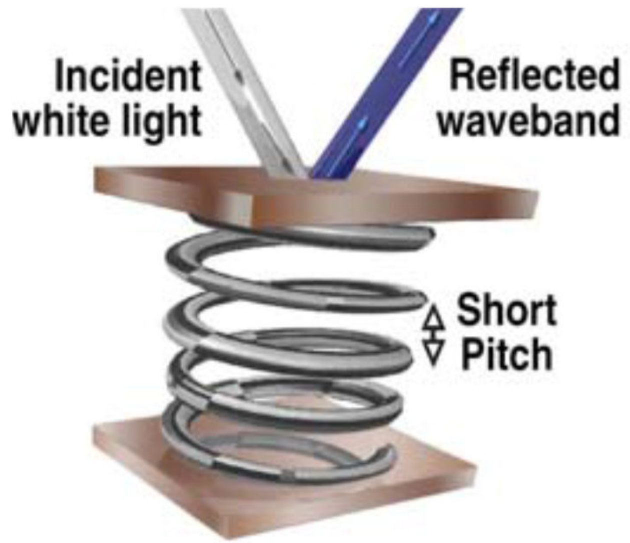
But materials have to be initially in thermodynamical equilibrium, not presenting beautiful schlieren texture:



The selected reflection beam is red at lower *t*, is blue at higher *t* in the mesophase range

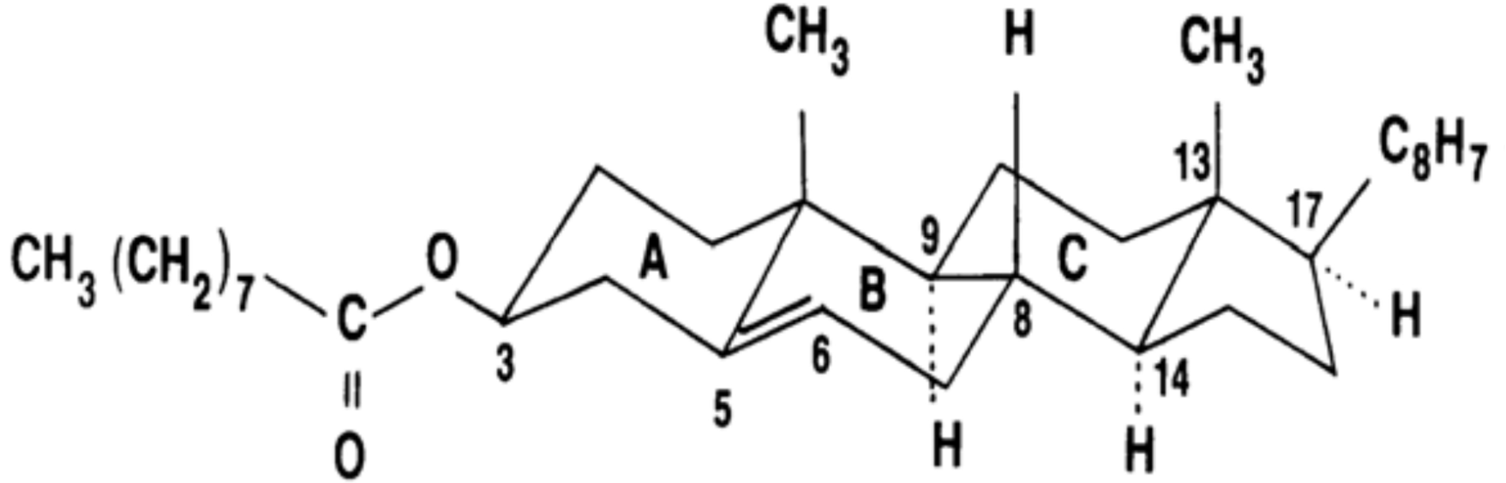


cooler



warmer

A good CLC is a blend of cholesteryl oleyl carbonate (COC) and cholesteryl pelargonate (CP)

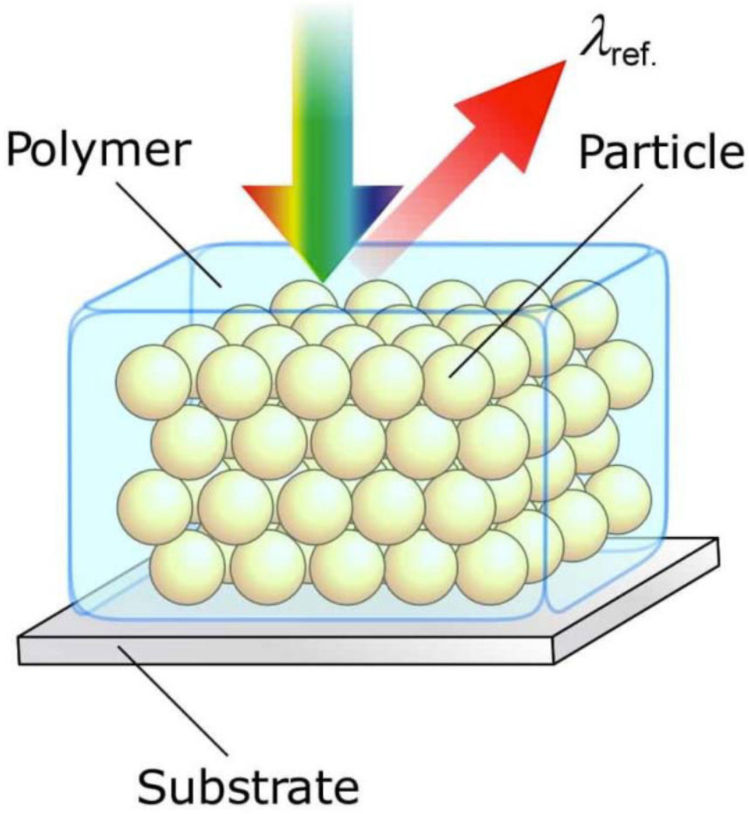


Chemical structure of cholesteryl pelargonate

Example:

Blood
pulse at
inner wrist

But it is more efficient for Thermography to pack CLC in small spheres covered by surfactants



and to insert them in a polymer band, or layer, or even more practical, to create an ***ink of balls*****,** to be used for painting the skin

Encapsulated CLC

CLC Material -Types

Encapsulated —the liquid crystal material is encapsulated in a 5-10 micron sphere suspended in a water based binder material-provides excellent protection.

The ***micro-encapsulation process offers chemical contaminant resistance and radiation*** protection.

Unencapsulated —the material is in its native form-susceptible to contamination, however, once applied, produces brilliant colours.

The liquid crystals can be:

narrow band -1 or 2^{o}C

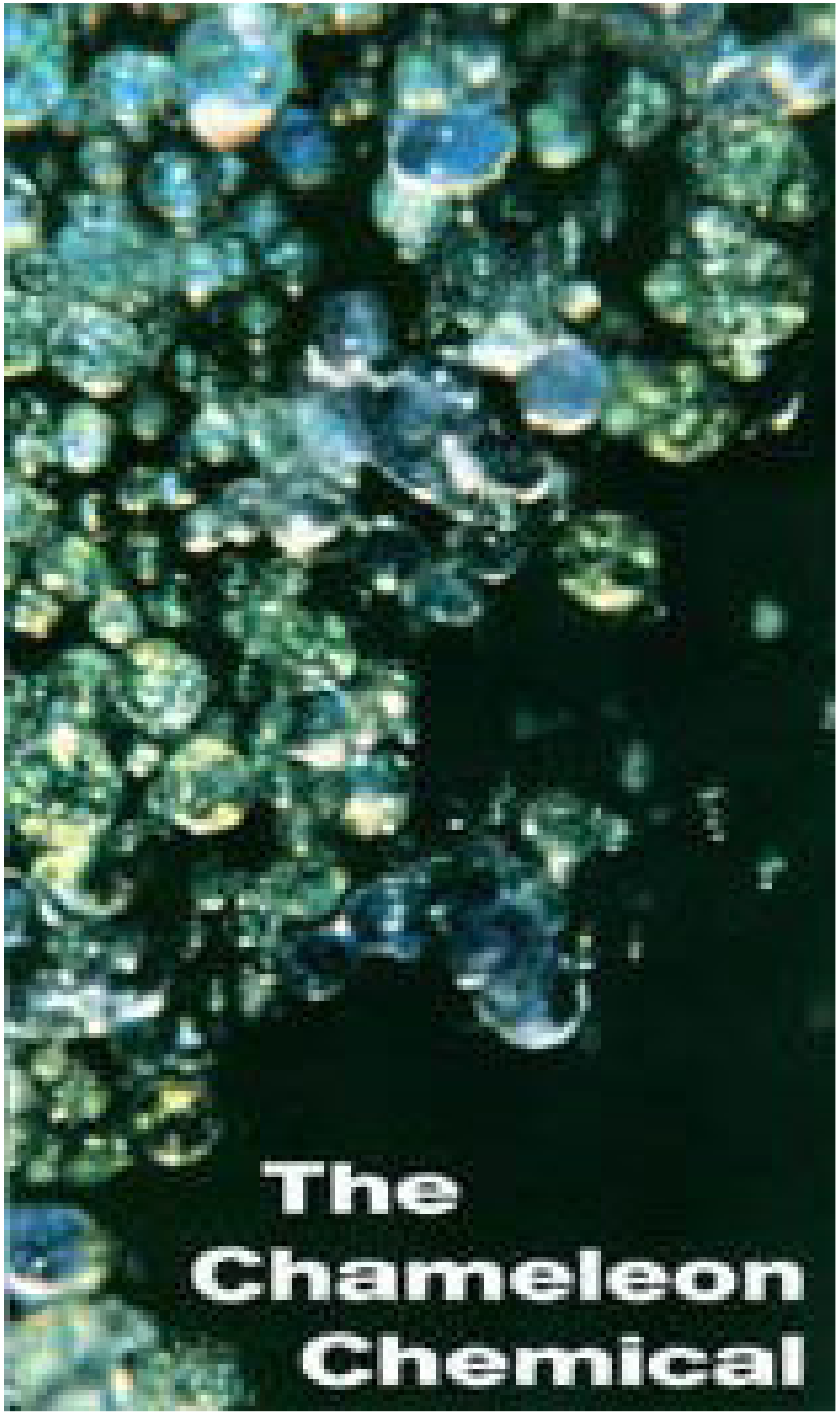
wide band -5 to 30^{o}C.

A colour/temperature response of a typical liquid crystal chemical make up helps in selecting the liquid crystal composition for a particular application.

Thermography is suggesting diagnosis and allowing screening of diseases, since in most cases illnesses exhibit hot areas where the tissues are misworking

In other cases, a bad blood circulation provides cold areas in the body

This is a landscape of CLC encapsulated droplets



This is a more interesting application

Every person is different

Also hands are different

upper, 10a; lower, 10b

The photographs in Figure show a student's hand that was coated with black paint containing a temperature sensitive cholesteric liquid crystal.

His fingers initially warm and reflecting in the blue, were due to good blood circulation.
His circulation was degraded by nicotine from smoking one cigarette, and his fingers cooled.

3.1.2. Application to Quality Control

Test with *encapsulated CLC inks or sheets*:

Turbine and compressor blades in Aeronautics; the presence of surface cracks or of surface tensions can be tested by thermal mapping.

Any piece with flat surface in Mechanical and Construction Industry, can be checked for surface cracks and not proper heat conductor material used

Printed circuit boards in Electronics can be tested: misworking elements are much hotter than planned, and their condition can be checked when in operation.

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3.1. Conclusions

•CLC are sensitive to temperature variation: as high is the temperature, as short is the helix pitch

•They can be used as thermometers or in Thermography

•Thermographic maps are useful in Medicine and in Aeronautic, Electronic, Mechanic and Construction Industry

Now it is time to have a cup of tea

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3.2. Weak anchoring and free energy of a NLC cell

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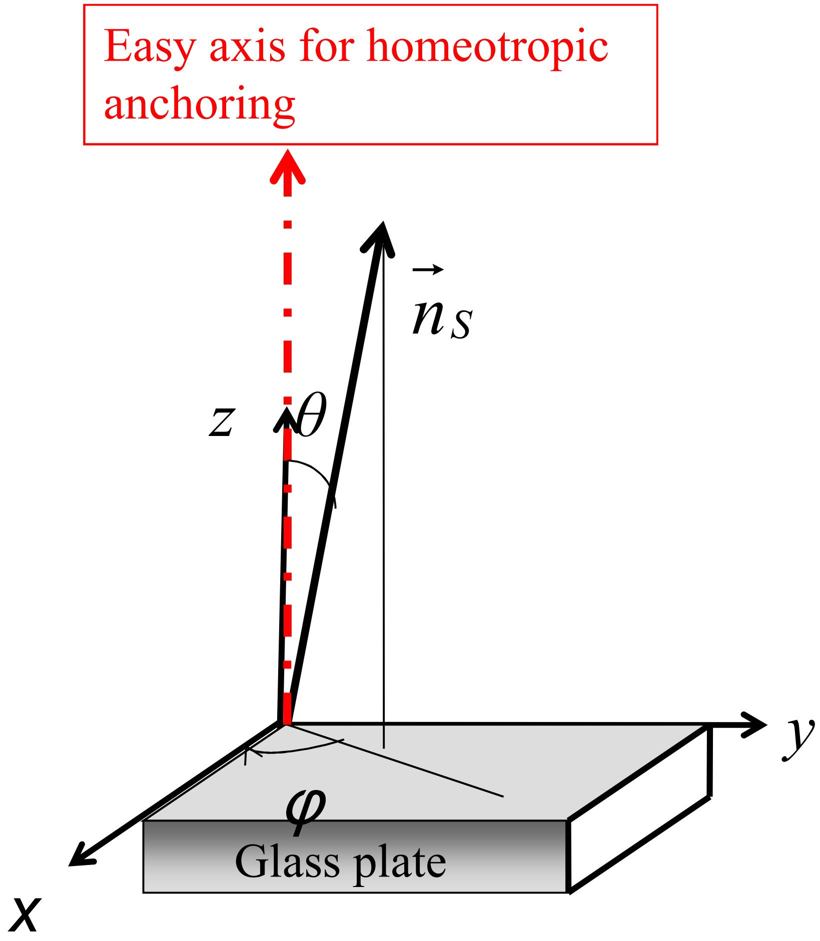
The 1st successful attempt of describing the free energy contribution of weak anchoring in a NLC cell was done by Rapini- Papoular in Orsay (France) in 1969

their paper had thousands of quotations

3.2.1. Weak anchoring with homeotropic easy axis



Their idea was to treat the anchoring as a surface field trying to align the director at the surface along the easy axis

$$F_S = -\frac{1}{2} w_H (\vec{n}_S \cdot \vec{k})^2 \quad (41)$$

where w_H is the *anchoring strength*

then

$$F_S = -\frac{1}{2} w_H (\vec{n}_S \cdot \vec{k})^2 = -\frac{1}{2} w_H \cos^2 \theta_S \qquad (42)$$

The “-” sign means that if $\theta_S = 0$ the suface free energy has a minimum

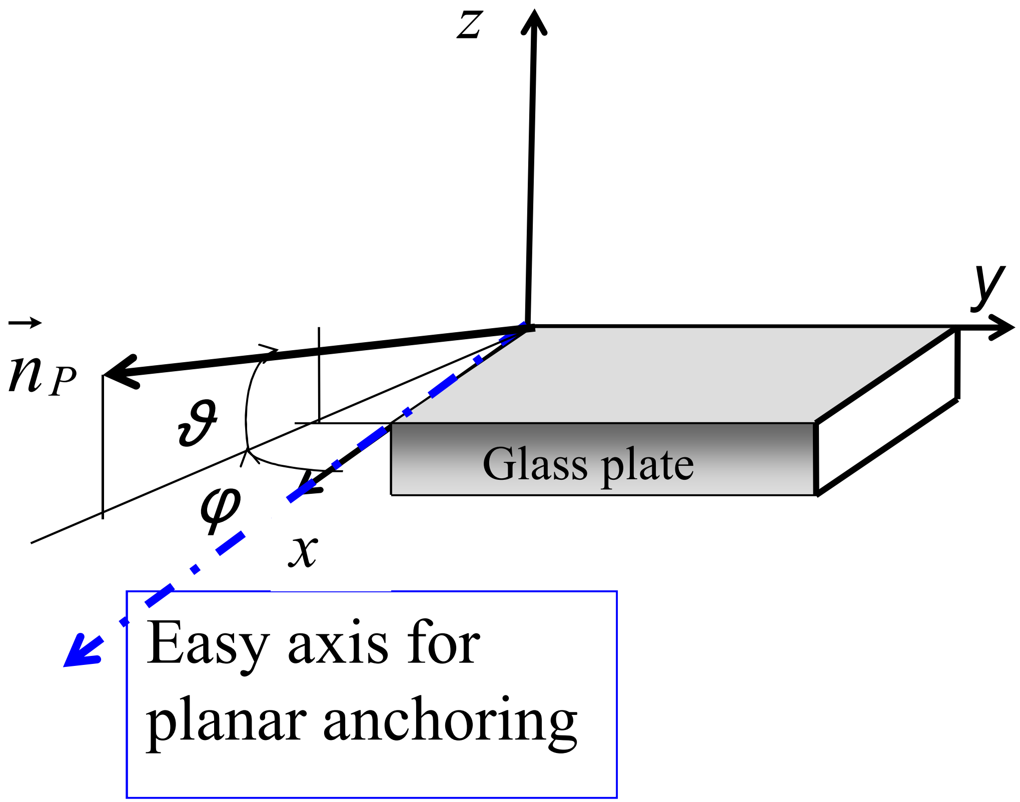
Of course adding a constant to the previous value does not change the position of the minimum. Let us add $w_H/2$, thus

$$F_S = \frac{1}{2} w_H \left(1 - \cos^2 \theta_S\right) = \frac{1}{2} w_H \sin^2 \theta_S \qquad (42')$$

which is more convenient for the calculation.

3.2.2. Weak anchoring with unidirectional planar easy axis

With the same approach, we have to write:



$$F_S = -\frac{1}{2} w_P (\vec{n}_S \cdot \vec{i})^2 =$$

$$= -\frac{1}{2} w_P \cos^2 \vartheta \cos^2 \varphi \qquad (43)$$

and only if φ is constant, and particularly $\varphi = \varphi_o = 0$, it is possible to write as before:

$$F_S = \frac{1}{2} w_P (1 - \cos^2 \vartheta) = \frac{1}{2} w_P \sin^2 \vartheta \qquad (43')$$

Mark that in SI the strengths w_H, w_P are measured in J/m^2

3.2.3. Functionals of general type: E-L eq. with weak boundary conditions

3.2.3.1.Functionals of general type

A situation more general than the one treated with the NLC cell free energy presented in the 1° lecture, eq. (5), arises when the functional *F*, being the cell free energy, is not only the integral of the free energy density *f* in the cell bulk, but also depends on a definite function $F_S(\theta_1, \theta_2)$ set at the cell surface.

$$F(\theta,\ \theta') = \int_{z1}^{z2} f(z,\theta(z),\theta'(z))\mathrm{d}z +$$

$$+ F_{s1}(\theta_1) + F_{s2}(\theta_2) \qquad \text{(w1)}$$

where $$\theta_1 \equiv \theta(z_1),\ \ \theta_2 \equiv \theta(z_2) \qquad \text{(w2)}$$

In any case the kernel *f* is an esplicit continuous function of *z*, and the director tilt angle θ as well, with its 1° derivative.

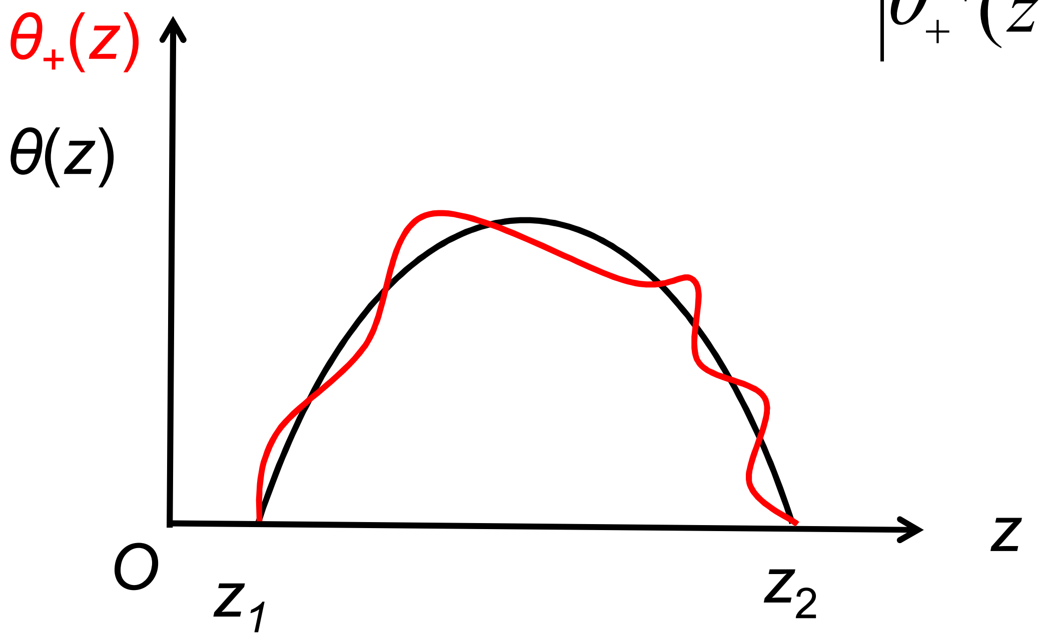
$F(\theta,\theta')$, regarded as function of *$\theta(z)$ and $\theta'(z)$, and of $F_S(\theta_1,\theta_2)$ is called a **functional of general type** in the Dominion z_1-z_2* :

$\theta(z)$ (and consequently $\theta'(z)$) is unknown, and has to be found.

As usual, we are looking for it in the ensemble of the virtual director lines $\theta_+(z)$ having tangent lines $\theta_+'(z)$ among which the actual profile $\theta(z)$ characterized by the actual $\theta'(z)$ arises, providing the functional F to be extreme.

As known, $\theta_+(z)$ are curves ε-close of 0-order to $\theta(z)$ such as $\left|\theta_+(z) - \theta(z)\right| < \varepsilon$, $\theta'_+(z)$ are ε-close of 1st order such as

$$\left|\theta_+'(z) - \theta'(z)\right| < \varepsilon$$



Now the **boundary conditions** at the border of the Dominion *provide no more fixed values*: $\theta(z_1) \neq \theta_1=0$, $\theta(z_2) \neq \theta_2=0$. Our task is to find the eq.s that $\theta(z_1)$, $\theta(z_2)$ have to satisfy at the cell surface.

Let us remind that a Functional *F has a* ***relative extremal*** *if on the curve θ(z) it has a value either always greater or always smaller than on every* curve $\theta_+(z)$ ε-close to $\theta(z)$

This is the recipe for calculating θ(z)

3.2.3.2. Euler-Lagrange equation for extremal generalized functionals

As already done, let us define a continuous finite function *η(*z*)* *going to zero at the dominion extremes,* such as

$$\theta_+(z) = \theta(z) + \alpha\eta(z) \qquad (6)$$

where α<<1 is a small real number. Then

$$\theta_+(z_{1,2}) = \theta(z_{1,2}) \qquad (7)$$

at the boundary, which functions has to be determined.

Then the free energy by substituting (6) into def.(5) is a function of α:

$$F(\alpha) = \int_{z1}^{z2} f[z, \underbrace{\theta(z) + \alpha\eta(z)}_{\theta_+(z)}, \underbrace{\theta'(z) + \alpha\eta'(z)}_{\theta'_+(z)}]\mathrm{d}z +$$

$$+ F_s[\underbrace{\theta(z_1) + \alpha\eta(z_1)}_{\theta_+(z1)}] + F_s[\underbrace{\theta(z_2) + \alpha\eta(z_2)}_{\theta_+(z2)}] \qquad (8)$$

being extremal for α=0. Hence, deriving *F* with respect to *α,* we get

$$F'(\alpha)\Big|_{\alpha=0} = 0 = \int_{z1}^{z2} [f_{\theta+}\eta(z) + f_{\theta'+}\eta'(z)]\mathrm{d}z +$$

$$+ F_{s,\theta+}\eta(z_1) + F_{s,\theta+}\eta(z_2) \qquad \text{(w10)}$$

Re-writing *as done in the fixed boundary case* the 1° integral and integrating by parts the 2° integral with differential factor $\eta'(z)\mathrm{d}z$, we obtain:

$$0 = \int_{z1}^{z2} f_\theta \eta(z)\mathrm{d}z + f_{\theta'}\eta(z)\Big|_{z1}^{z2} - \int_{z1}^{z2} \eta(z)\frac{\mathrm{d}}{\mathrm{d}z} f_{\theta'}\mathrm{d}z +$$

$$+ F_{s,\theta}\eta(z_1) + F_{s,\theta}\eta(z_2) \qquad \text{(w11)}$$

Mark that in (w11) the correct function θ(z) providing *F*-extremal is automatically chosen. Re-combining terms we obtain:

$$0 = \int_{z1}^{z2} \left[f_\theta - \frac{\mathrm{d}}{\mathrm{d}z} f_{\theta'} \right] \eta(z) \mathrm{d}z +$$

$$+ \left\{ F_{s,\theta}(z_1) - f_{\theta'}(z_1) \right\} \eta(z_1) +$$

$$+ \left\{ F_{s,\theta}(z_2) + f_{\theta'}(z_2) \right\} \eta(z_2) \qquad \text{(w12)}$$

Discussing eq. (w12) we recognize that the integral provides the already established E-L eq.:

$$f_\theta - \frac{\mathrm{d}}{\mathrm{d}z} f_{\theta'} = 0 \qquad \text{(13)}$$

Moreover, if the condition at the boundary is fixed, $\eta(z_1),\ \eta(z_2)$ identically vanish and the situation at the boundary is back to the previous one:

$$\begin{cases} \theta(z_1) = \theta_1 \\ \theta(z_2) = \theta_2 \end{cases} \tag{14}$$

But if the condition at the boundary is free, this means that

$$\eta(z_1) \neq 0,\ \eta(z_2) \neq 0 \tag{w13}$$

and thus the **boundary conditions** looking for extremals of *F* become

$$\boxed{\begin{cases} F_{s,\theta}(z_1) - f_{\theta'}(z_1) = 0 \\ F_{s,\theta}(z_2) + f_{\theta'}(z_2) = 0 \end{cases}} \tag{w14}$$

3.2.4. Homeotropic cell with ε_a<0-NLC under Electric field normal to the cell plates: weak anchoring

We have just demonstrated that E-L eq. , being bulk eq., remains the same, irrespectively to the anchoring type.

Then in our case E-L eq. writes

$$\theta''(K_{11}\sin^2\theta + K_{33}\cos^2\theta) +$$
$$+\frac{1}{2}\left[-\theta'^2(K_{11}-K_{33}) + \varepsilon_o|\varepsilon_a|E^2\right]\sin 2\theta = 0 \qquad (24)$$

as already obtained in 2° lecture, 2.2.2. as well.

It shows, as we have already noted, the presence of a threshold. In fact, if $\theta \rightarrow 0$ also $\theta' \rightarrow 0$, then (24) reads:

$$\theta'' K_{33} + \varepsilon_o |\varepsilon_a| E^2 \theta = 0 \qquad (25)$$

Eq. (25) becomes the pendulum canonic eq. as well:

$$\theta'' + k_H{}^2 \theta = 0 \qquad (26)$$

where

$$k_H \equiv \sqrt{\frac{\varepsilon_o |\varepsilon_a|}{K_{33}}} E \qquad (27)$$

But now…

the boundary conditions are no more relevant to **strong anchoring, *but to weak anchoring*!**

This means that at the surfaces, the constraints

$$\begin{cases} F_{s,\theta}(z_1) - f_{\theta'}(z_1) = 0 \\ F_{s,\theta}(z_2) + f_{\theta'}(z_2) = 0 \end{cases} \qquad \text{(w14)}$$

shall be satisfied.

By assuming

$$F_S = \frac{1}{2} w_H \sin^2 \theta_S \qquad (42')$$

for both cell plates (symmetric boundary conditions), and

$$f = \frac{1}{2}\left[\theta'^2 (K_{11} \sin^2 \theta + K_{33} \cos^2 \theta) + \varepsilon_o |\varepsilon_a| E^2 \cos^2 \theta\right] \qquad (20)$$

like already seen in 2.1., we get

$$f_{\theta'} = \theta'(K_{11} \sin^2 \theta + K_{33} \cos^2 \theta) \qquad (23)$$

Thus the **boundary conditions** in our case write:

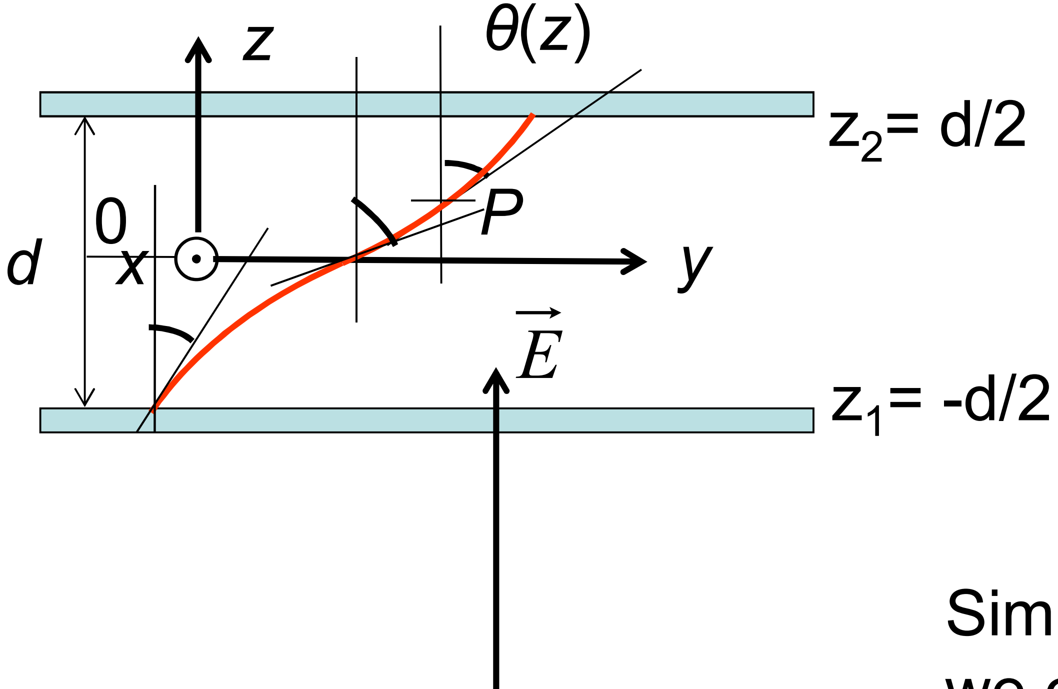
$$\begin{cases} \frac{1}{2} w_H \sin 2\theta - \theta'(K_{11} \sin^2\theta + K_{33}\cos^2\theta) = 0, \\ \text{when} \quad \theta \equiv \theta_1 \ , \\ \frac{1}{2} w_H \sin 2\theta + \theta'(K_{11} \sin^2\theta + K_{33}\cos^2\theta) = 0, \\ \text{when} \quad \theta \equiv \theta_2 \end{cases} \qquad (43')$$

Linearizing sinθ, cosθ close to the threshold:

$$w_H \theta - \overbrace{\theta' K_{11} \theta^2}^{O(3)} - \theta' K_{33} = 0, \quad \text{when} \quad \theta \equiv \theta_1, \tag{43"}$$

$$w_H \theta + \underbrace{\theta' K_{11} \theta^2}_{O(3)} + \theta' K_{33} = 0, \quad \text{when} \quad \theta \equiv \theta_2$$

Notice that the 2nd term is small of 3d order with respect to the other two



Simplyfing, eventually we obtain:

$$\begin{cases} \theta - L_H \theta' = 0, & \text{when} \quad z \equiv z_1, \\ \theta + L_H \theta' = 0, & \text{when} \quad z \equiv z_2 \end{cases}$$

(43*)

where $L_H \equiv \dfrac{K_{33}}{w_H}$. Mark that in SI we have $[L_H]$ = N/(J/m^2) = m

L_H is called "***extrapolation length***" of the NLC weak anchored cell: soon we will see why.

Eq. (43*) are differential eq. with separable variables.
Let us re-write them:

$$\begin{cases} \dfrac{\mathrm{d}\theta}{\mathrm{d}z} = \dfrac{\theta}{L_H}, & \text{when} \quad z \equiv z_1, \\ \dfrac{\mathrm{d}\theta}{\mathrm{d}z} = -\dfrac{\theta}{L_H}, & \text{when} \quad z \equiv z_2 \end{cases} \tag{44}$$

then

$$\begin{cases} \ln\dfrac{\theta}{\theta_{10}} = \dfrac{z}{L_H}, & \text{when} \quad z \equiv z_1, \\ \ln\dfrac{\theta}{\theta_{20}} = -\dfrac{z}{L_H}, & \text{when} \quad z \equiv z_2 \end{cases} \tag{44'}$$

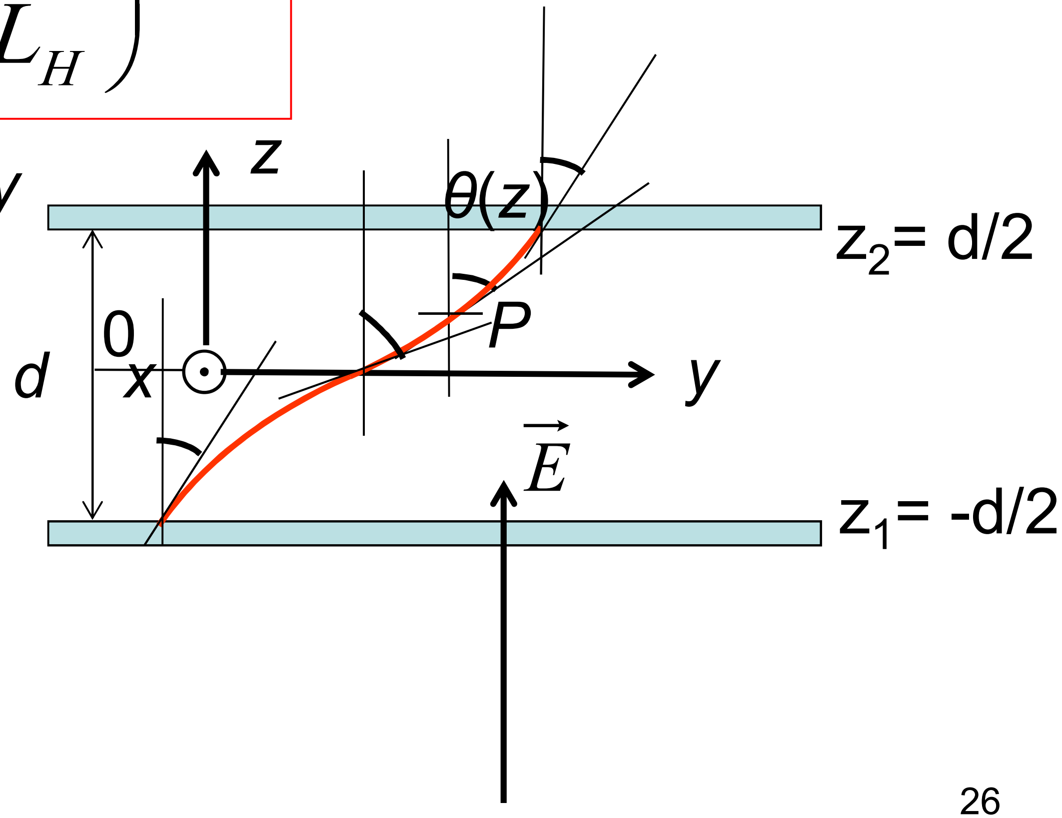
and the solutions finally read:

$$\begin{cases} \theta_1 = \theta_{10} \exp\left(\dfrac{z_1}{L_H}\right) > 0 \\ \theta_2 = \theta_{20} \exp\left(-\dfrac{z_2}{L_H}\right) > 0 \end{cases} \qquad (44^*)$$

Mark that due to symmetry

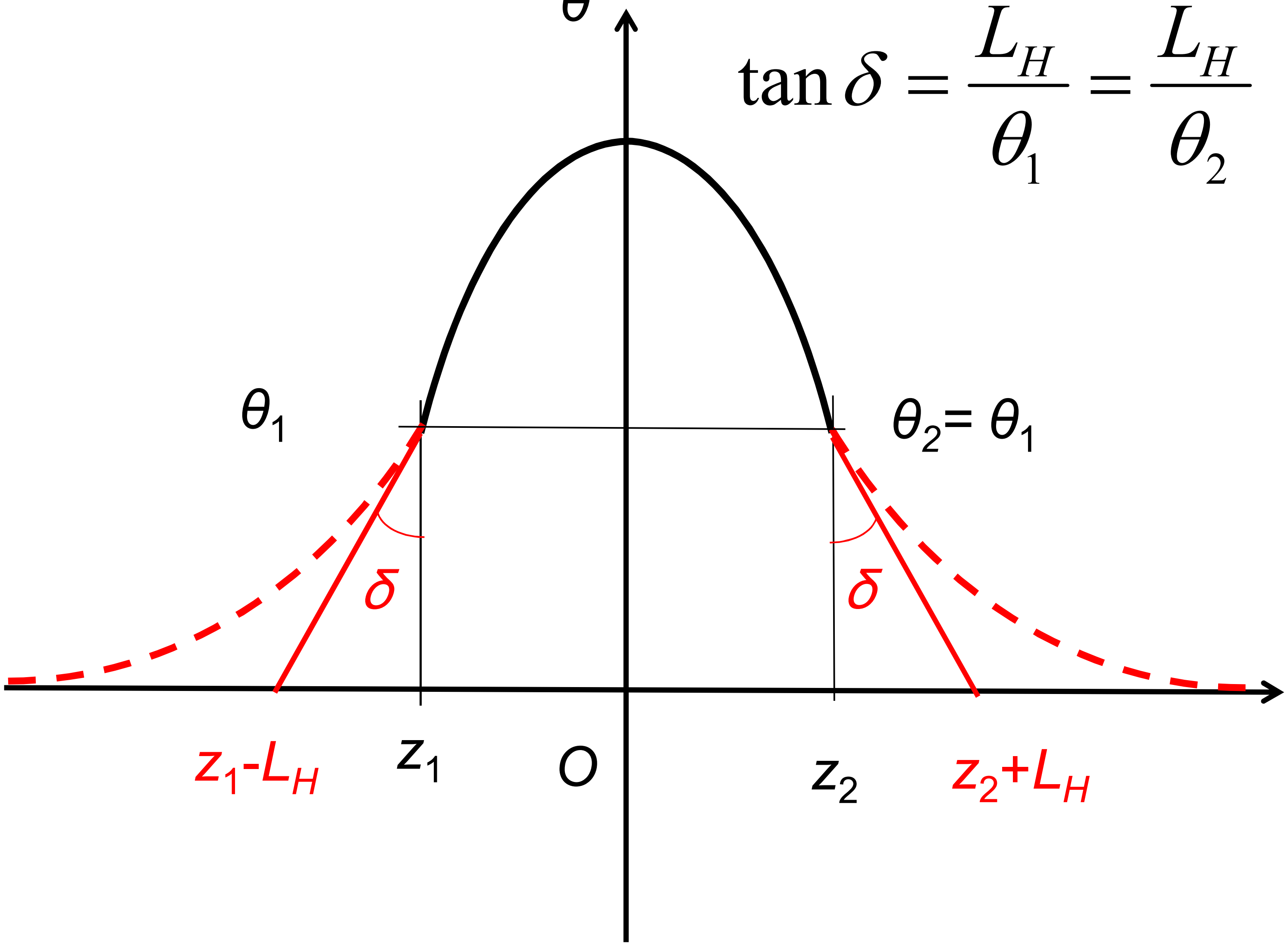
$\theta_{20} = \theta_{10}$, $\theta_2 = \theta_1$

The anchoring *does not succeed* any more to keep the director *homeotropic* at the surface



From (44*) it ìs easy to see that the angle δ formed by the geometrical sub-tangents to the exponential curves at z_1 and z_2 gives

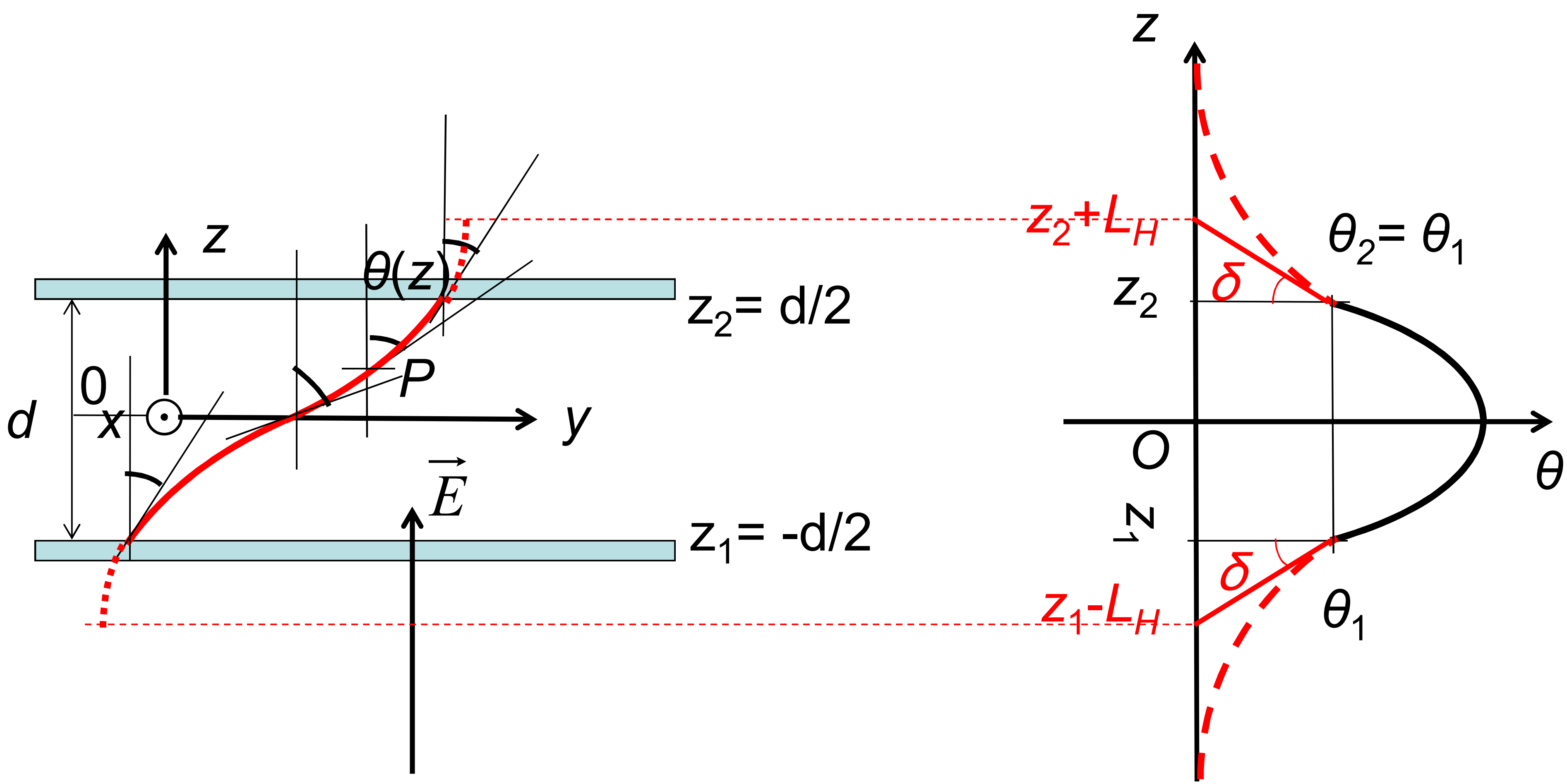
$$\tan\delta = \frac{L_H}{\theta_1} = \frac{L_H}{\theta_2} \qquad (45)$$



We can conclude that, if the *hypothetical behavior outside the interval $z_1, z_2 = z_1 + d$* ***would be linear*** *as the exponential geometrical tangents in z_1, z_2, then the NLC cell with thickness d exhibiting a symmetric weak anchoring strength* ***should present homeotropic alignment at the co-ordinates $z_1 - L_H$, $z_2 + L_H$***,

*For this reason L_H is called "***H-NLC cell extrapolation length***"*

Here the conclusion is graphically reported.



According to this conclusion, the distance ($d+2L_H$) plays the role of half wavelength of the initial distortion

Hence

$$k_H(d + 2L_H) = \pi \qquad (46)$$

and, due to (27)

$$k_H \equiv \sqrt{\frac{\varepsilon_o |\varepsilon_a|}{K_{33}}} E \qquad (27)$$

finally obtaining the threshold

for the bend electric Frederiks transition *with weak anchoring:*

$$E_{th.w} = \left(\frac{\pi}{d + 2L_H} \right) \sqrt{\frac{K_{33}}{\varepsilon_o |\varepsilon_a|}} \qquad (47)$$

Using the NLC MBBA

K_{33} = 7.5*10^{-12}N, ε_o= 8.85*10^{-12}F/m, ε_a= -0.7

in a cell with d = 10 μm, w_H = 10^{-5}J/m^2=10^{-5}N/m,

We get L_H = 7.5*10^{-7}m = 0.8 μm, and the threshold field value is obtained as $E_{th.w}$= **0.30 V/μm**. Remember that with strong anchoring it was E_{th}= **0.35 V/μm**: *the threshold diminishing is 15%.*

If w_H = 10^{-6}J/m^2, then $E_{th.w}$= **0.14 V/μm** , *53% of reducing.*

For the **application to display**, strong anchoring insures rapid switch-off; weak anchoring insures diminishing of the threshold voltage

*There is a competition surface-field: it is necessary, as every time when there is a competition, to look for a **compromise***

3.2. Conclusions

- The E-L eq. does not depend on the anchoring
- The weak anchoring affects only the boundary conditions
- The extrapolation length of a NLC-cell identify the point outside the cell where the linear extrapolated profile vanish if the anchoring is weak
- The threshold of a Frederiks transition diminishes with weak anchoring

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3.3. LC Application to Display, Monitor, TV: Mechanism of cell switching

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MEPhI, Moscow, 24 September 2014

3.3.1. Unidirectional Planar NLC (= PN)

A LC for electro-optic application to Display, Monitor and TV must not present any *schlieren* in each pixel, which has to be uniform, either in the state OFF or ON for what is concerning the transmission of light

Let us start considering NLC

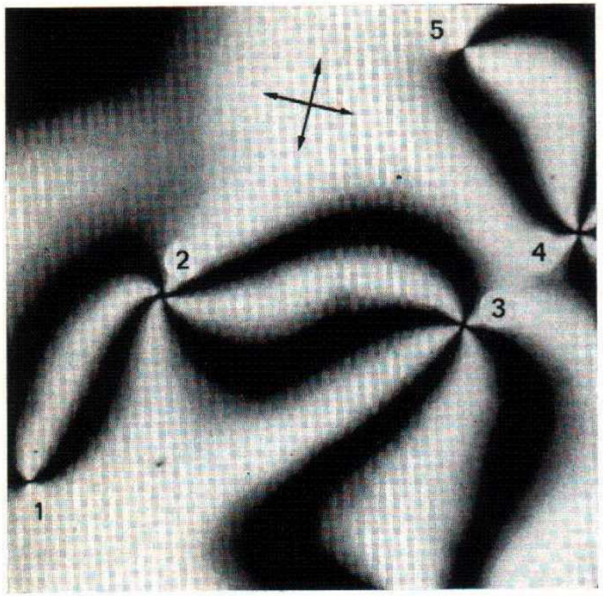


Plate 1

Nematic schlieren texture. Orientation of the crossed polarizers is indicated by the plotted cross. Strength of the points: No. 1: $s = +\frac{1}{2}$, No. 2: $s = -1$, Nos. 3 and 4: $s = +1$, No. 5: $s = -\frac{1}{2}$.
4-n-Octyloxyphenyl 4-n-butyl-cyclohexanecarboxylate 71 °C, x 150.

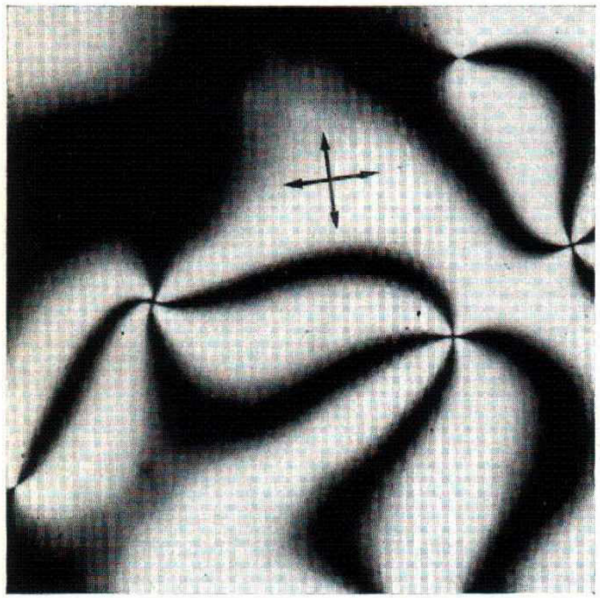
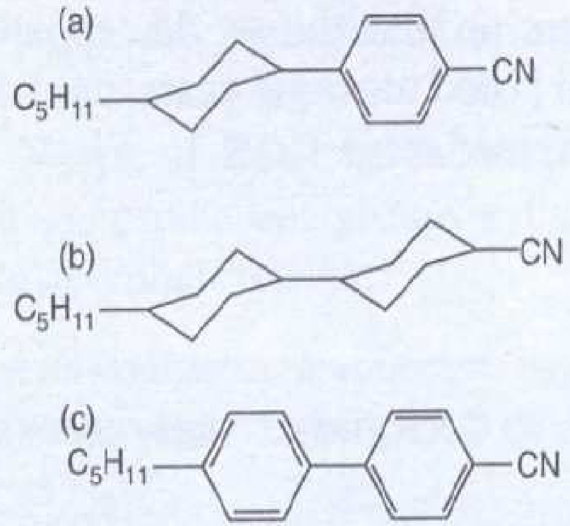


Plate 2

Same section as in plate 1. Polarizers rotated counter-clockwise by 22.5°.

Important compounds for the birth of Display Industrie



Liquid crystal materials prepared by Merck (a, b) and BDH (c) are shown above. In structure (a) a cyclohexane ring is joined to a phenyl ring, while in (b) two cyclohexane rings are joined together.

Together these compounds invented by George Gray and Rudolf Eidenschink dominated the materials used in twisted nematic displays for more than a decade. However materials development never stands still, and new and better compounds were discovered for the twisted nematic and other types of liquid crystal display that became available. The chemical stability of the cyano-biphenyls, phenylcyclohexanes and bicyclohexanes meant that their core structures were ideally suited to liquid crystal displays. Chemical modification of the basic structures was possible to produce a wide variety of new compounds, and these were marketed by BDH in the UK, E. Merck in Germany and increasingly by chemical companies in Japan.

1° demand is that the range of N-mesophase shall be very large around **room temperature.** In particular, if for military use, they have to work from -30°C till +60°C

2° demand is that they have to exhibit a short relaxation time from OFF to ON state and viceversa (this require small viscosity)

3° demand is that they must possess long life

For all these reasons, if the way was open by Gray of Hull (GB) with the discovery of alkyl- and alkoxycyanobiphenyl series, the up-today working materials are **mixtures of 10 compounds**

At left, a picture (at nano-scale) of a mlc layer of **5CB**

At right, an ancient TN NLC-watch

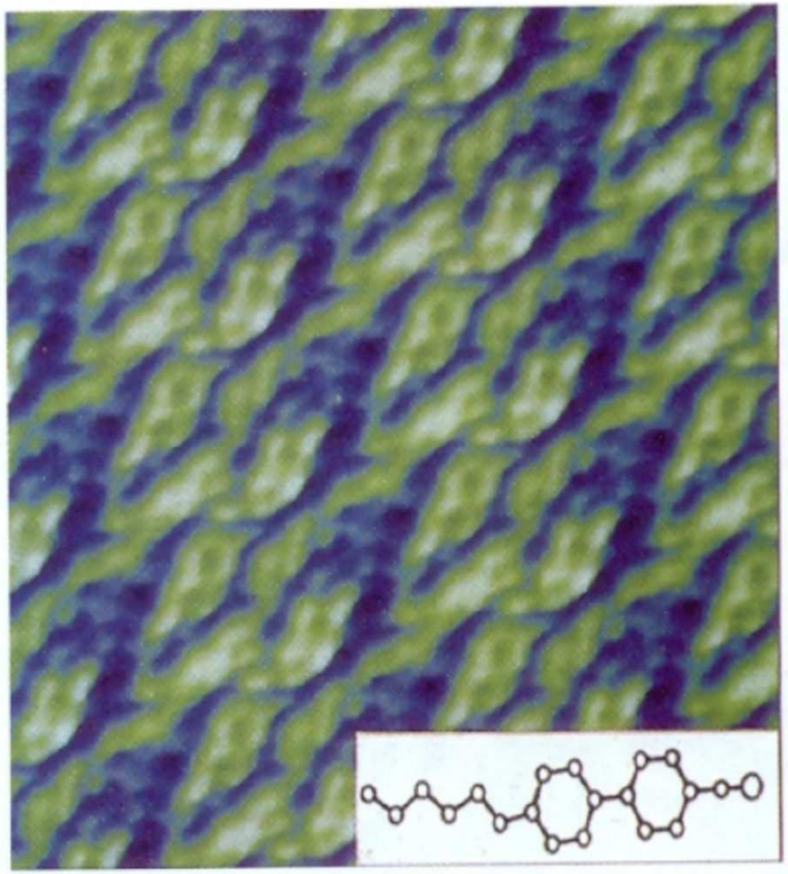
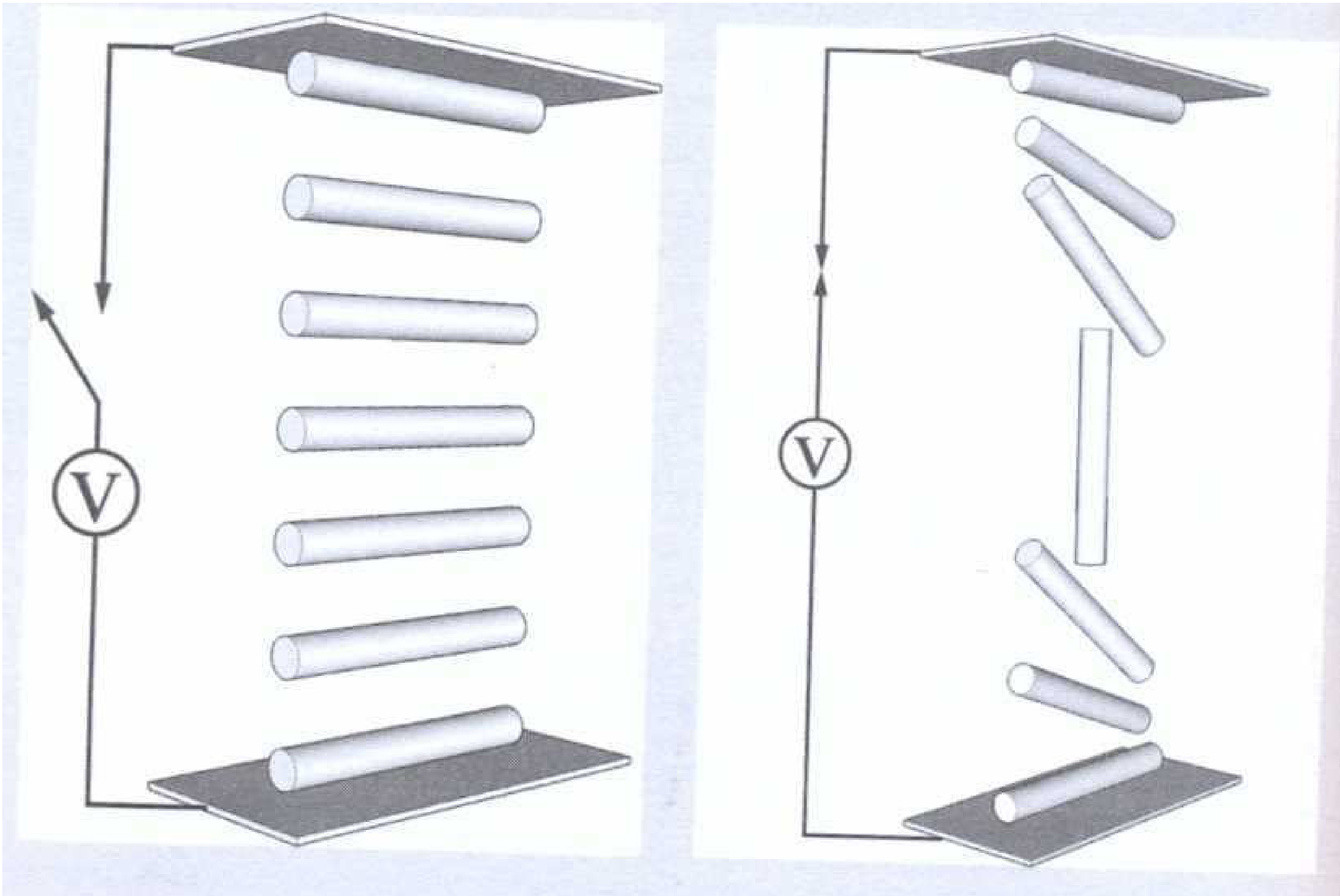


Plate 10 An image of a thin film of liquid crystal molecules obtained using scanning tunnelling microscopy. The alignment of the molecules is similar to that adopted in a nematic liquid crystal. Inset is a representation of the molecular structure of the molecules being viewed. Courtesy of Dr Jane Frommer, IBM Almaden Research Centre. (See Technical Box 4.3, pp.88–89)

Plate 11 One of the first twisted nematic liquid crystal displays (Courtesy of Martin Schadt). (See Figure 10.4, p.220)

The unit cell of the *1st display mode* was based on Frederiks transition from **unidirectional Planar N** to a **quasi-homeotropic N (**with electric field definitely greater than the threshold)



Each digit of Display is made by 7 cells

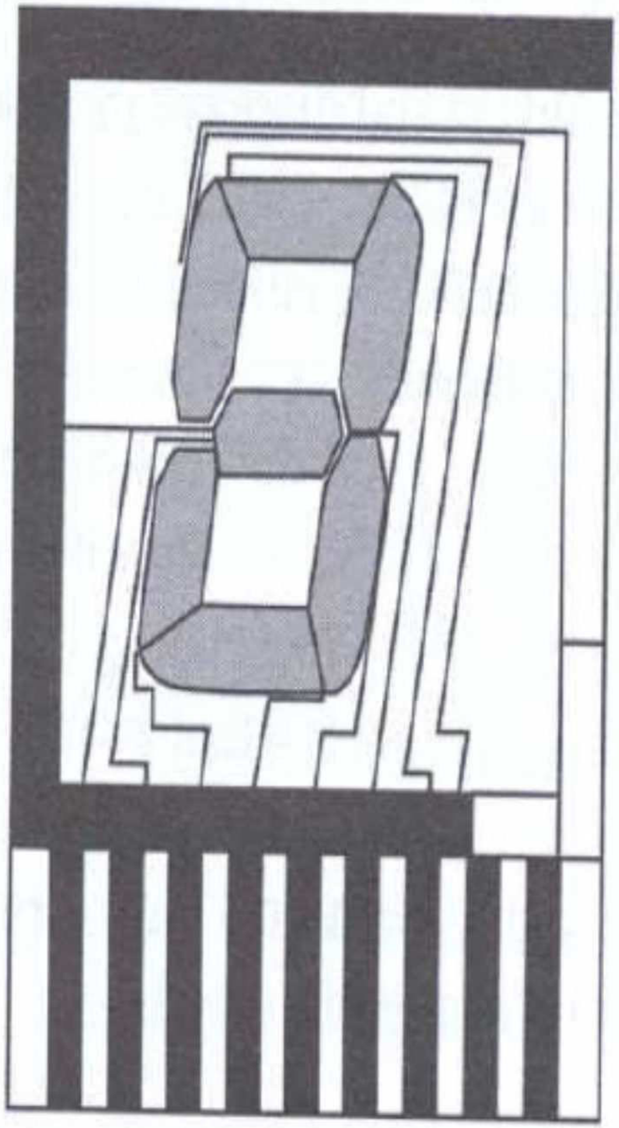
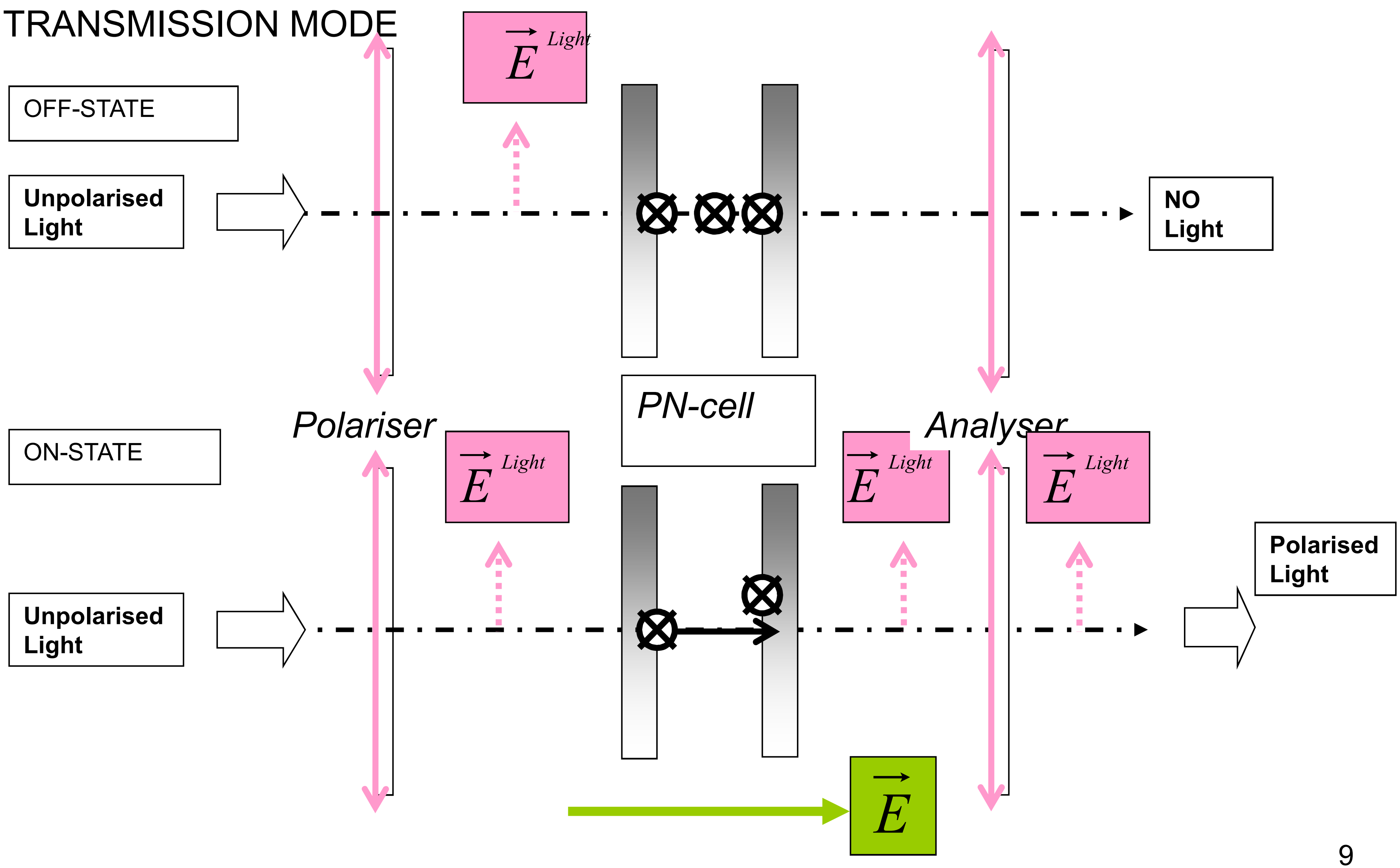


Figure 11.1 The familiar seven-segment display.

PN-display mechanism



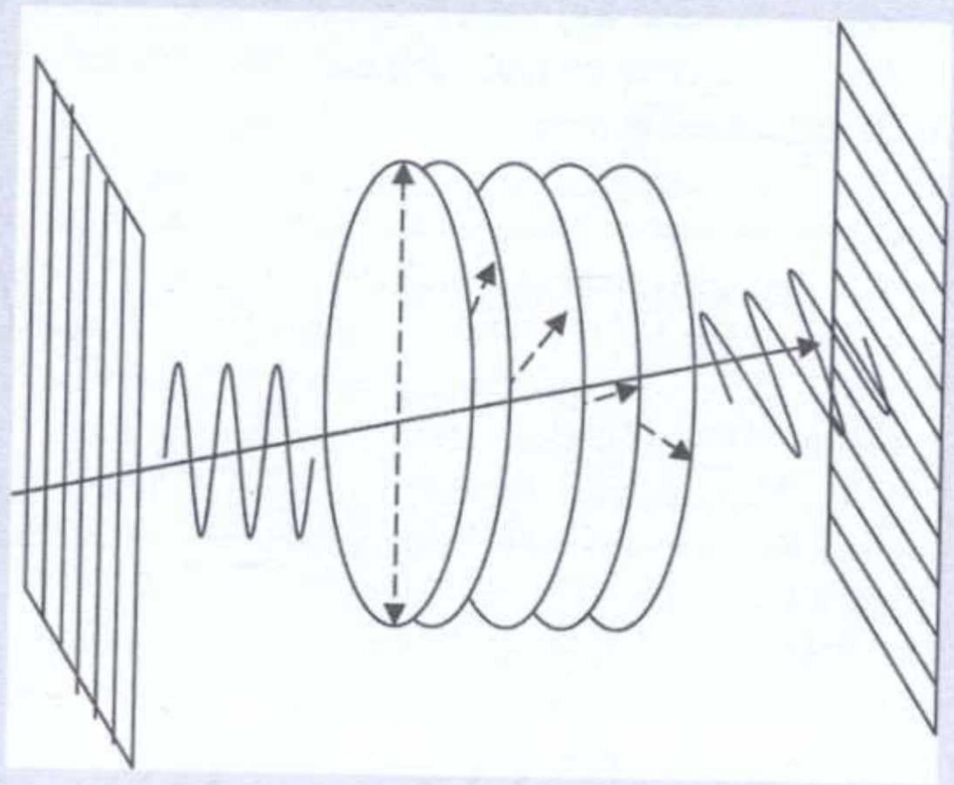
***Transition time* ~ ms**

3.3.2. Twisted NLC cell (= TN)

In 1911 Maugain discovered that a 90° twisted structure of NLC turns by 90° the polarization plane of light beam impinging onto its surface optic axis

Mauguin's twist experiment

An important experiment that Mauguin performed was to prepare a liquid crystal film in which the optic axis, or director, twisted by 90° through the sample. He did this by rubbing his microscope slides, as he had done before, but rotating one by 90° with respect to the other. He found a remarkable effect. The polarization direction of the light twisted with the director, so the emergent light polarization was at right angles to the incident polarization. So, however he oriented his liquid crystal sample, light was transmitted. This effect is known as 'guiding', and relies on having a thin sample roughly equal to the wavelength of the light being guided.



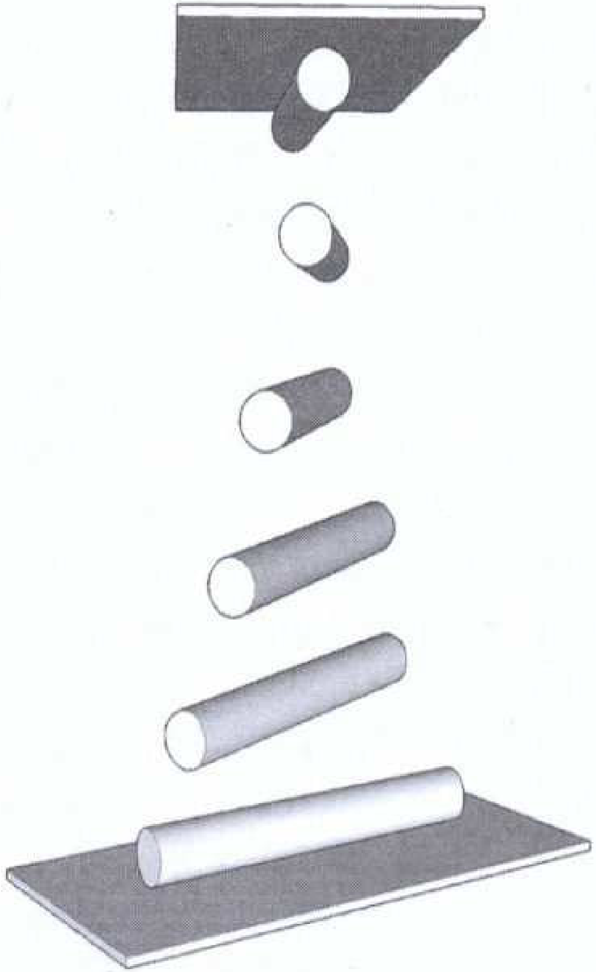
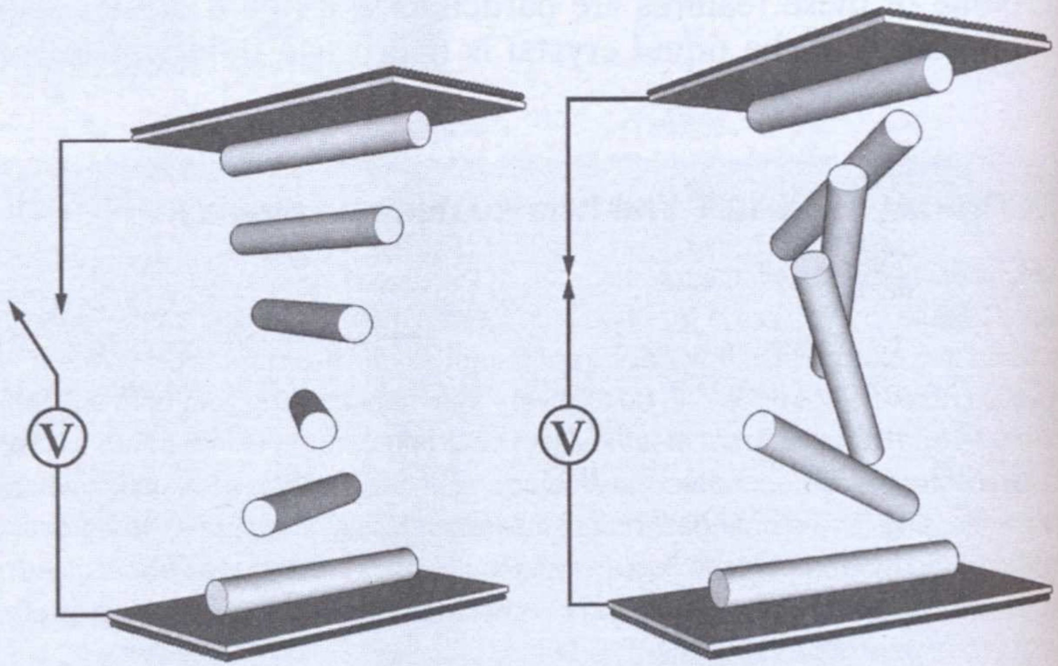


Figure 9.1 Mauguin's twisted structure. The top and bottom plates represent microscope slides, which Mauguin twisted with respect to each other. The alignment of the molecules, or more accurately the optic axes, was fixed at the surfaces, but in between the surfaces the optic axes twisted by the same amount as the angle between the microscope slides. Mauguin did not treat the surfaces of the slides, so he selected regions (domains) where the optic axes were parallel to the surfaces.

Historically, the *2nd mode* of Display consists of a Frederiks transition in a Twisted N cell

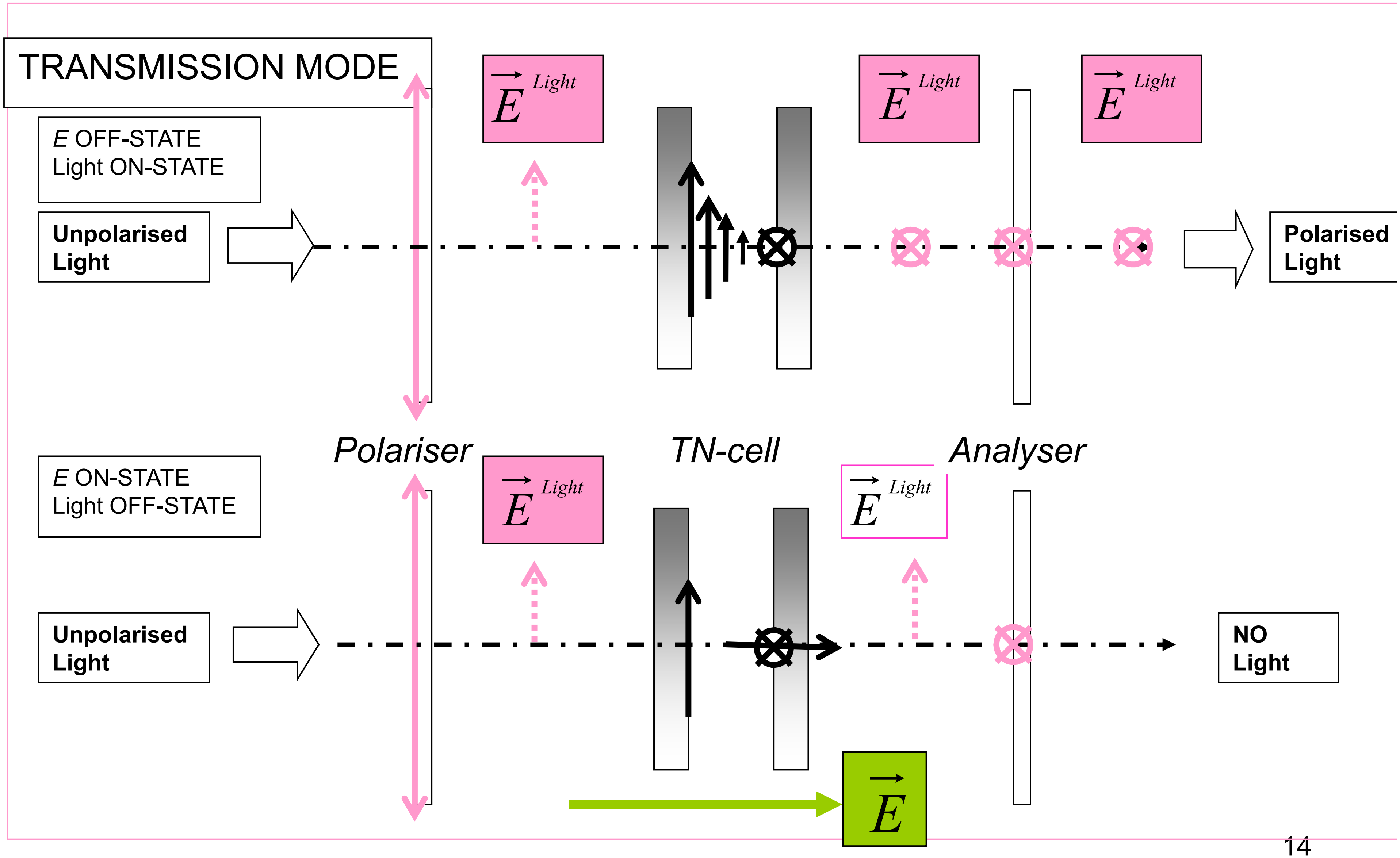
Top glass plates of cells. The alignment direction for the liquid crystal is perpendicular (90°) to the alignment direction on the bottom plates. This is indicated by a twist of the top plate with respect to the bottom plate. The inside surfaces of the plates are electrically conducting to allow application of a voltage. The outside surfaces of the plates have thin polarizers attached so that their optical transmission direction is perpendicular to the transmission direction of the bottom plates.

Bottom glass plates of cell. The alignment direction for the liquid crystal is perpendicular to the alignment direction on the top plates. The inside surfaces of the plates are electrically conducting to allow application of a voltage. The outside surfaces of the plates have thin polarizers attached so that their transmission direction is perpendicular to the transmission direction of the top plates.



Schematic representation of the operation of a twisted nematic cell: left = OFF STATE in which light is transmitted; right = ON STATE in which no light is transmitted.

TN-display mechanism



Transition time ~ ms

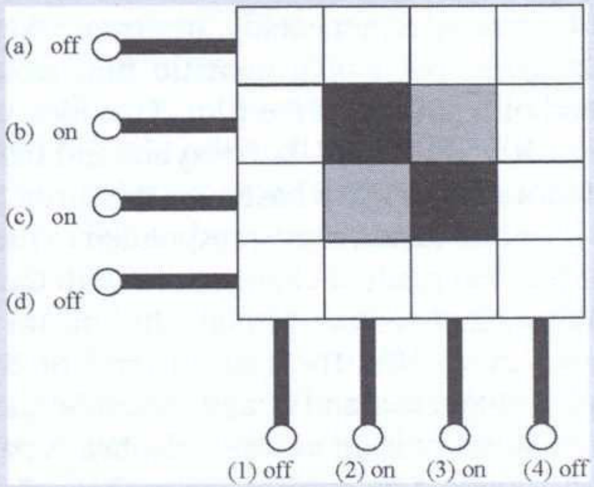
For Monitors and TV, main problems are:

Matrix addressing

Multiplexing

TECHNICAL BOX 11.1 Matrix addressing and multiplexing

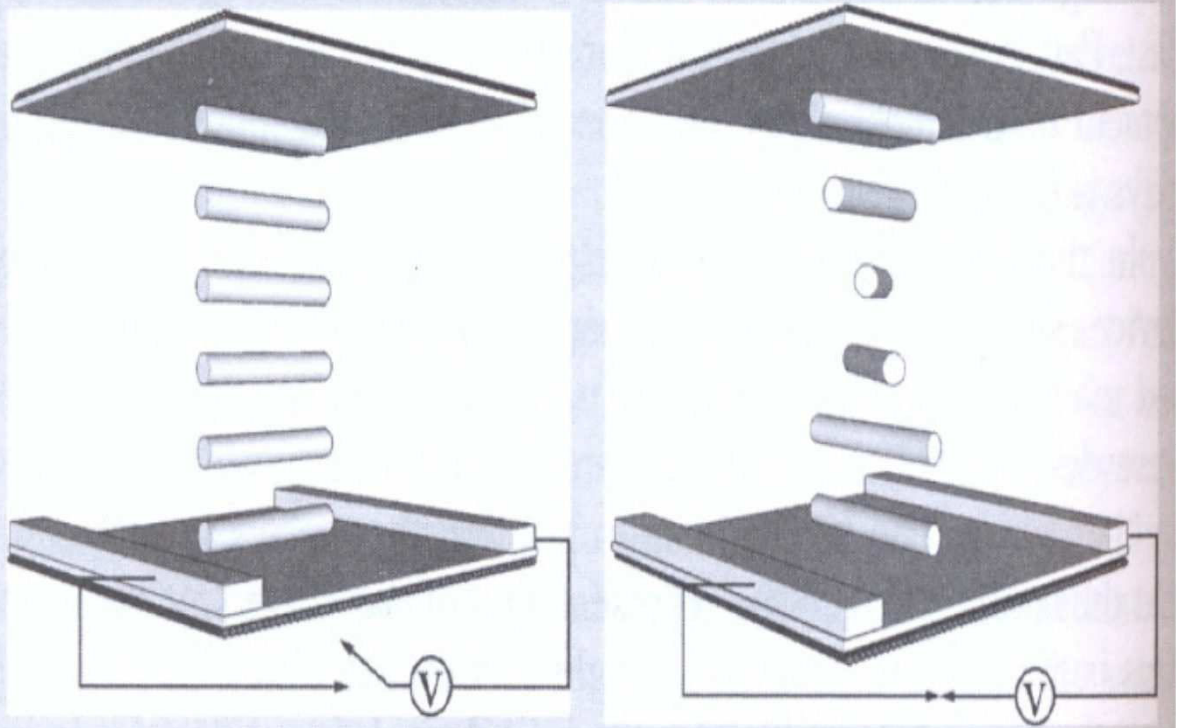
The problem with displays made up of separately switched (addressed) pixels (picture elements) is that for complex images, the number of electrical connections becomes very large. One way of dealing with this is to use a technique known as **matrix addressing**. This is where the elements of the image (pixels), now small square dots, are arranged as a matrix, each row and column of which has a separate electrical connection. Since the display is a sandwich with electrical connections on both sides of the liquid crystal film, the row connections can be on one side of the film, and the column connections on the other. If, say, half the required voltage to activate a particular pixel is applied to a row, but then the other half applied to a single column, then only that pixel identified by the specific row and column numbers will receive the full voltage and be switched on. This is the principle of matrix addressing. If the number of rows is n and the number of columns is m, then the total number of connections is $(n + m)$ instead of $n \times m$, which would be required for individual addressing of each pixel.



But it is not quite as simple as that, since an image will require a number of individual pixels in the matrix to be activated. For example, in the figure above pixels 2b and 3c are to be activated by switching rows b and c and columns 2 and 3, but unwanted pixels 3b and 2c are also activated. To deal with this, another concept is introduced: **multiplexing** or time-sharing. If the pixels required

Further developments:

In-Plane Switching mode (IPS)



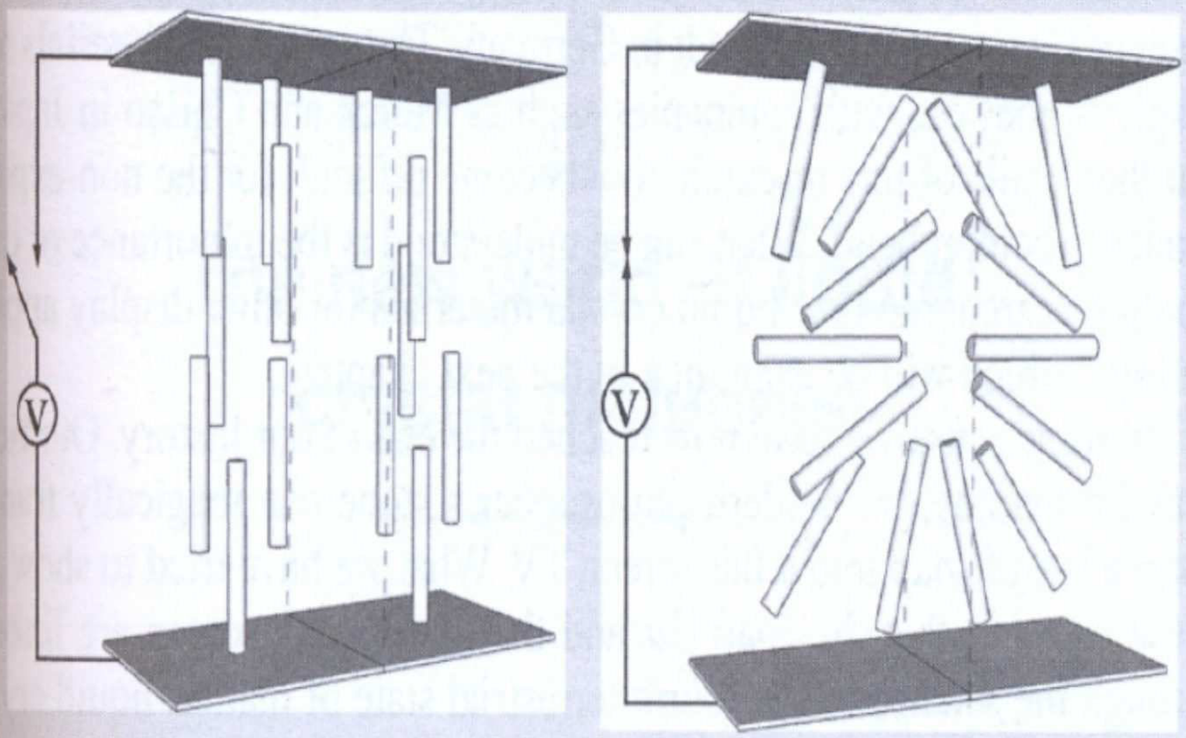
IPS off state – no light transmitted   IPS on state – light transmitted

The optical characteristics of the film still changed from untwisted to twisted, but the molecules of the liquid crystal remained in the plane of the containing plates and the electrical signals were connected to just one of the plates. The upside of this arrangement was that the angle of view of the cells was very much improved; the downside was that the active plate was more complicated to manufacture and the electrical connections all on one plate reduced the light transmittance through the display.

This mode, known as **VAN** (=**V**ertical **A**ligned **N**ematic)

(Why "Vertical"? It should be "Homeotropic")

Is the best for HD TV, obtaining a very large view angle



VAN cell off, no light transmitted

VAN cell on, light transmitted

The VAN cell illustrated above is divided into two and treated in such a way that one half of the cell tilts to the right, while the other half tilts to the left. This is one way of dealing with the problem of the angle of view. By having half the pixels tilting one way and the other half tilting the other way, the symmetry of the image is maintained: it looks exactly the same from the left as from the right. The images above are only schematic, but illustrate that the response of the liquid crystal to the applied voltage is greatest in the centre of the cell, away from the aligning surfaces of the electrodes.

Plate 12 A modern flat-screen liquid crystal display television set. These are currently manufactured up to a size in excess of 1 m diagonal. For scale, an image one of the first twisted nematic displays is included. Main image courtesy of Sharp, first twisted nematic display image courtesy of Martin Schadt. (See Figure 11.2, p.248)

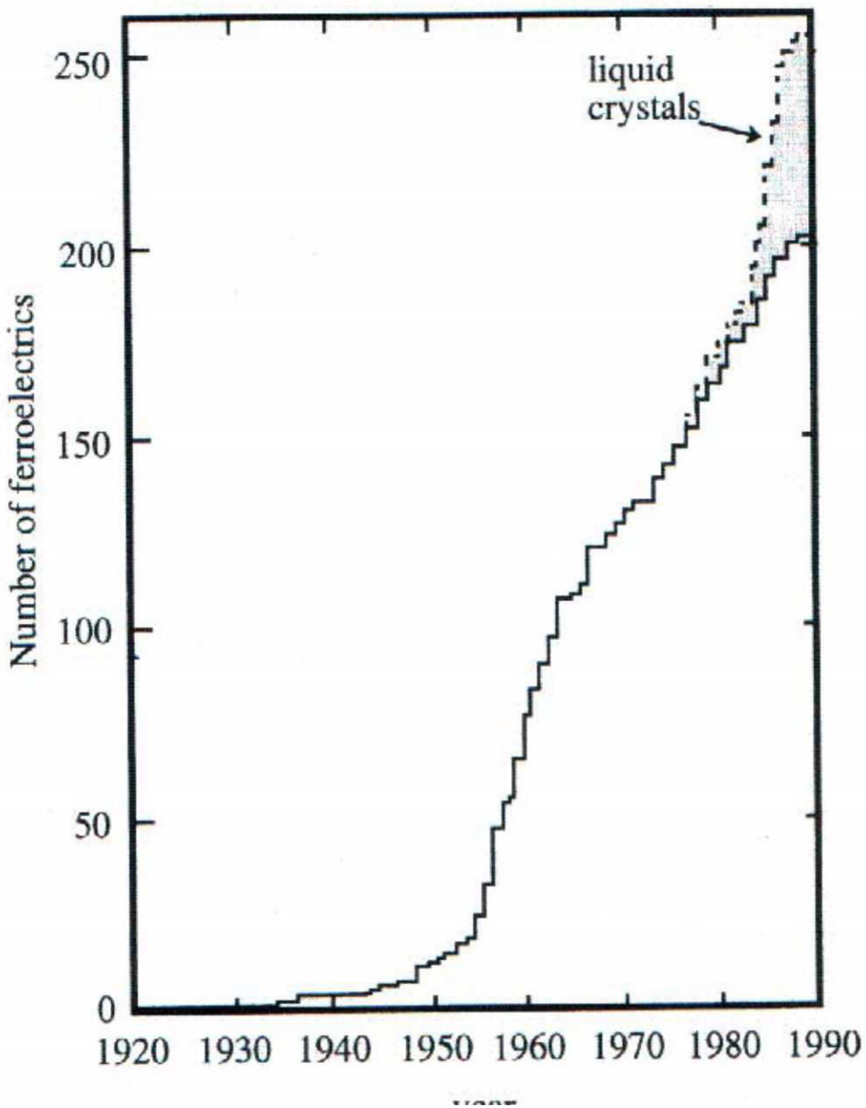
Flat screen, 1 m-diagonal

3.3.3. CHIRAL SMECTIC C* DISPLAY

SURFACE STABILIZED FERROELECTRIC LC CELL (= SSFLC)

Invented by **Clark** (Boulder, Colorado) and **Lagerwall** (Göteborg, Sweden), still not in the market, but only as Canon prototype

Ferroelectric materials development



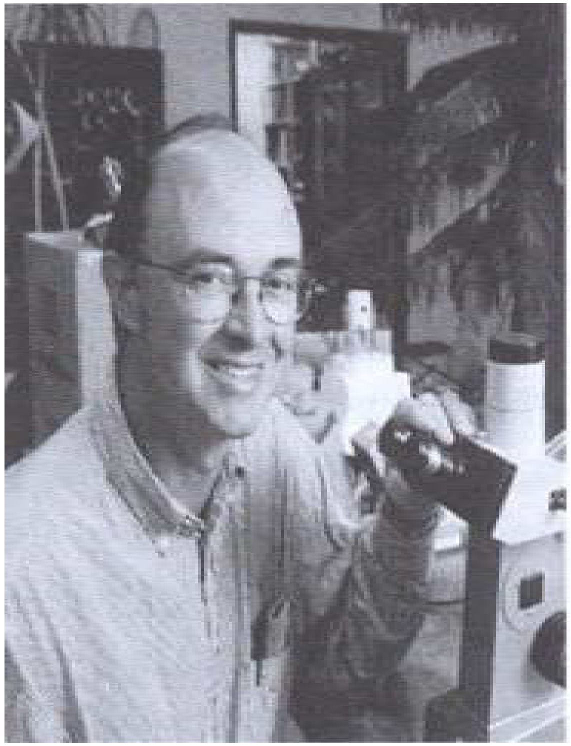


Figure 12.9 Bob Meyer (b. 1943).

Bob Meyer, Harvard Univ, 1st understood that Smectic C* are Ferroelectric (1973)

C*mlc as fishes with *right side white* and *left side black*

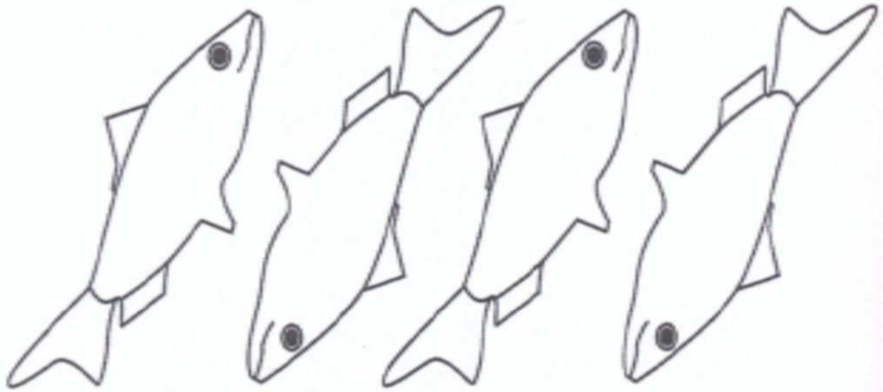
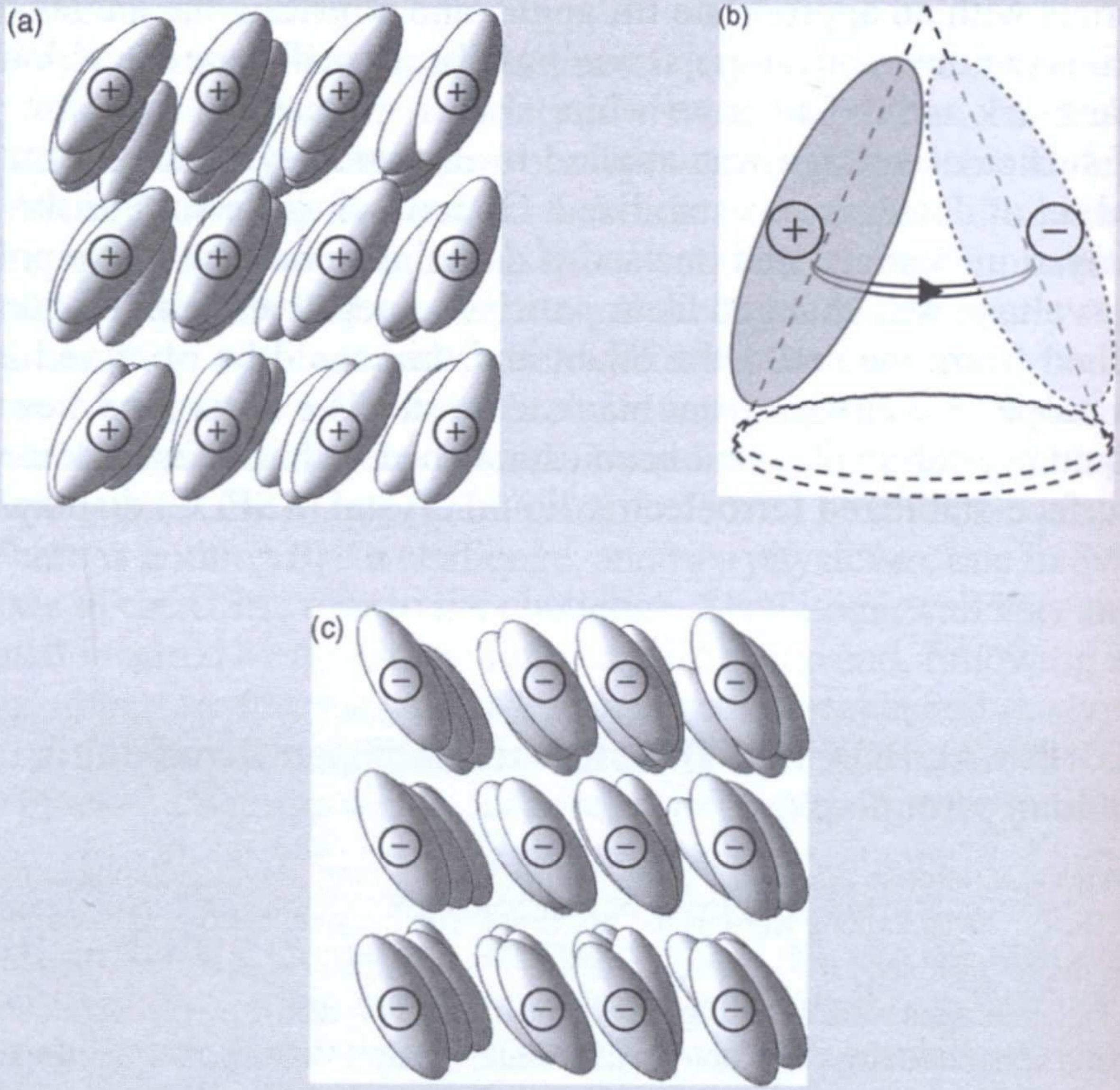


Figure 12.10 Packing of fish tilted in a layer. Only the right-side is visible from the front: the fish are tilted to the right. Viewed from the back, only the left sides would be visible, and the fish would be tilted to the left. (Adapted from de Gennes[16] and Goodby[17].)



A single molecule rotates from left to right around the surface of an (imaginary) cone, and now presents a negative charge on the surface, but with a reversed tilt direction.

Fishes side white or black, director side charge plus or minus

And an electric field can act!

Smectic C*

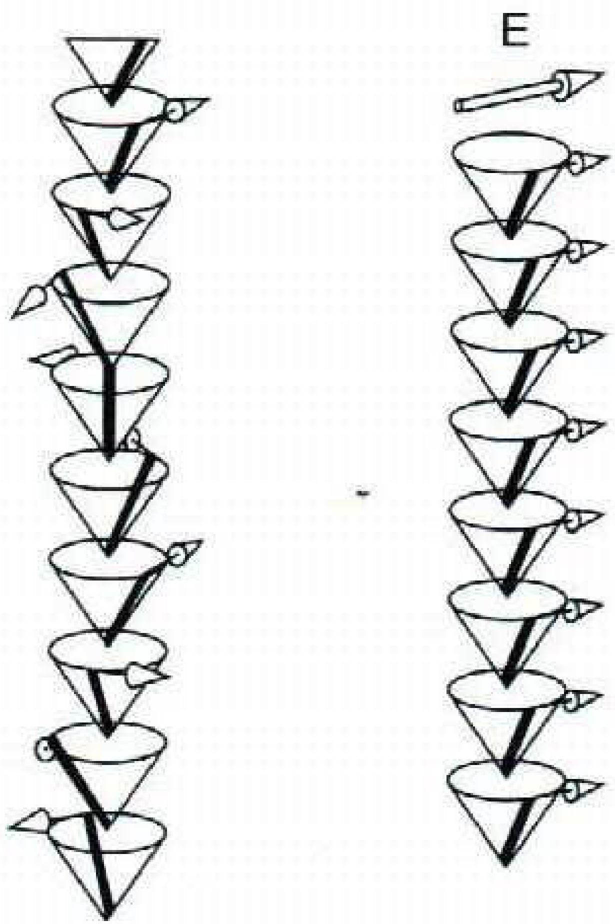


Figure 15. The helical configuration of the director–polarization couple is unwound by a sufficiently strong electric field *E*. The increasing field induces a macroscopic polarization (which is thus not spontaneous) and finally polarizes the medium to saturation (all dipolar contributions lined up parallel to the field), as shown to the right.

Surface stabilization of Smectic C*

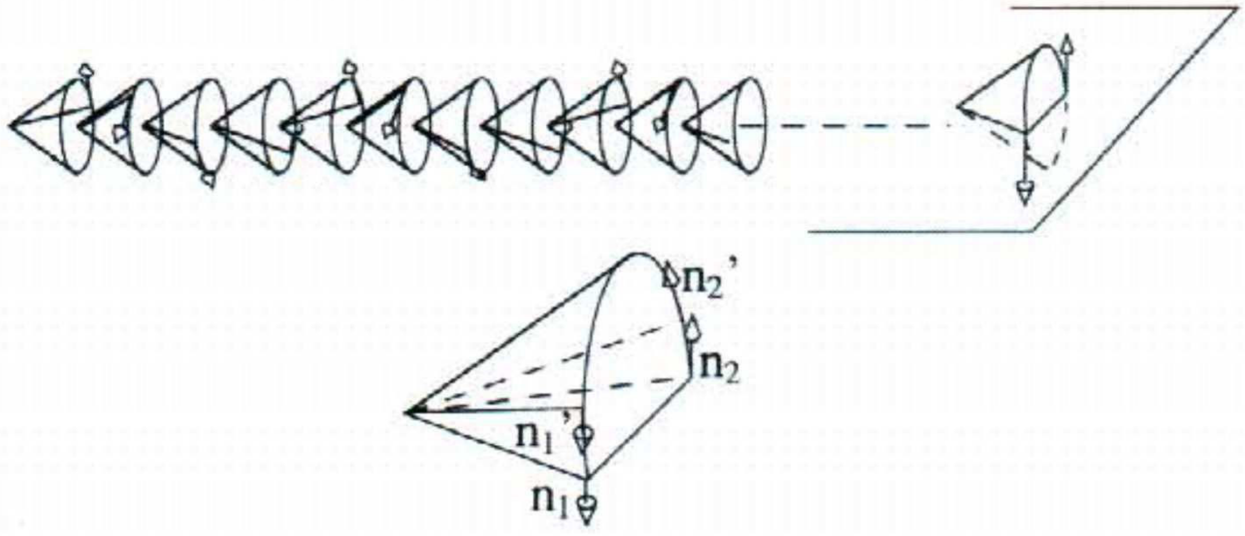
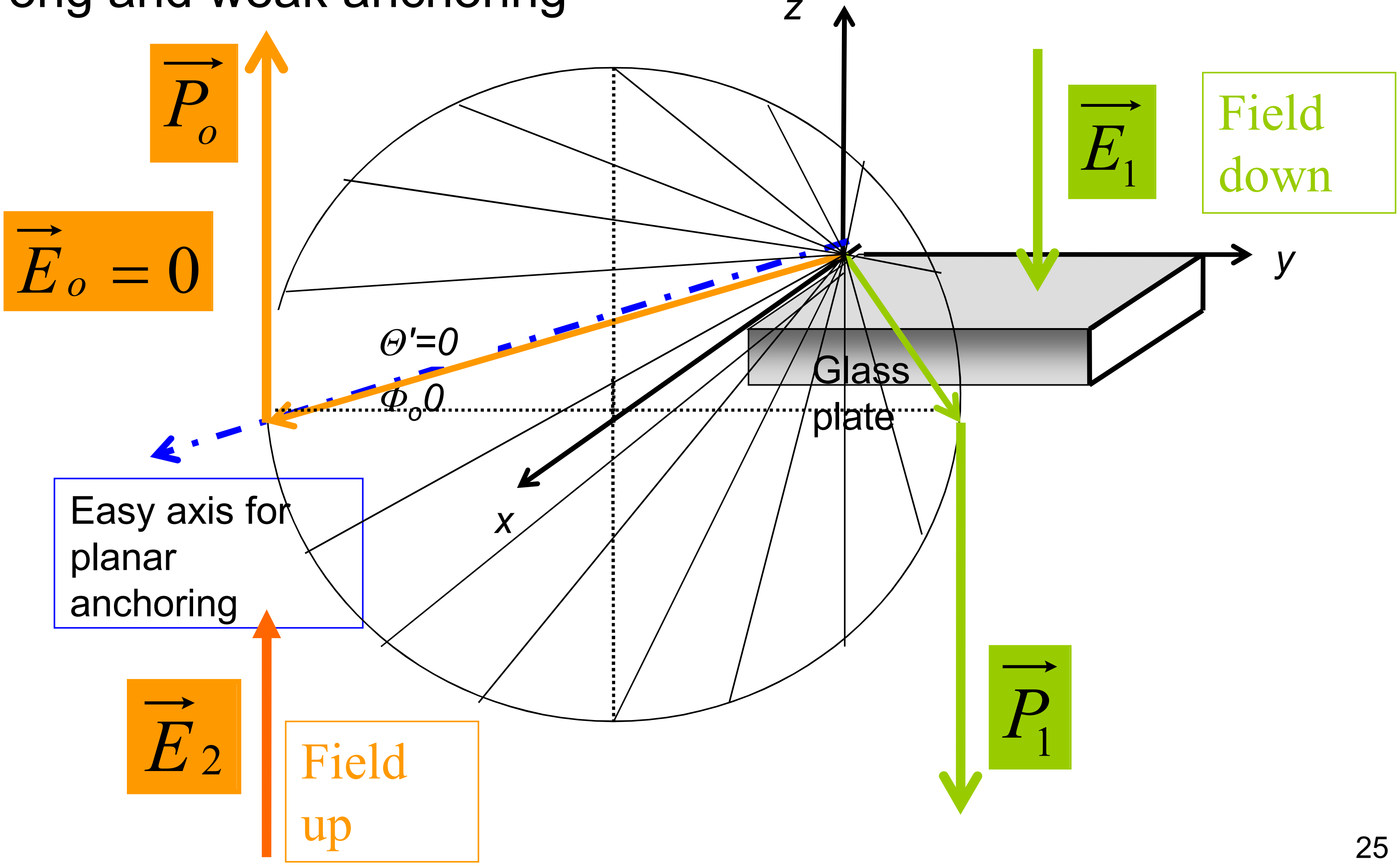


Figure 16. Elastic unwinding, by the surfaces, of the helical twist in the bookshelf geometry of smectic C*. The helical bulk state is incompatible with the surface conditions and therefore can never appear in sufficiently thin cells. The surface acts as an external symmetry breaking agent, reducing the degeneracy of the bulk to only two selected states. In the most attractive case these are symmetric, which also leads to a symmetric bistability of the device. The two memorized director states, n_1 and n_2 (n_1' and n_2' in the case of a pretilt different from zero) represent polarization states of opposite (or nearly opposite) direction.

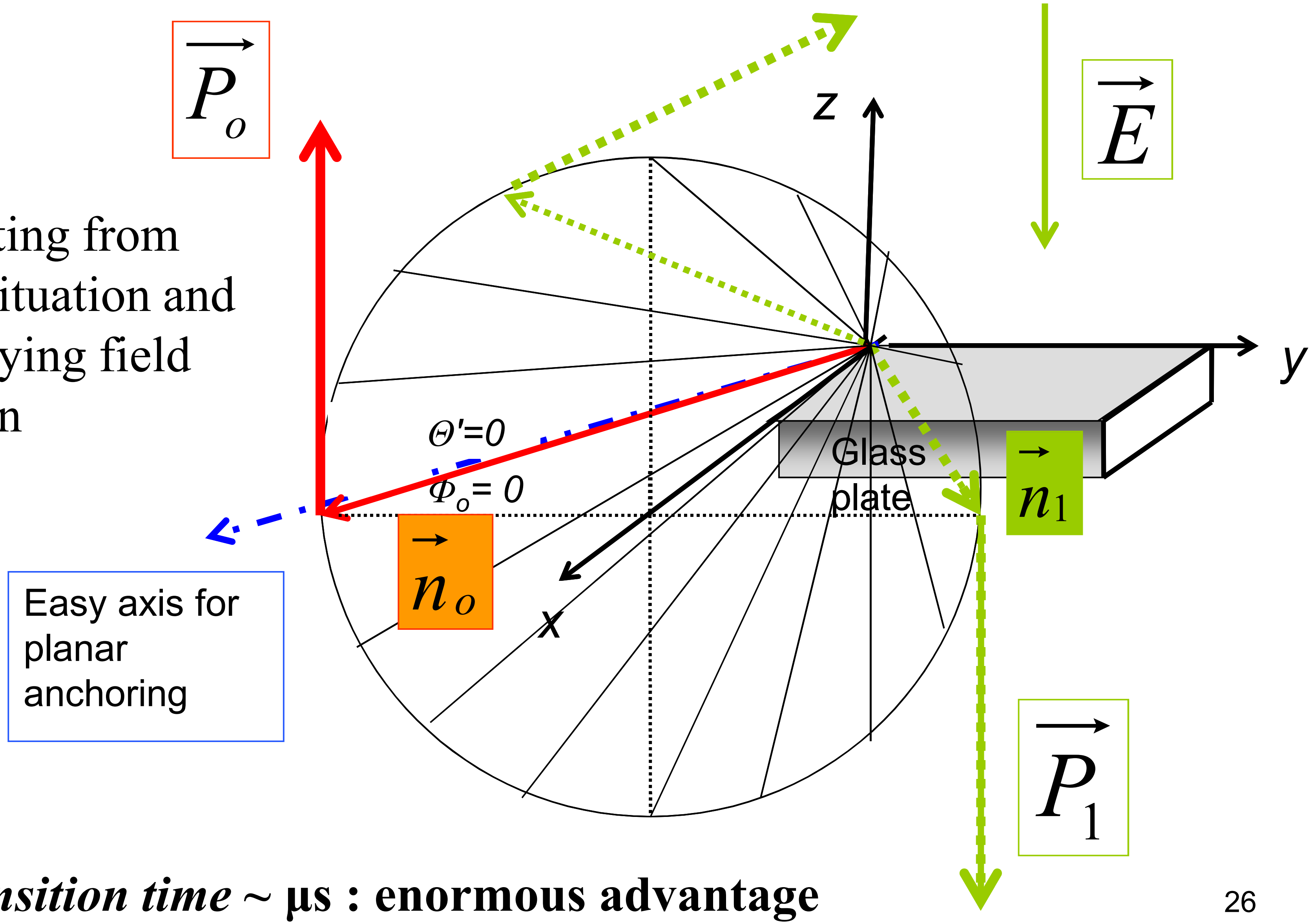
SMECTIC C* FERROELECTRIC LC

Static situation at the surfaces (and in the bulk too) with either strong and weak anchoring



Dynamic of the transition Dipole up - Dipole down

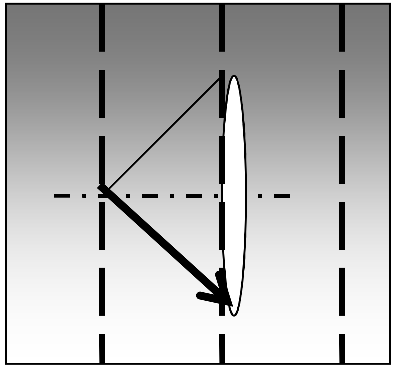
Starting from up-situation and applying field down



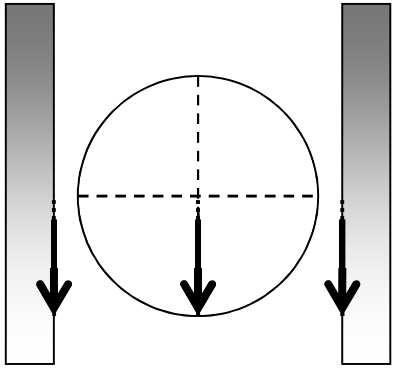
Transition time **~ µs : enormous advantage**

C* Ferroelectric display mechanism

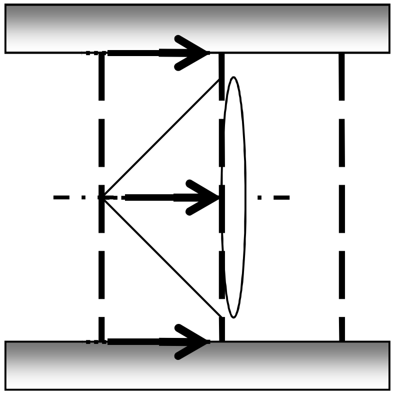
In a surface stabilized ferroelectric LC cell (SSFLC-cell) the homogeneous order in the whole cell is in the OFF-state is ensured by the surface. The smectic C* ideally must have 90^o- opened cone, in order to act as light shutter. The geometry is ***bookshelf*.**



Cell from above. Note the smectic layers (separated by dashed lines)

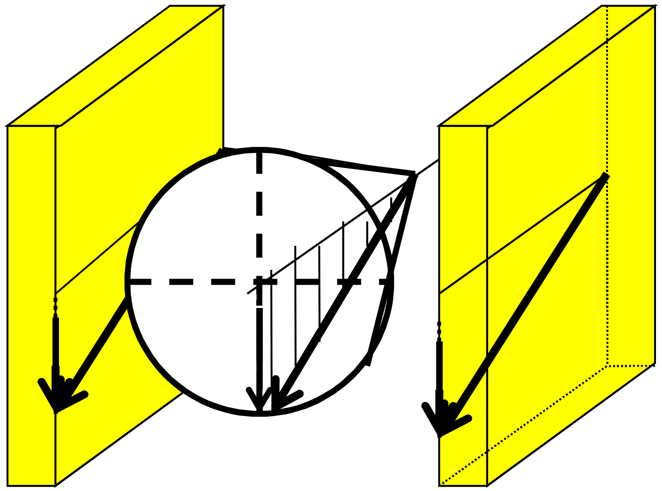


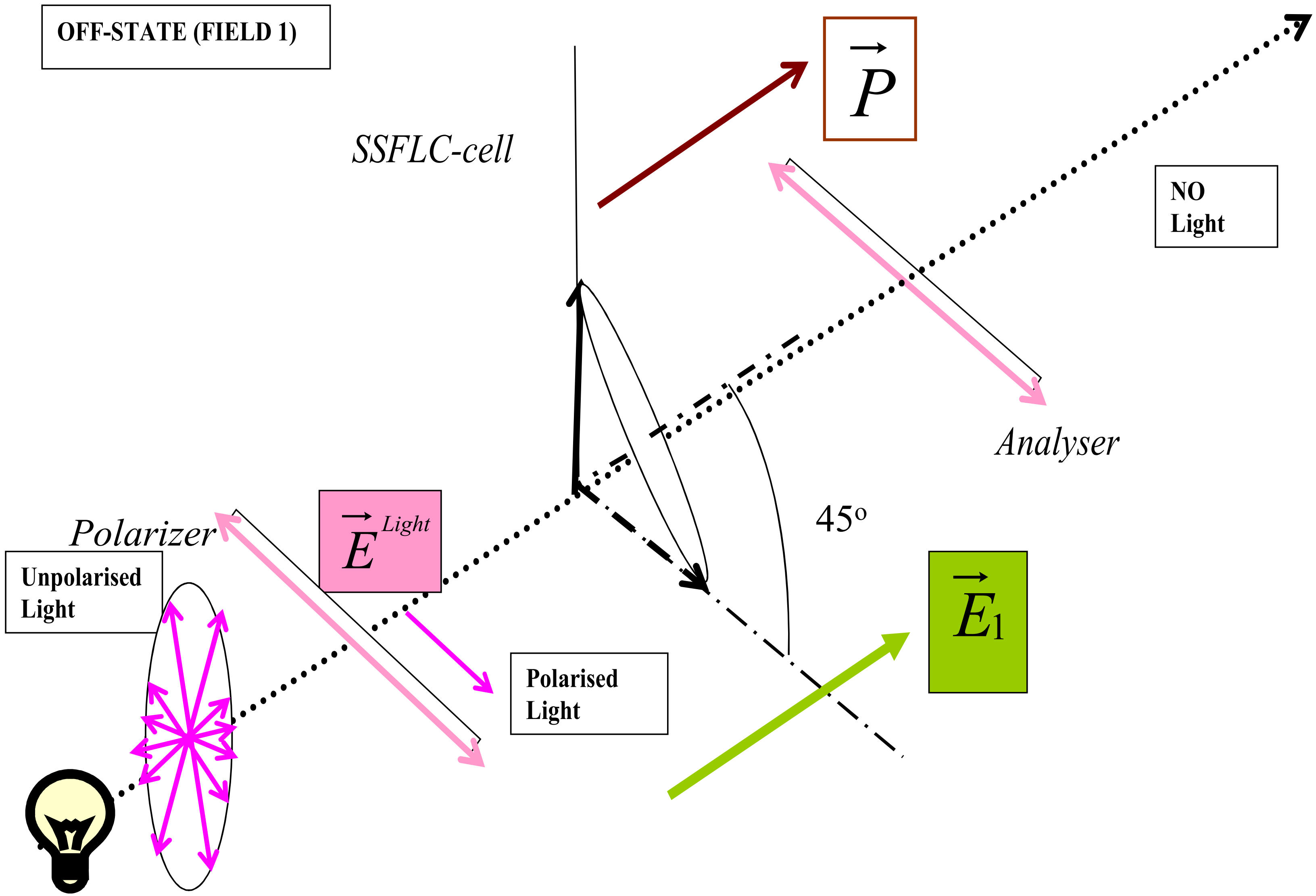
Cell from the lateral side perpendicular to smectic layers



Cell from the lateral side parallel to smectic layers

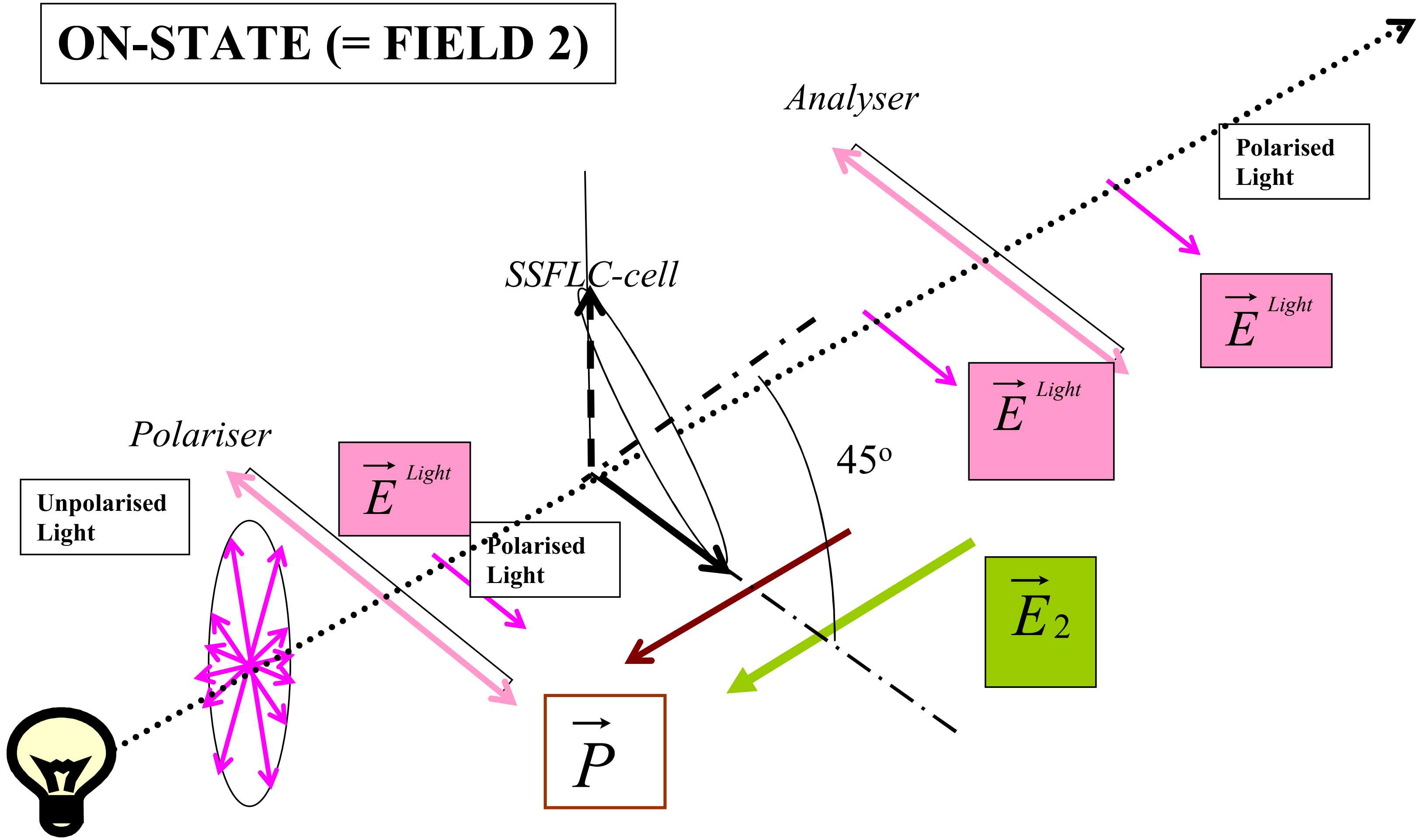
Axonometry of the same cell




OFF-STATE (FIELD 1)
SSFLC-cell
$\vec{P}$
NO Light
Analyser
Polarizer
Unpolarised Light
$\vec{E}^{Light}$
Polarised Light
45°
$\vec{E}_1$

1

ON-STATE (= FIELD 2)



Why Monitors and HD TV based on Smectic C* are not yet on the market?

There is a big problem not yet solved: the so-called "**mechanical shock**", which Smectic C*s face very afraid: they are more viscous than NLC, and

if a person touches with one finger the screen, the C*material "glues" the two panels, and the screen is not working any more.

But scientists are thinking, let us hope that the problem *with new materials* will be solved

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3.3. CONCLUSIONS

- LC can act as energy transducers
- They are suitable for transmitting information, in advanced Display, Monitor, TV technology
- Display, Monitor and flat screen TV on the market are based on NLC technology (Twisted N, In-Plane Switching, and Vertical Aligned N modes
- C* based HD TV large screen are very promising, provided the “shock problem” will be solved

3. References

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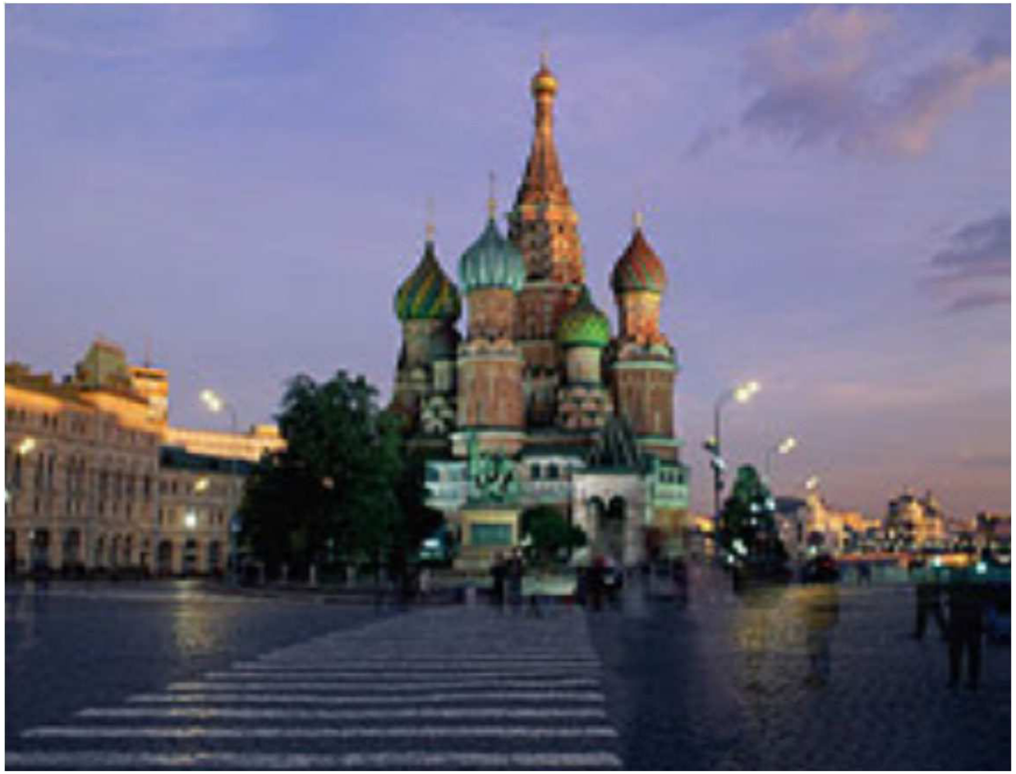
- S. Chandrasekhar, "*Zhidkie Kristalli*", 1980, MIR, Moskwa (in Russian)
- J.A. Castellano, "*Liquid Gold: the Story of Liquid Crystal Displays and the Creation of an Industry*", 2005, World Scientific, Singapore
- G. Barbero and L.R. Evangelista, "*An Elementary Course on the Continuum theory for Nematic Liquid Cristals*", 2001, World Scientific, Singapore

3.4. Application of CLC to fun

It is possible also to use CLC ink for body painting

Maybe not in the Red Square…



…at least in winter

Спасибо за внимание