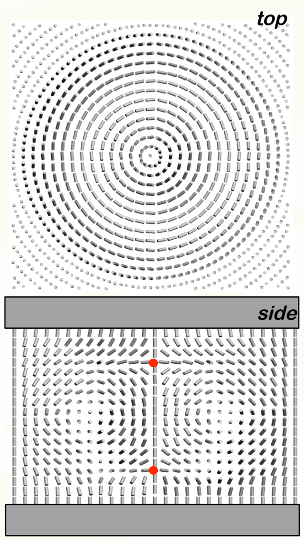
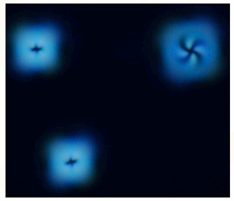
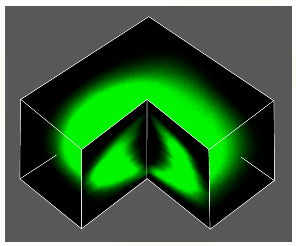
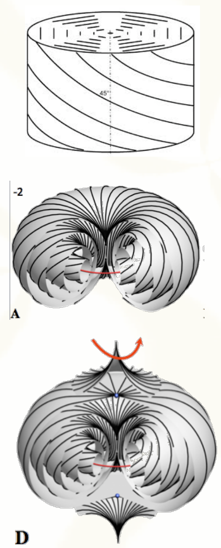
3D structures



chiral nematic skyrmions

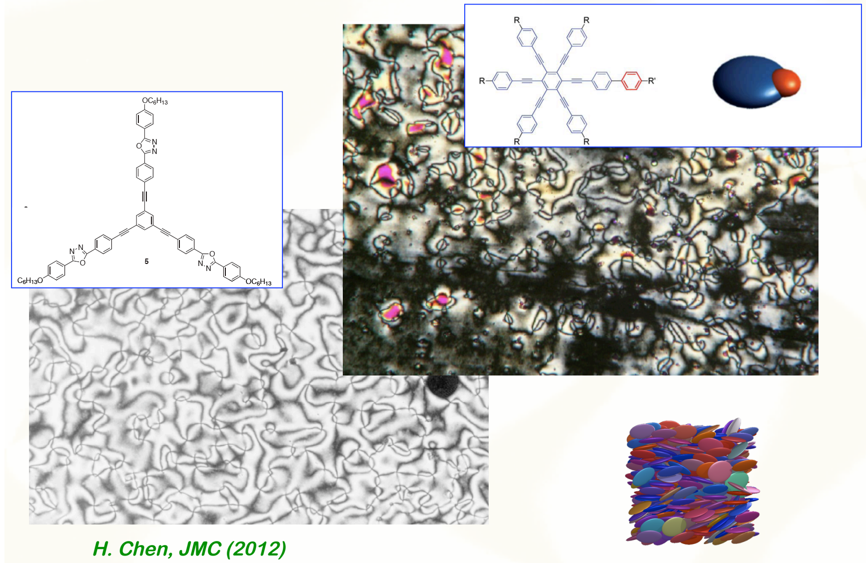






Smalyukh, Nat. Mat. (2011)

discotic nematics

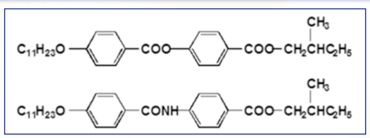


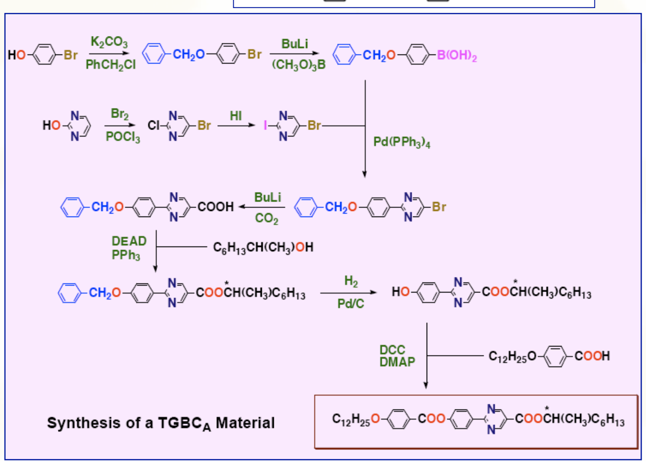
H. Chen, JMC (2012)

molecules

Iso – Smectics - Xtal

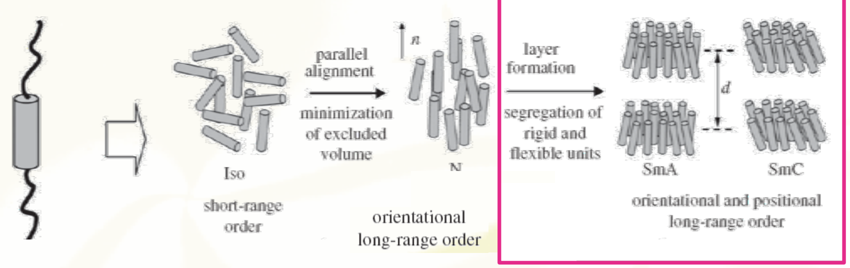
Iso - Xtal

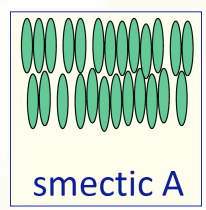


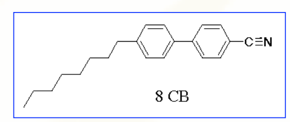


J. Goodby (York)

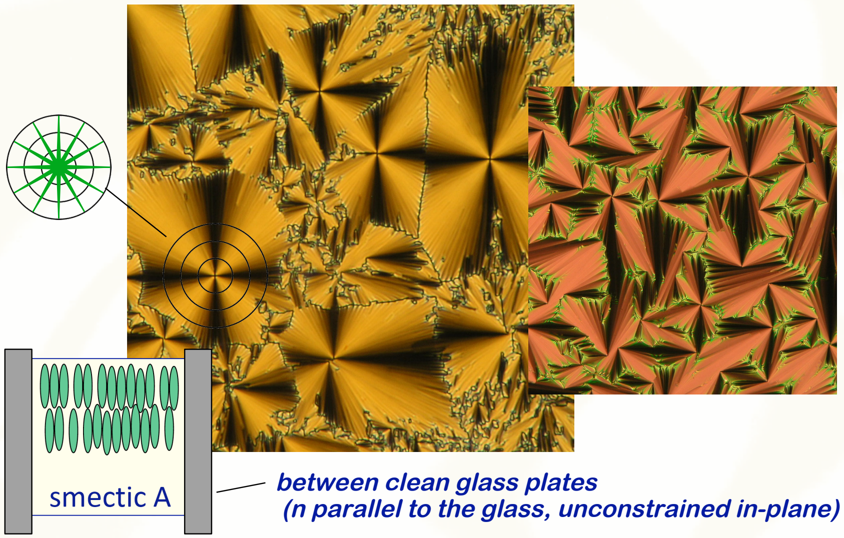
pathways to LCs - fluid interfaces (positional ordering)







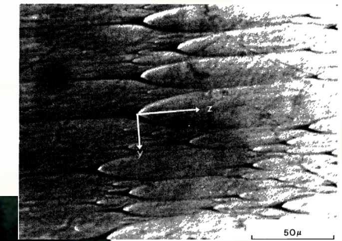
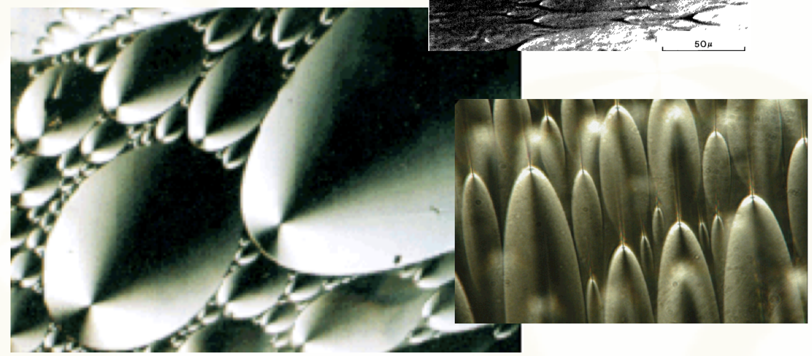
smectic A textures



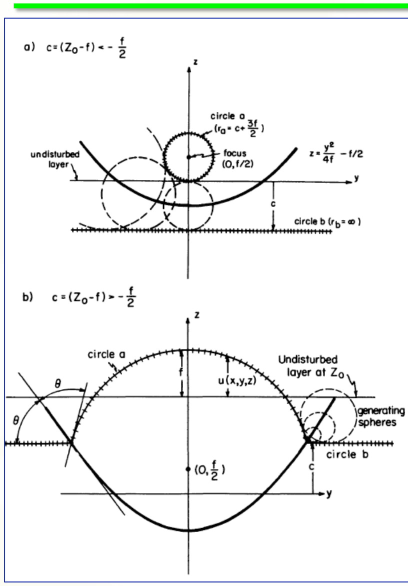
between clean glass plates
(n parallel to the glass, unconstrained in-plane)

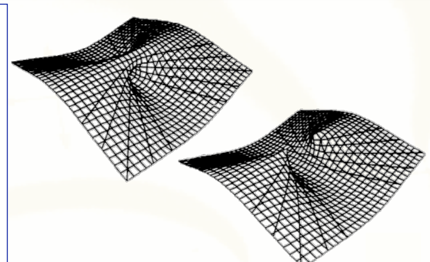
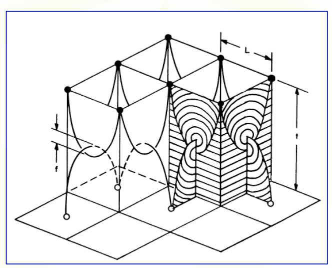
smectic A focal conic domains

Georges Friedel
1922

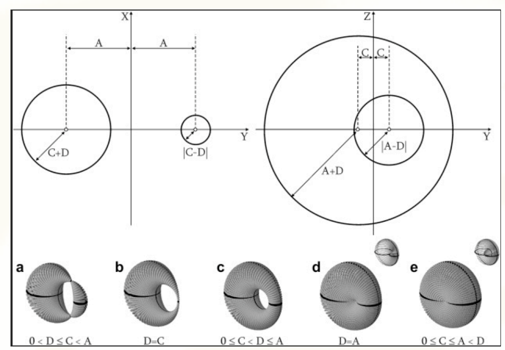



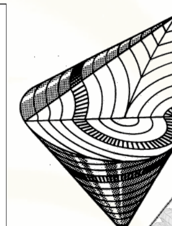
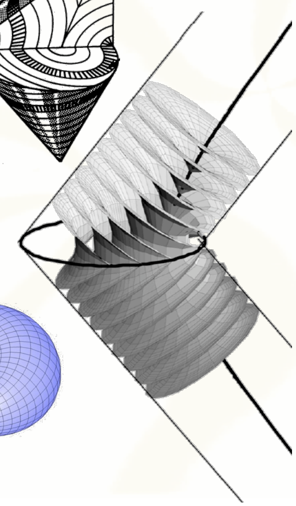
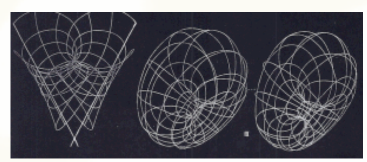
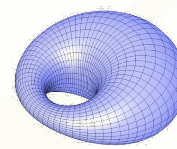
cyclides of Dupain - parabolic



cyclides of Dupain – ellipse / hyperbola



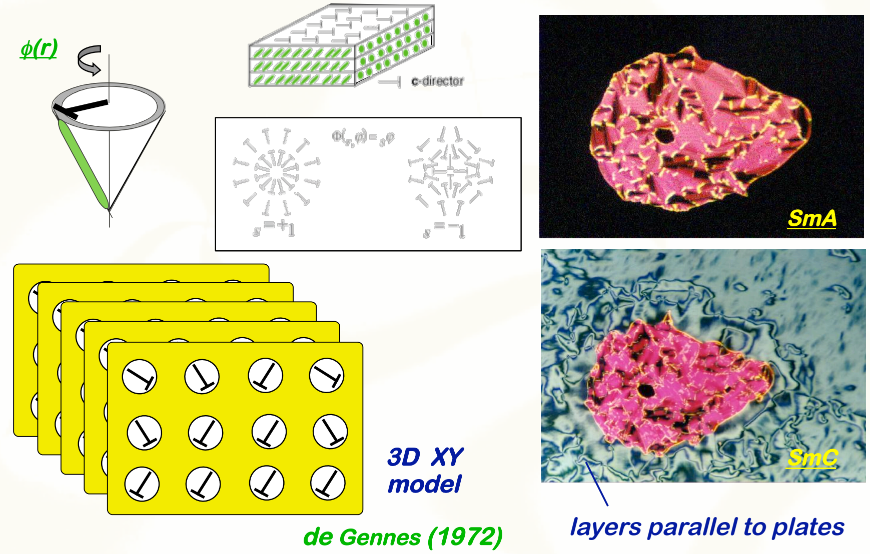





J.C. Maxwell from amazon.com

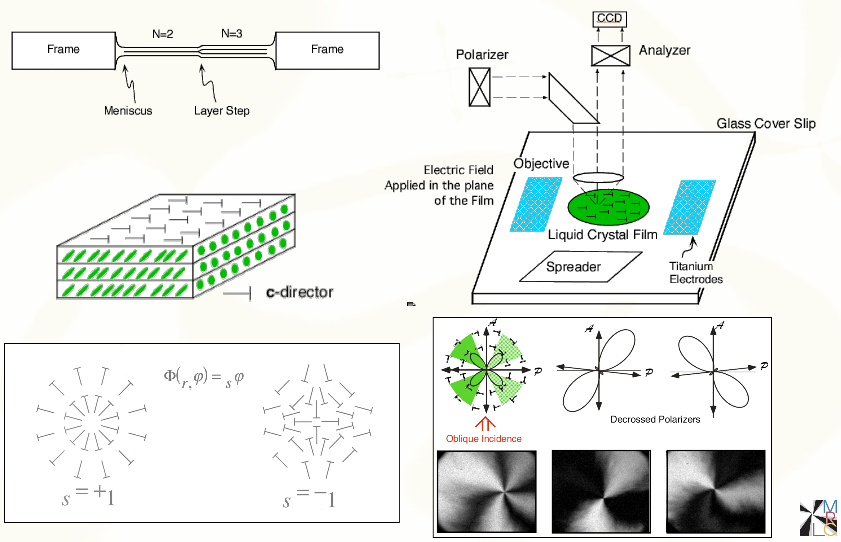
textures - what do they depend on?

- the phase
- cell thickness
  - optics
  - structure
- surface treatment
- thermal history
  - cooling rate
  - increasing or decreasing T
- adjacent phases
- Impurities
- flow
- inhomogeneities
  - quenched disorder
  - particles

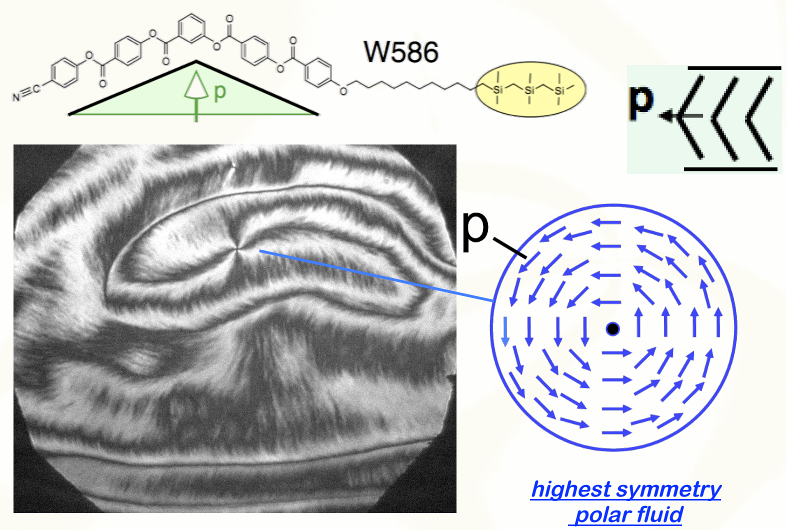
smectic C



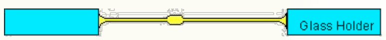
freely suspended smectic films



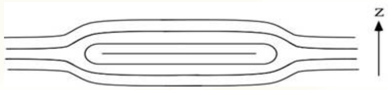
single-layer films - polar smectic A (Sm AP)

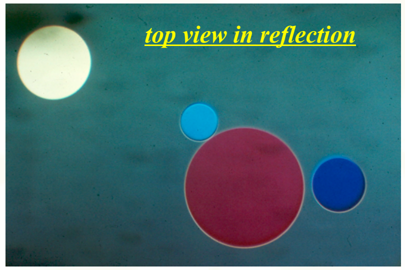


islands

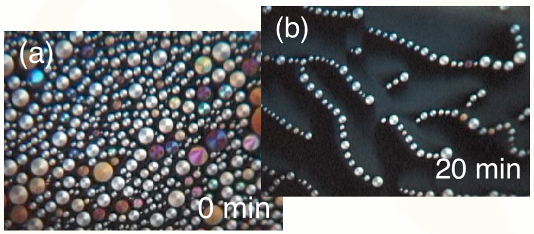


side view





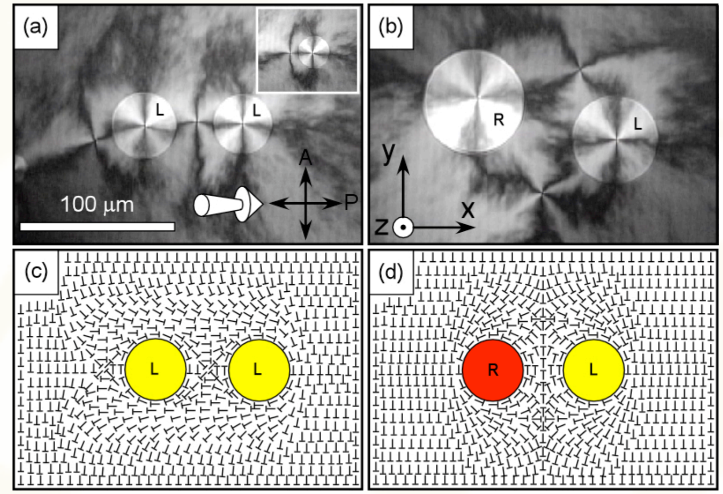
island emulsions



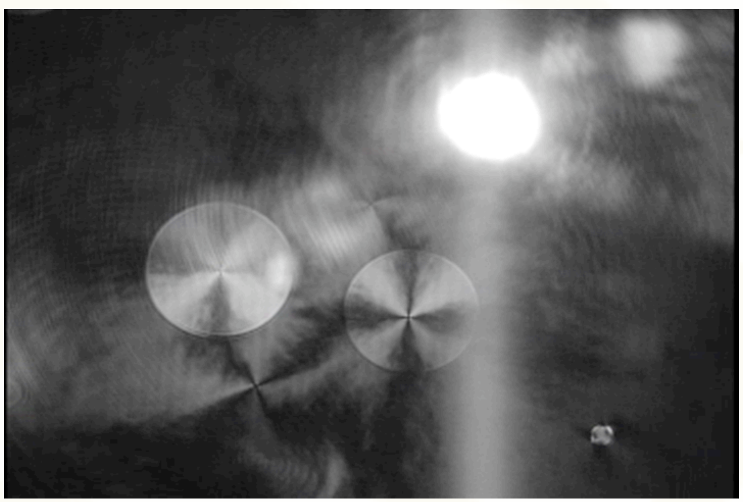
OASIS
Observation and Analysis of Smectic Islands in Space

structure vs. handedness

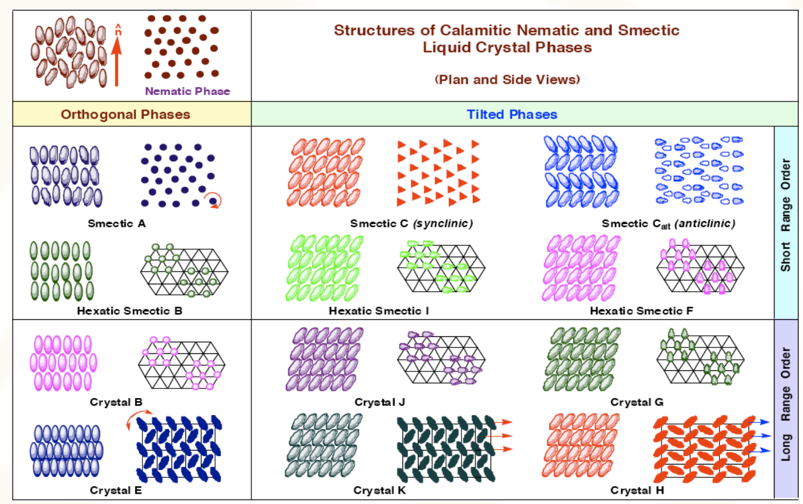
homochiral dipolar heterochiral quadrupolar



real time

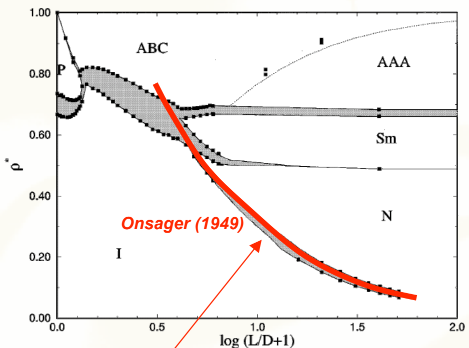


calamitic liquid crystal phases

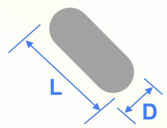


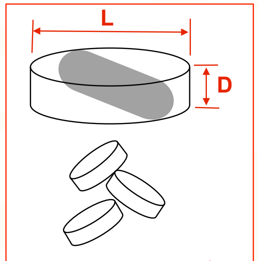
molecular origins of nematics, smectics

hard spherocylinders



Bolhuis, Frenkel, JCP (1997)



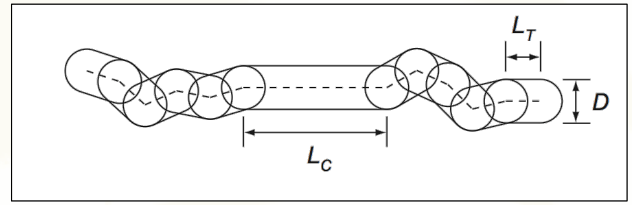


$\phi_c = V_{rods}/V \sim$
$(NLD^2)/(NL^2D) = D/L$

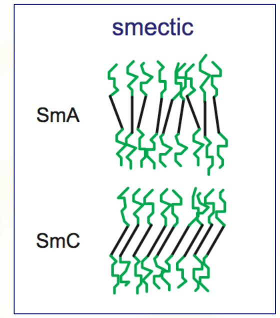
$\rho_c \sim 1/(L^2 D)$

$\Delta S_{tr} = -k_B \ln(1 - V_{excl}/V) \sim k_B \rho L^2 D,$
$\Delta S_{or} = k_B \ln \Omega_N/\Omega_I \sim k_B$
$\Delta S_{or} + \Delta S_{tr} = 0$

adding flexible tails…

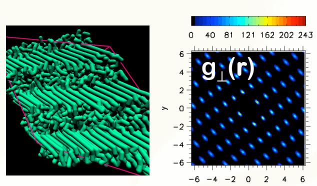


- soft spherocylinder polymer with rigid core and flexible chains
- molecular flexibility controlled by bond angle bending spring constant K_{bend}
- studied using NPT MD simulation



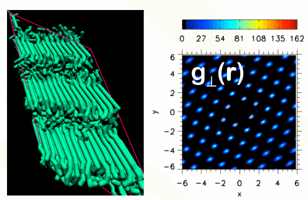
gives smectic phases

SmF



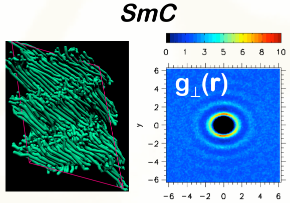
$\beta K_{bend} = 1/4$, $\beta PD^3 = 6$

SmI



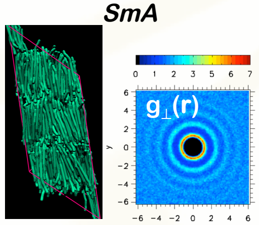
$\beta K_{bend} = 1$, $\beta PD^3 = 5$

SmC



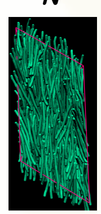
$\beta K_{bend} = 4$, $\beta PD^3 = 1.8$

SmA



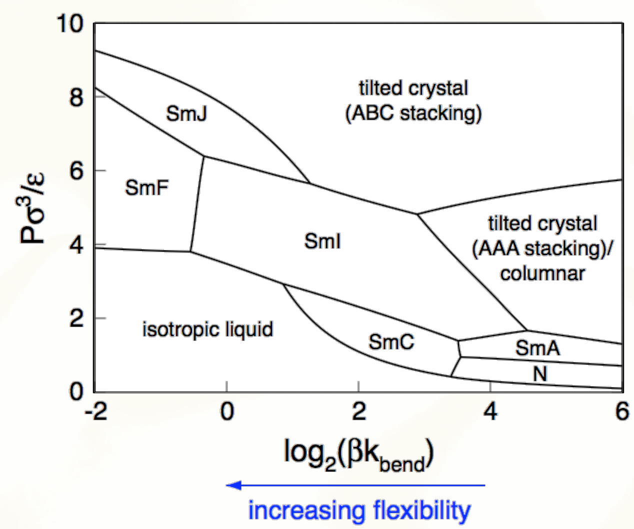
$\beta K_{bend} = 16$, $\beta PD^3 = 1.2$

N

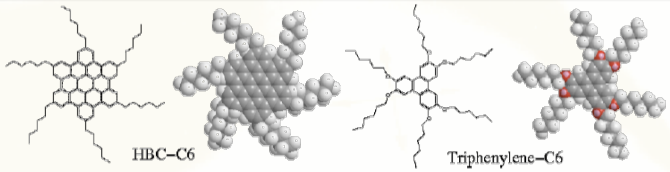


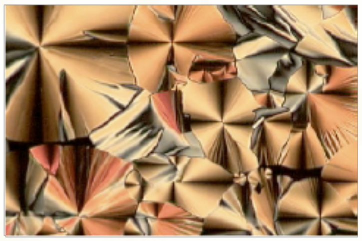
$\beta K_{bend} = 64$, $\beta PD^3 = 0.4$

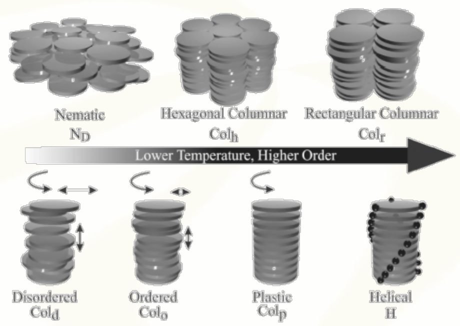
phase diagram of flexible-tail spherocylinders



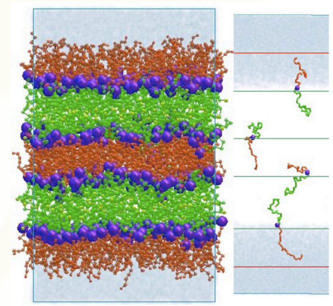
discotic columnar phases





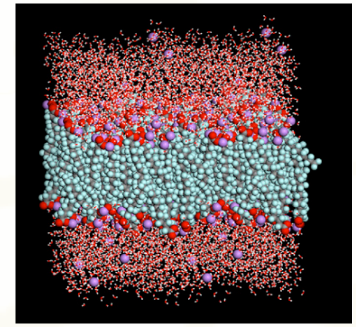


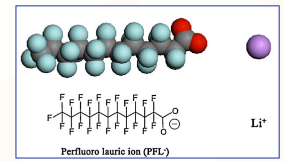
pathways - fluid interfaces generate anisotropy



hydrophobic
hydrophillic
water

G. Srinivas, IBM Almaden

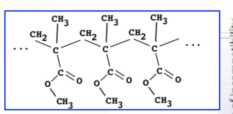




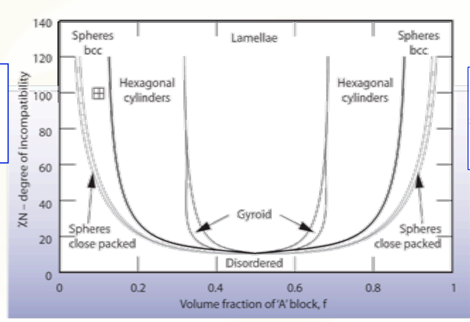
Long et al. J Fluor Chem (2012)

block copolymers

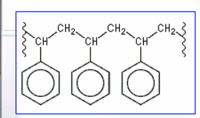
Controlling Order in Block Copolymer Thin Films for Nanopatterning Applications



PMMA

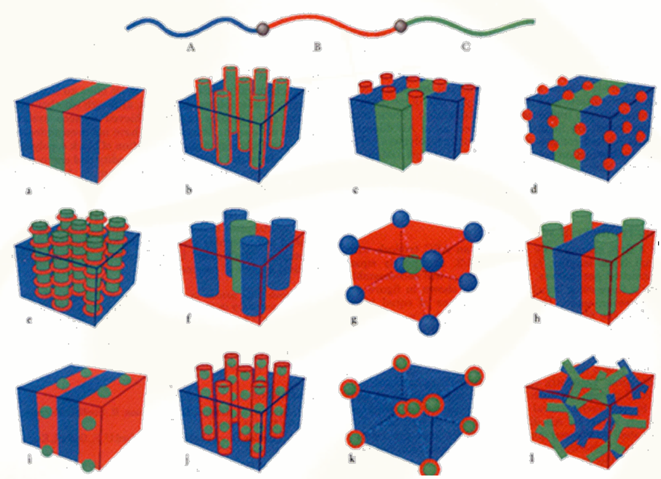


Phase diagram for polystyrene and PMMA, predicted using self-consistent mean field theory

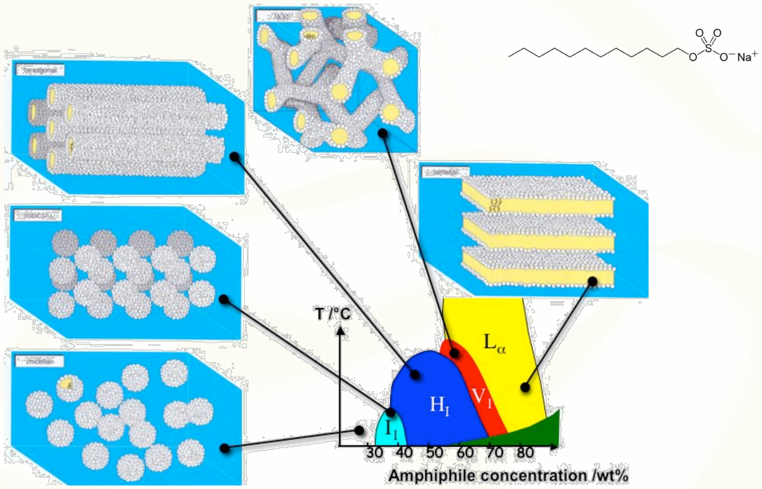


polystyrene

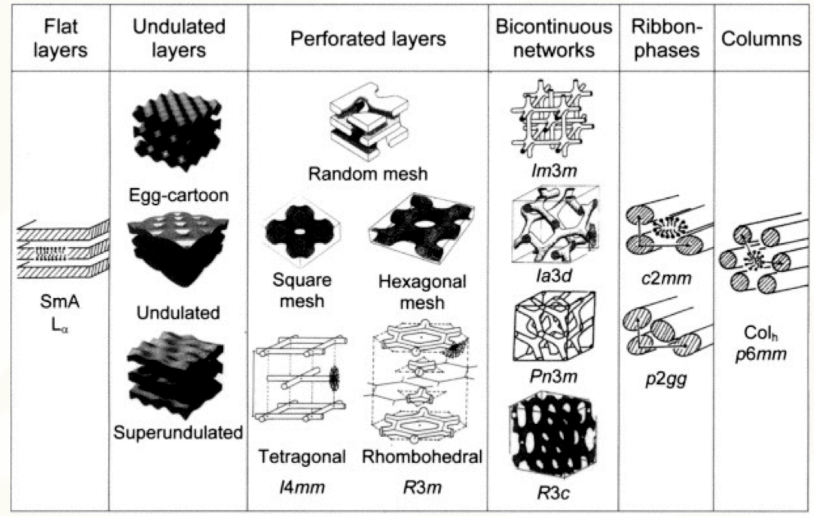
triblock copolymers



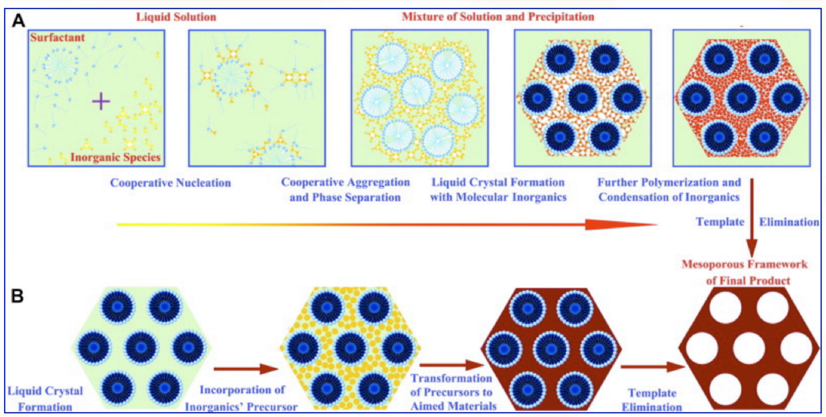
lyotropics



lyotropic variations



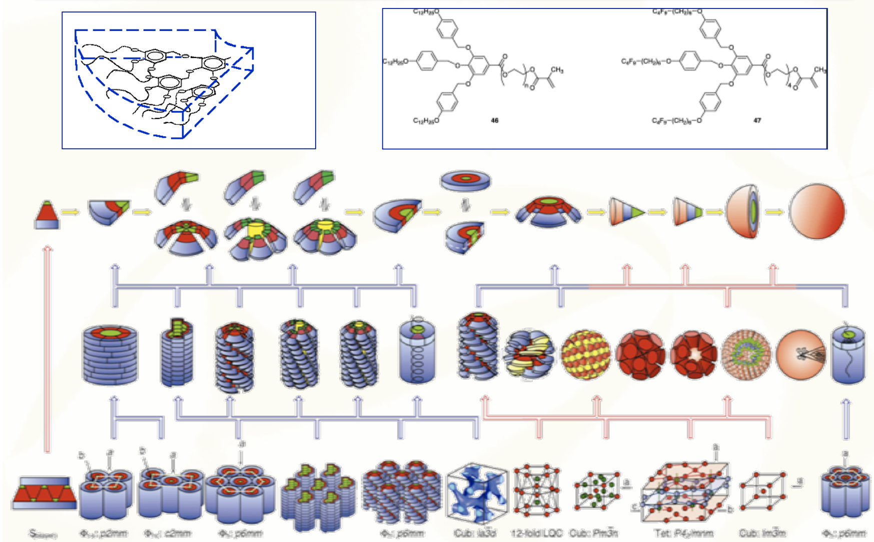
nanoporous silica from lyotropic liquid crystals



1. Title: **ORDERED MESOPOROUS MOLECULAR-SIEVES SYNTHESIZED BY A LIQUID-CRYSTAL TEMPLATE MECHANISM**
Author(s): KRESGE CT; LEONOWICZ ME; ROTH WJ; et al.
Source: NATURE Volume: **359** Issue: **6397** Pages: **710-712** DOI: **10.1038/359710a0** Published: **OCT 22 1992**
Times Cited: **9,613** (from Web of Science)

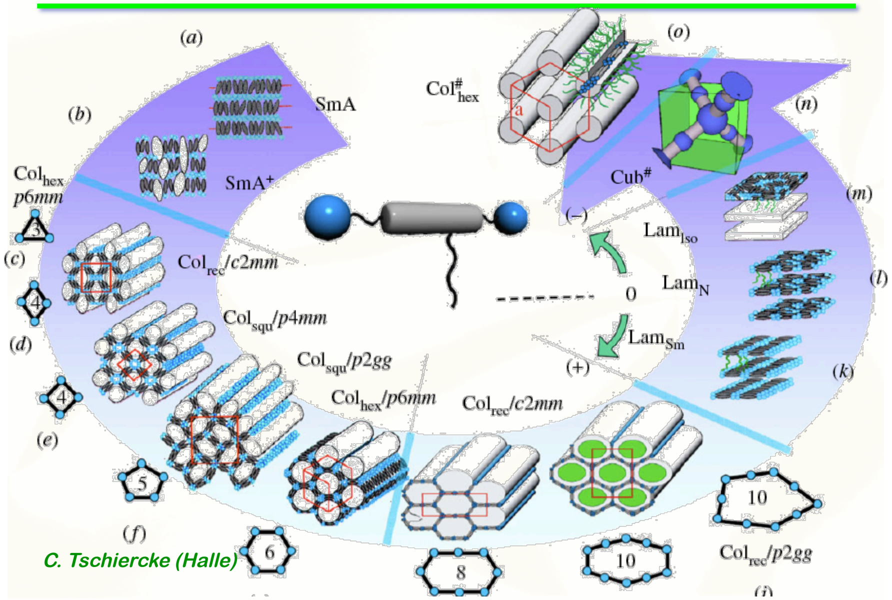
~ 10 of the 20 most cited liquid crystal papers

hierarchical self assembly



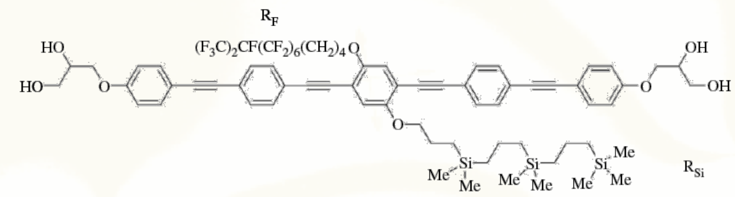
V. Percec (Penn)

bola-amphiphiles

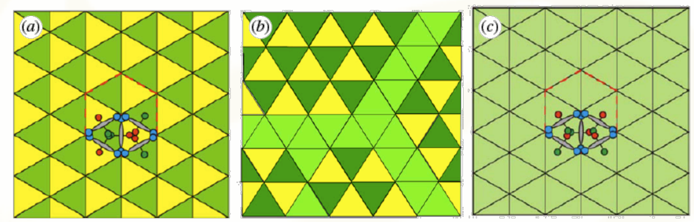


C. Tschiercke (Halle)

bola-amphiphiles



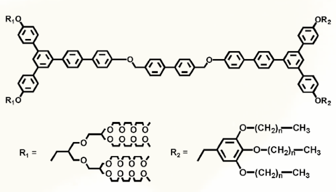
Cr 83 $Col_{hex}/p3m1$ 85 $Col_{hex}/p6mm$ 189 Iso (°C)



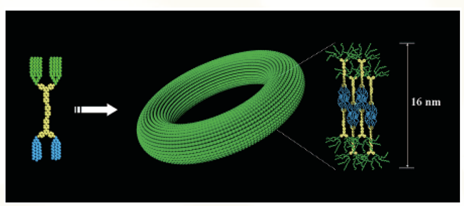
$Col_{hex}/p3m1$ $Col_{hex}/p6mm$ $Col_{hex}/p6mm$

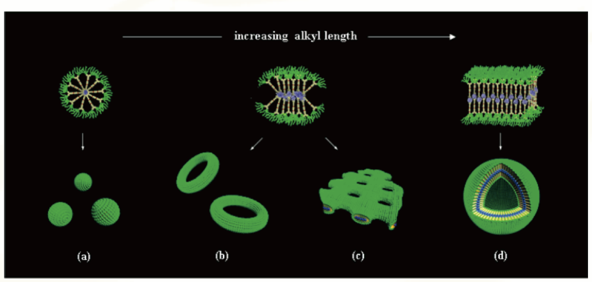
C. Tschiercke (Halle)

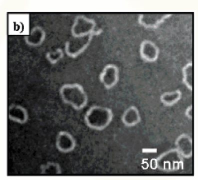
agressive amphiphilics



1 n= 5, **2** n=9, **3** n=13

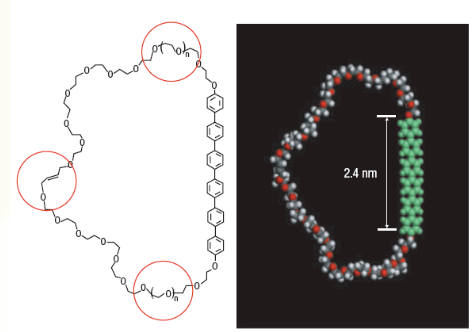






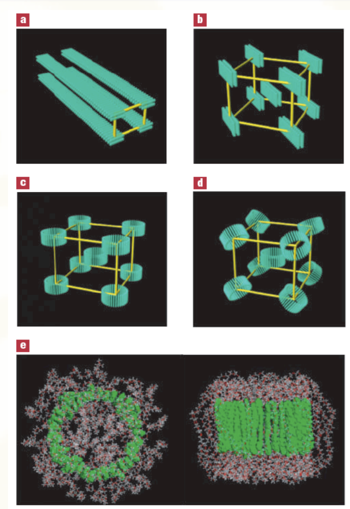
Myongsoo Lee (Seoul)

amphiphilic rings



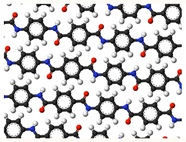
1: n = 7 (f_{coil} = 77%) rec $\underset{48.7}{\overset{52.2}{\rightleftharpoons}}$ ortho $\underset{71.7}{\overset{89.8}{\rightleftharpoons}}$ tet $\underset{127.1}{\overset{130.8}{\rightleftharpoons}}$ cub $\underset{156.6}{\overset{159.9}{\rightleftharpoons}}$ i

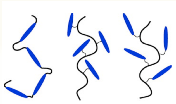
2: n = 13 (f_{coil} = 82%) obl $\underset{29.9}{\overset{50.3}{\rightleftharpoons}}$ ortho $\underset{40.8}{\overset{60.6}{\rightleftharpoons}}$ cub $\underset{164.9}{\overset{169.5}{\rightleftharpoons}}$ i

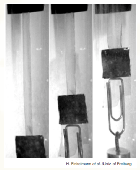


Myongsoo Lee (Seoul)

polymers and elastomers

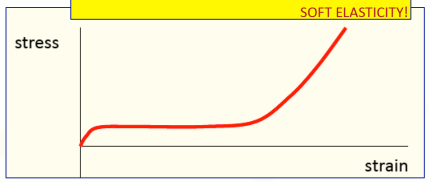


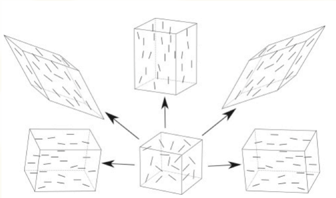


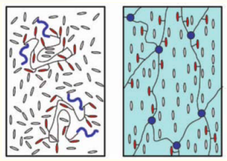


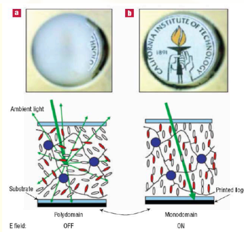
$$\mathcal{F} = \frac{1}{2}a'\mathbf{Q}^2 - \frac{1}{3}b\mathbf{Q}^3 + \frac{1}{4}c\mathbf{Q}^4 + \frac{1}{2}\eta(\mathbf{e} - \frac{\gamma}{\eta}\mathbf{Q})^2 + ..$$

SOFT ELASTICITY!



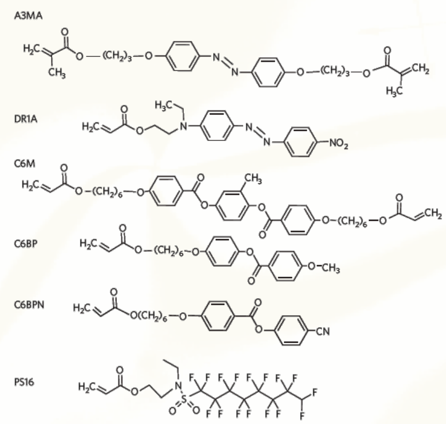


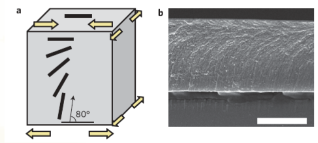


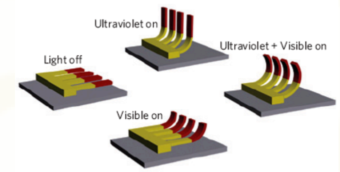


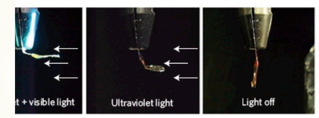
photoactuated cilia

photopolymerized side chain polymer network with azo-based mesogens



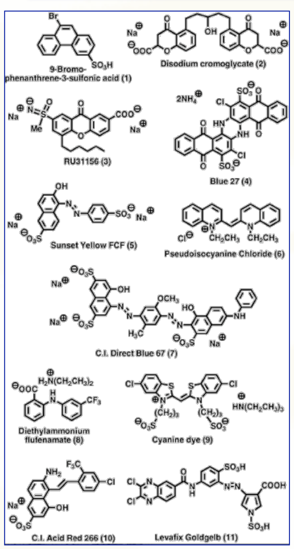


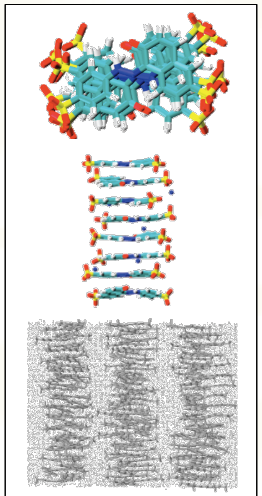




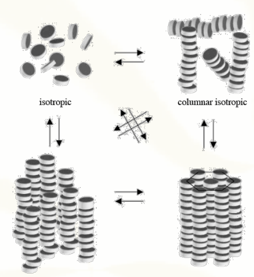
D. Broer, Nat. Mat.(2009)

chromonic liquid crystals

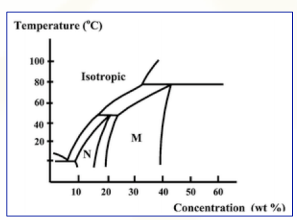




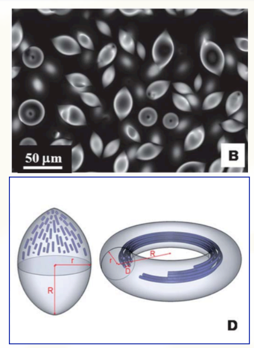
M. Wilson, JACS (2012)



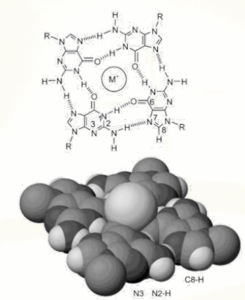
nematic *columnar*



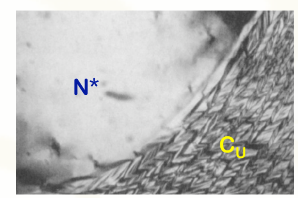
chromonic liquid crystals



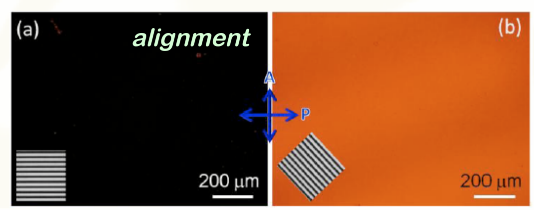
Lavrentovich (Kent State)

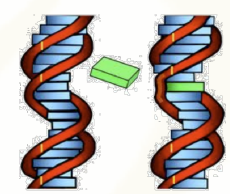


guanine quartets



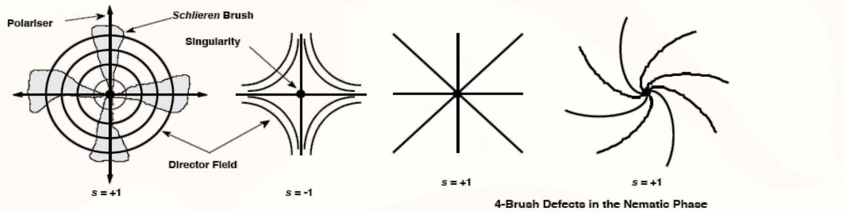
Spada, JACS (1989)

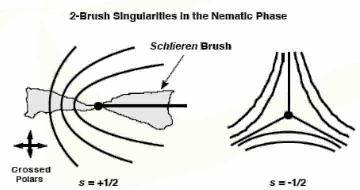


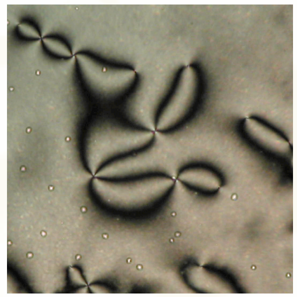


DNA

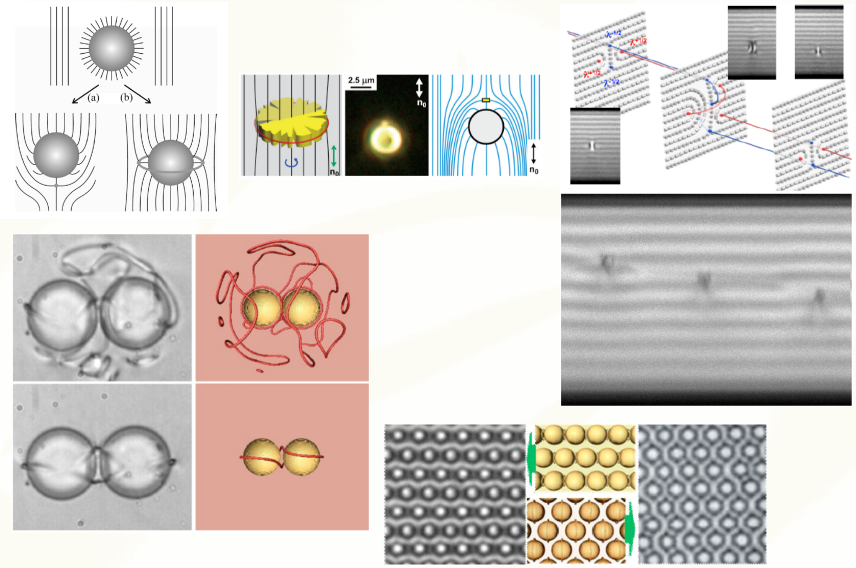
defects- 2D







nematic defects – 3D



Maier – Saupe model of the isotropic / nematic transition

$$S = < \frac{1}{2}(3\cos^2\theta - 1 >$$

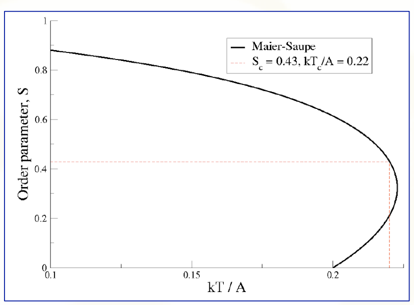
$$S = \frac{2\pi}{Z}\int_0^\pi \left(\frac{3}{2}\cos^2\theta - \frac{1}{2}\right)\exp\left[-\frac{V(\theta,S)}{kT}\right]\sin\theta d\theta$$

$$V(\theta,S) = -AS\left(\frac{3}{2}\cos^2\theta - \frac{1}{2}\right)$$

$$Z = 2\pi\int_0^\pi \exp\left[-\frac{V(\theta,S)}{kT}\right]\sin\theta d\theta$$

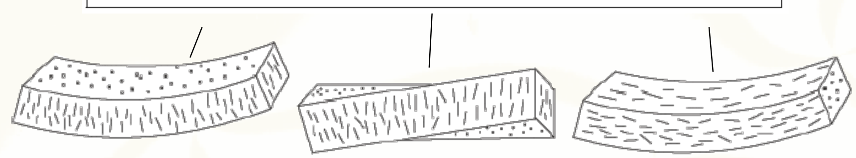
$$S = \frac{3}{4}\left[\frac{\exp(x^2)}{xD(x)} - \frac{1}{x^2}\right] - \frac{1}{2}$$

$$\frac{kT}{A} = \frac{3}{2}\frac{S}{x^2},$$



nematic elasticity

$$g = \frac{1}{2}k_{11}(\nabla\cdot\mathbf{n})^2 + \frac{1}{2}k_{22}(\mathbf{n}\cdot\mathrm{curl}\,\mathbf{n})^2 + \frac{1}{2}k_{33}(\mathbf{n}\times\mathrm{curl}\,\mathbf{n})^2$$



splay

twist

bend

$$g = \frac{1}{2}k_{22}\left(\frac{\partial\theta}{\partial z}\right)^2$$

$$\frac{\partial^2\theta}{\partial z^2} = 0 \qquad \theta = \alpha z$$

Oseen / Frank (1930s – 1950s)

optical properties: polarization rotation

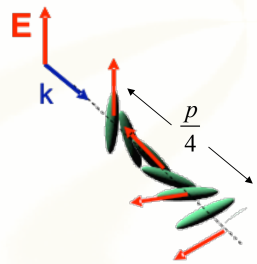
1911

Charles Mauguin

-constructs nematic cells

-surface alignment by rubbing glass with paper

-observes that polarization follows optic axis if $\lambda << p$



'Mauguin limit'

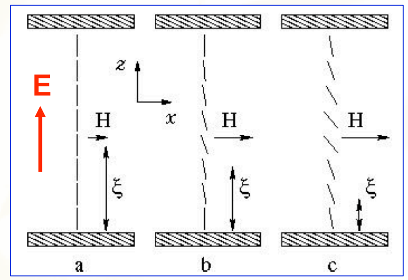
coupling to applied fields

$$g_m = \frac{1}{2}\vec{H}\bullet\ddot{\chi}\bullet\vec{H}$$

$$\chi_{ij} = \chi_\perp\delta_{ij} + \chi_a n_i n_j \qquad \chi_a = \chi_\parallel - \chi_\perp$$

$$g_m = -\frac{1}{2}\chi_\perp H^2 - \frac{1}{2}\chi_a(\boldsymbol{n}\cdot\boldsymbol{H})^2.$$

$$g_e = -\frac{1}{8\pi}\epsilon_\perp E^2 - \frac{1}{8\pi}\epsilon_a(\boldsymbol{n}\cdot\boldsymbol{E})^2.$$



Freedericksz transition

$$n_x = \sin\theta(z), \qquad n_y = 0, \qquad n_z = \cos\theta(z)$$

$$\begin{aligned} \boldsymbol{\nabla}\cdot\boldsymbol{n} &= -\sin\theta\frac{\partial\theta}{\partial z}, \\ \boldsymbol{\nabla}\times\boldsymbol{n} &= \boldsymbol{j}\cos\theta\frac{\partial\theta}{\partial z}, \\ \boldsymbol{n}\cdot(\boldsymbol{\nabla}\times\boldsymbol{n}) &= 0, \\ \boldsymbol{n}\times\mathrm{curl}\,\boldsymbol{n} &= (\boldsymbol{k}n_x - \boldsymbol{i}n_z)\cos\theta\frac{\partial\theta}{\partial z}. \end{aligned}$$

Freedericksz transition...

1931:

V.K. Freedericksz

$$g = \frac{1}{2}\int_{-d/2}^{d/2} dz\left[\left(k_{11}\sin^2\theta + k_{33}\cos^2\theta\right)\left(\frac{\partial\theta}{\partial z}\right)^2 - \chi_a H^2\sin^2\theta\right]$$

$$g = \frac{1}{2}\frac{k}{\xi^2}\int_{-d/2}^{d/2} dz\left[\xi^2\left(\frac{\partial\theta}{\partial z}\right)^2 - \sin^2\theta\right] \qquad \xi = \sqrt{k/\chi_a H^2}$$

$$\xi^2\frac{\partial^2\theta}{\partial^2 z} + \sin\theta\cos\theta = 0$$

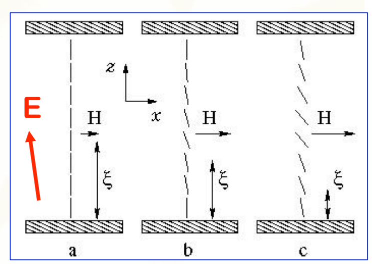
$$\xi^2\left(\frac{\partial\theta}{\partial z}\right)^2 + \sin^2\theta = \sin^2\theta_m$$

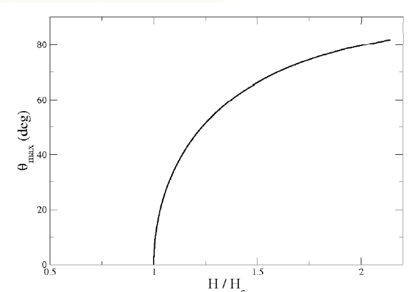
$$\frac{1}{2}d - z = \xi\int_0^\theta \frac{d\theta'}{\left(\sin^2\theta_m - \sin^2\theta'\right)^{1/2}} = \xi\csc\theta_m F(\csc\theta_m, \theta)$$

$$\frac{1}{2}d = \xi\csc\theta_m F(\csc\theta_m, \theta_m) = \xi K(\sin\theta_m)$$

Freedericksz transition

$$H_c = \sqrt{\frac{k_{33}}{\chi_a}}\frac{\pi}{d} \qquad \theta_m \sim 2\left[\frac{H}{H_c} - 1\right]^{1/2}$$





dynamics

static equilibrium: torque unbalance = $\xi^2 \frac{\partial^2\theta}{\partial^2 z} + \sin\theta\cos\theta = 0$

dynamic torque unbalance = $\gamma \frac{\partial\theta}{\partial t} = K\frac{\partial^2\theta}{\partial z^2} + \varepsilon_o \Delta\varepsilon E^2 \sin\theta\cos\theta$

reorientation time

$$\tau = \frac{\gamma d^2}{\pi^2 K(1-(E/E_c)^2)}$$

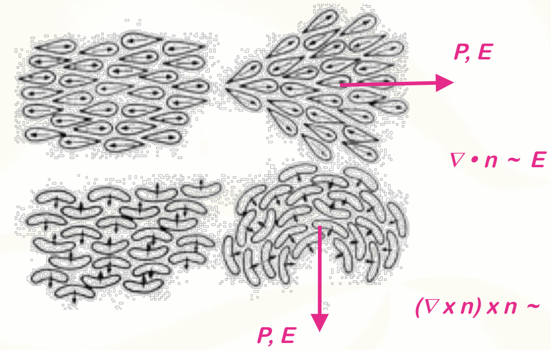
flexoelectricity

$$\boldsymbol{P} = e_1 \boldsymbol{n}(\boldsymbol{\nabla}\cdot\boldsymbol{n})$$

splay

$$\boldsymbol{P} = e_3(\boldsymbol{\nabla}\times\boldsymbol{n})\times\boldsymbol{n}$$

bend



for bend in an electric field:

g = K/2 [(∇ x n) x n]^2+ E•[(∇ x n) x n]

(∇ x n) x n ~ E

R.B. Meyer, PRL (1969)

chirality - blue phases