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

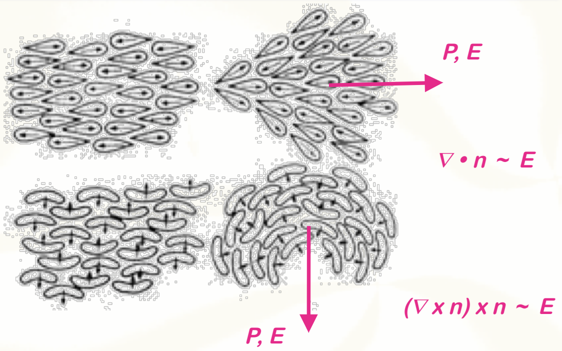
flexoelectricity

$P = e_1 n(\nabla\cdot n)$

splay

$P = e_3(\nabla\times n)\times n$

bend



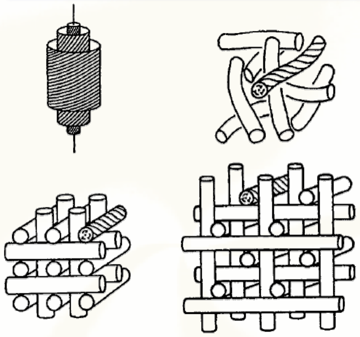
for bend in an electric field:

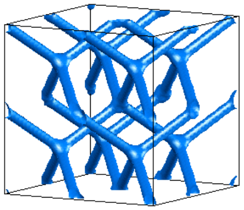
g = K/2 [(∇ x n) x n]²+ E•[(∇ x n) x n]

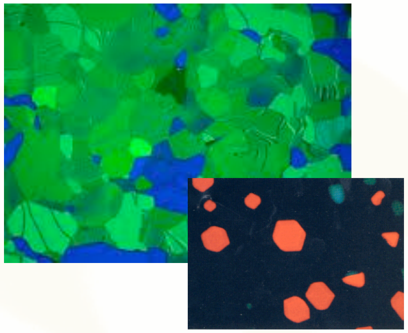
(∇ x n) x n ~ E

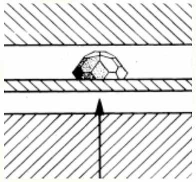
R.B. Meyer, PRL (1969)

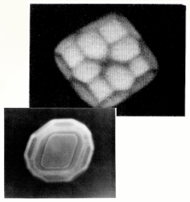
chirality - blue phases





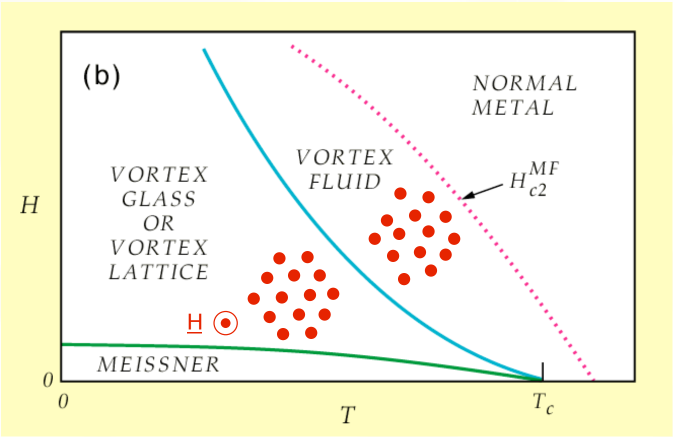






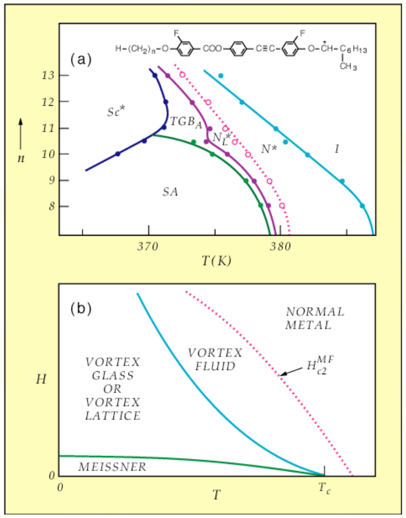
Cladis/ Pieranski (1990)

Abrikosov phase



chiral line nematic glass

- local TGB structure
- short range smectic order
- nematic-like helix
- shearable at high T
- chiral liquid domains
(a conglomerate of achiral molecules)



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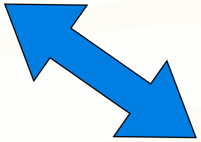
deGennes analogy

superconductors
superfluids



smectic liquid crystals

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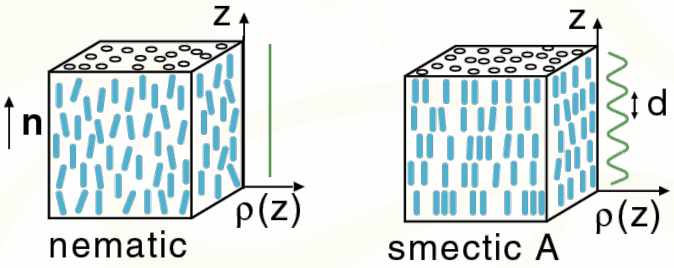
liquid crystal phases



normal

super-

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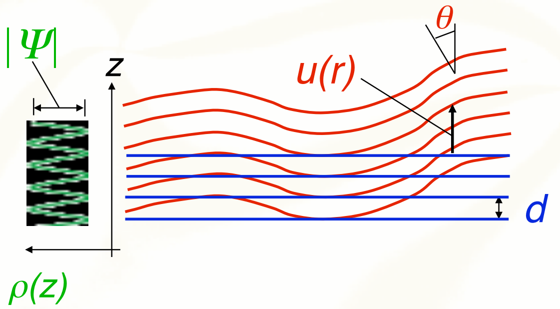
smectic order parameter

$$\Psi(r) = |\Psi|\, e^{i\phi(r)}$$

$$\phi(r) = 2\pi[u(r)/d]$$



$$\nabla\phi(r) = \theta(\rho)$$

the analogy

Superconductor	*Liquid Crystal*
ψ - Cooper pair amplitude	*ψ = density wave amplitude*
***A** = vector potential*	***n** nematic director*
***H** = ∇ x **A** = magnetic induction*	$Q \equiv \mathbf{n} \cdot \nabla \times \mathbf{n} =$ *twist*
normal metal	*nematic phase*
normal metal in a magnetic field	*cholesteric (N*) phase*
Meissner phase	*smectic-A phase*
Meissner effect	*twist expulsion*
London penetration depth, λ	*twist penetration depth, λ_2*
superconducting coherence length, ξ	*smectic correlation lenght, ξ*
vortex (magnetic flux tube)	*screw dislocation*
Abrikosov flux lattice	*twist grain boundary (TGB) phase*
Vortex Liquid	*N_L* phase*

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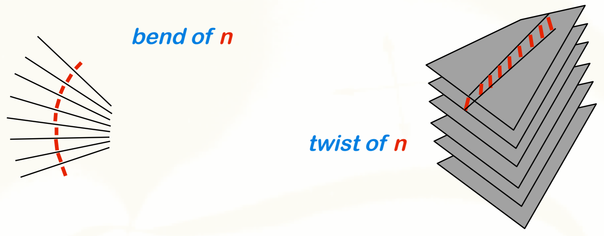
exclusion of bend and twist

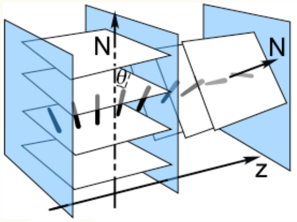


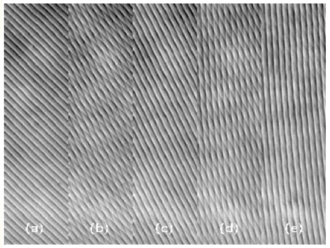
- layers without defects: must have

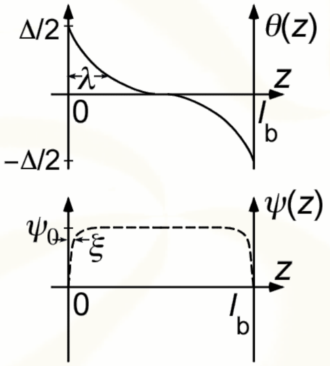
$$\oint \hat{\mathbf{n}} \cdot d\mathbf{l} = \int (\nabla \times \hat{\mathbf{n}}) \cdot d\mathbf{A} = 0$$

- so elastic constants K_2 , K_3 diverge at S_A transition
- $\hat{\mathbf{n}}$ corresponds to magnetic potential
- $\nabla \times \hat{\mathbf{n}}$ is expelled (Meissner effect)

TGB phase (liquid crystal Abrikosov phase)







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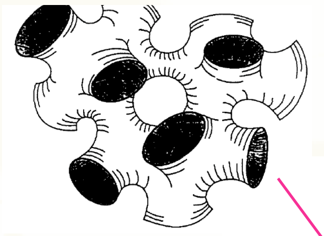
liquid crystals and the Higgs boson

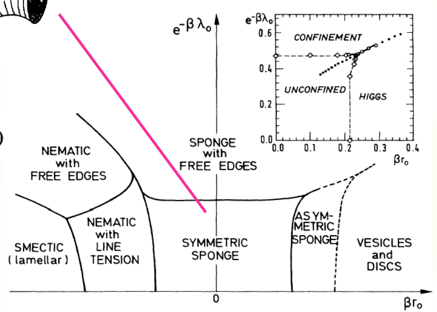


sponge phase

$$\mathcal{H}_0 = \int dS \left(r_0 + \tfrac{1}{2}\kappa_0 H^2 + \bar{\kappa}_0 K\right)$$

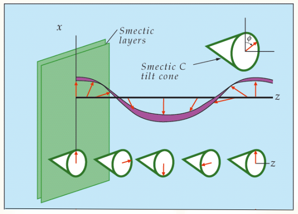
Huse & Leibler, PRL 1993
"Are Sponge Phases of Membranes Experimental Gauge-Higgs Systems?"

1 / (edge energy)



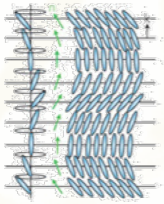
layer chemical potential

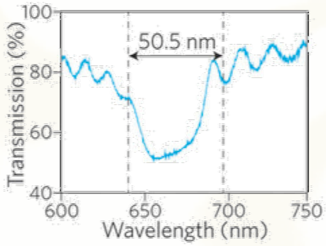
chiral SmC* helix

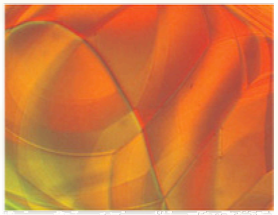


selective reflection

Helfrich and Oh (1970)



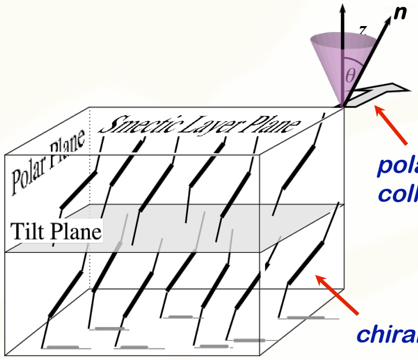




Coles & Morris (2010)

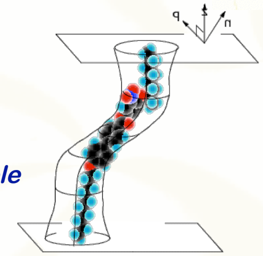
SmC* polar fluid

tilt & chirality ⇨ polarity

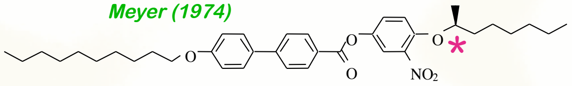


polar axis (C_2)
collective dipole

chiral molecules



Meyer (1974)



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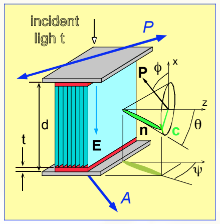
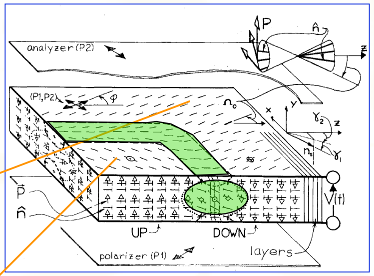
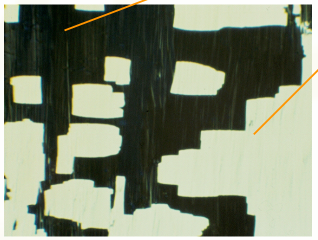
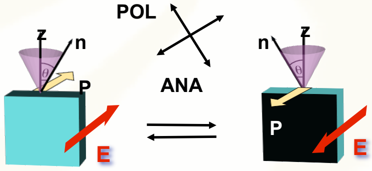
fluid ferroelectric domains



bookshelf geometry



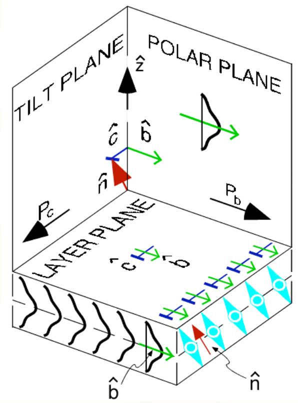




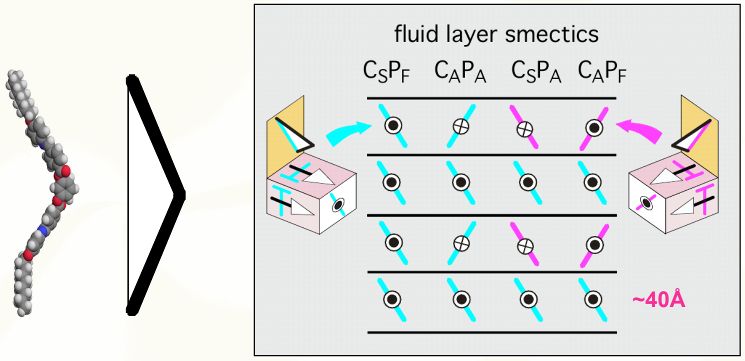
P > 0 (right handed)

B2 banana phases

tilt & polarity ⇨ chirality



the "B2" banana phases: fluid layer smectics



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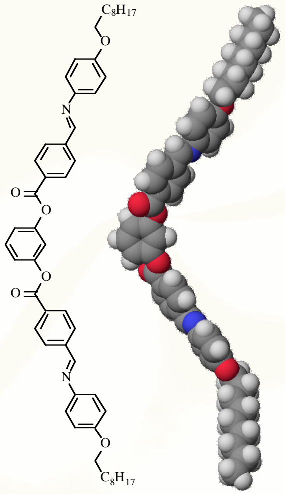
conglomerate EO in NOBOW



- **Spontaneous reflection symmetry breaking in smectics**

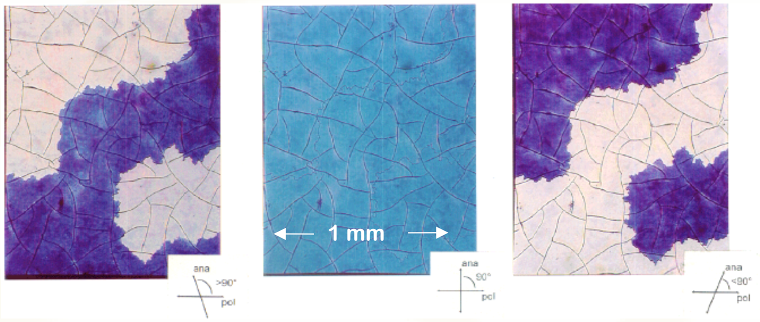
NonylOxyBOW **(NOBOW): B4 — 155 " B2 — 173 " I**

B4 phase: conglomerate domains

NOBOW cooling - I ➔ 173° ➔ B2, B3 ➔ 155° ➔ B4

upon cooling the B2 the B4 phase appears in many materials

- *weakly birefringentfluid phase*
- *spontaneously & homogeneously chiral*



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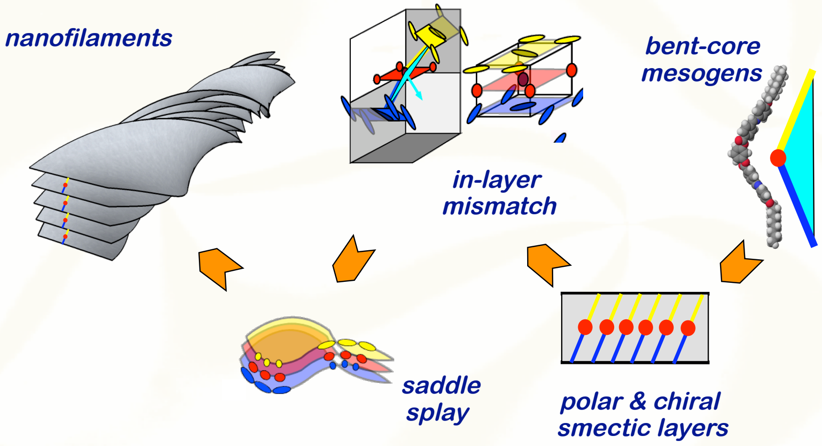
twisted ribbons



nanofilaments

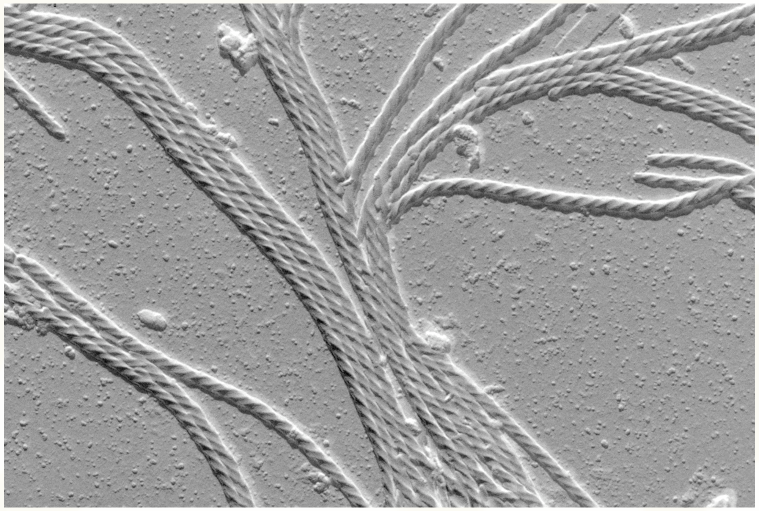
bent-core mesogens

in-layer mismatch

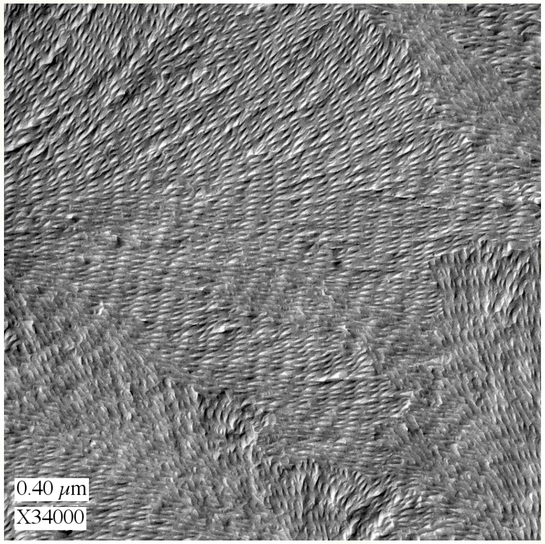
saddle splay

polar & chiral smectic layers

NOBOW filaments

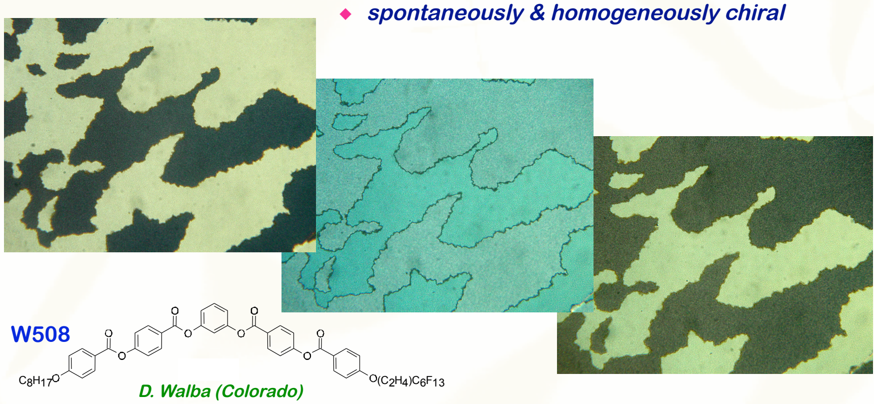


freeze fracture of the bulk B4 phase



isotropic conglomerate domains of achiral molecules

- *optically isotropic fluid phase*
- *spontaneously & homogeneously chiral*

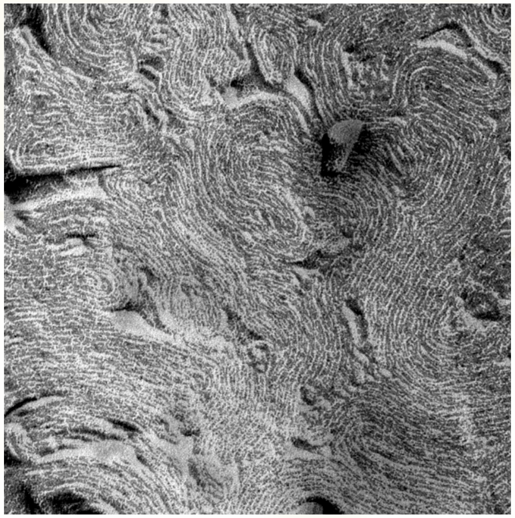


W508

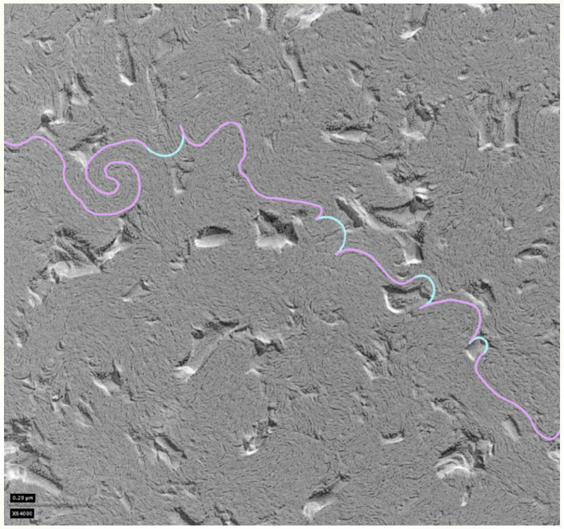
D. Walba (Colorado)

Cooling: I – 172 – Dark cg – 133 – X
Heating: X – 145 – SmCP – 175 – I

W508 "fingerprints"

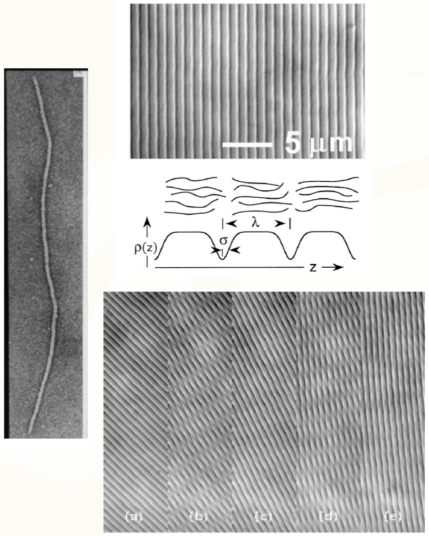


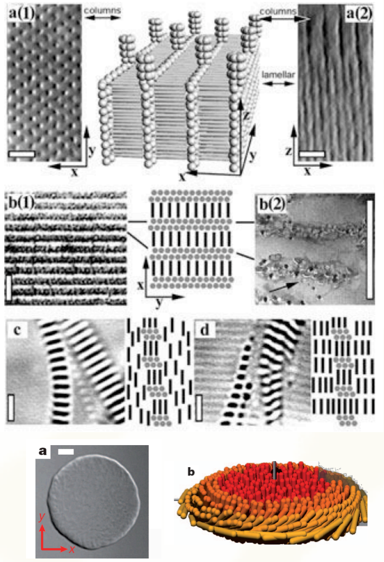
continuous layers yield homochirality



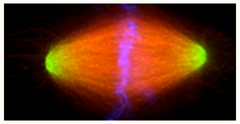
fd virus

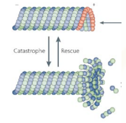
Fraden, Dogic, Meyer (Brandeis)

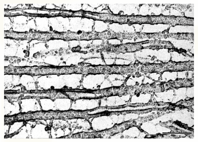


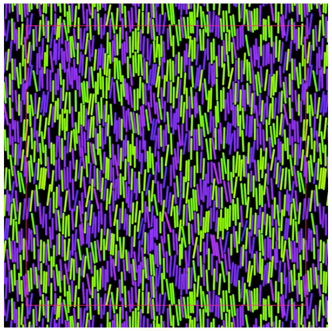


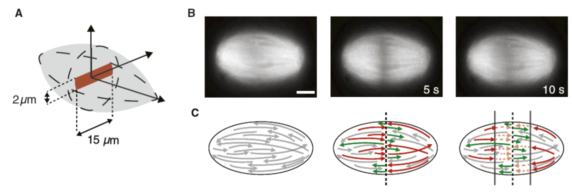
mesophase spindle structure and dynamics





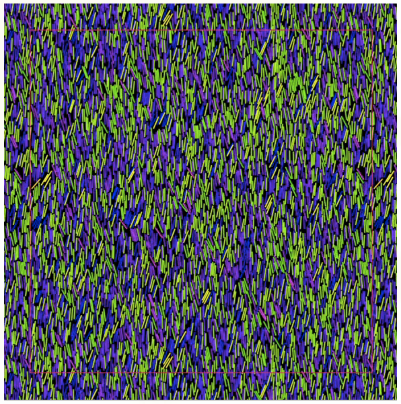




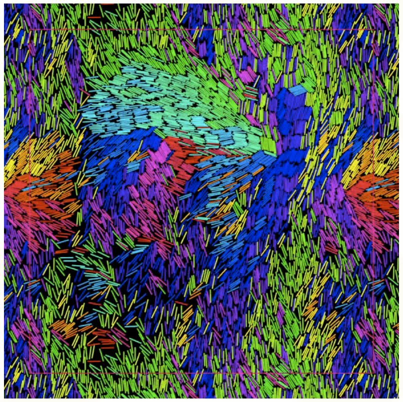


D. Needleman (Brandeis)

active nematics



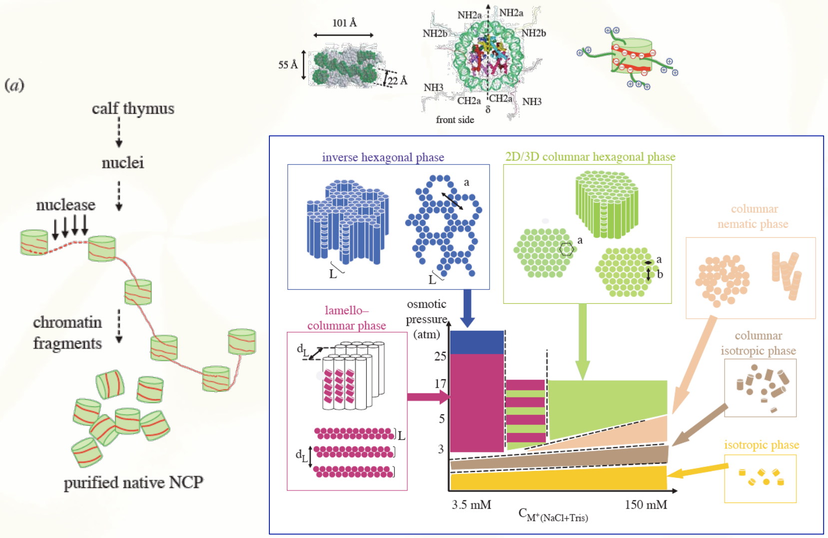
equilibrium nematic



force parellel to each rod axis

Glaser (Colorado)

nucleosome core particle liquid crystals



F. Livolant (Paris)

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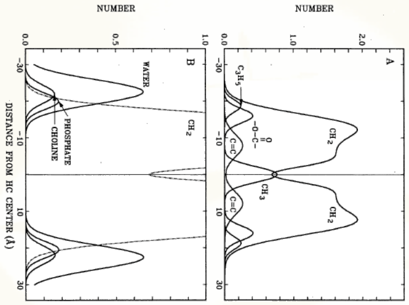
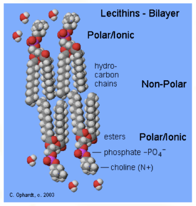
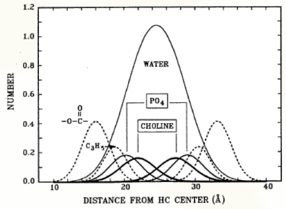
lipid bilayer structure

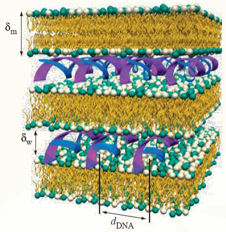


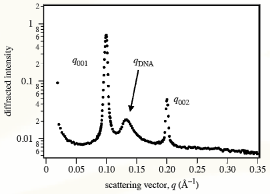


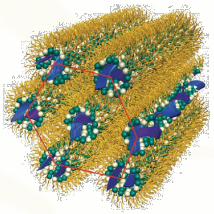


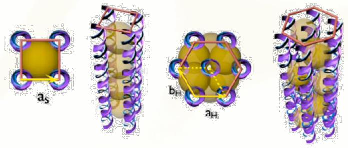
S. White (UC Irvine)

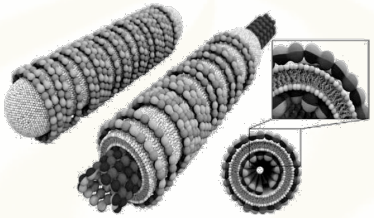
DNA cationic lipid and protein lipid complexes











C. Safinya (UCSB)

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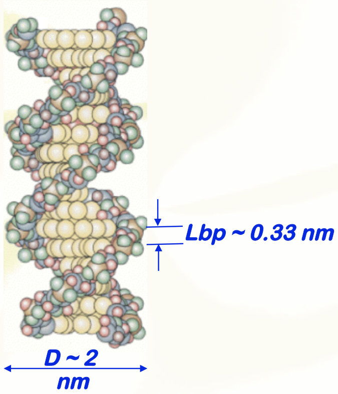
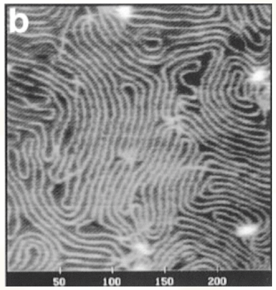
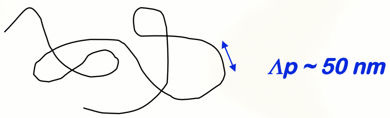
liquid crystals and the origin of life



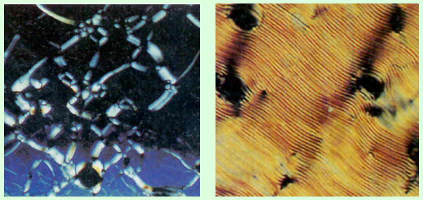


Y. Fang, J. Phys. Chem B (1997)



duplex DNA chiral nematic phase

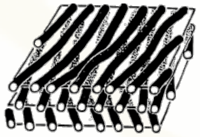
(N = 146 bp)

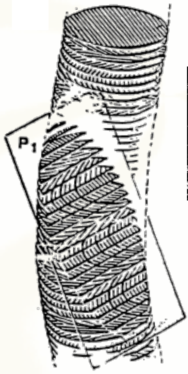


Strzelecka, Davidson, Rill, Nature (1988)

L = 50 nm ~ Λ_p

shape:
L/D ~ 25/1





dinoflagellate chromosome

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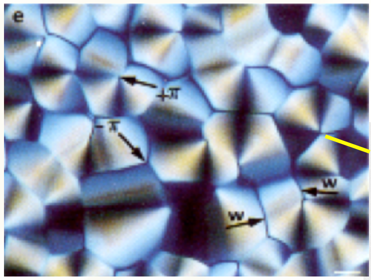
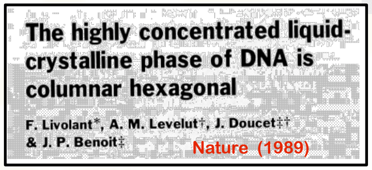
duplex DNA columnar phase



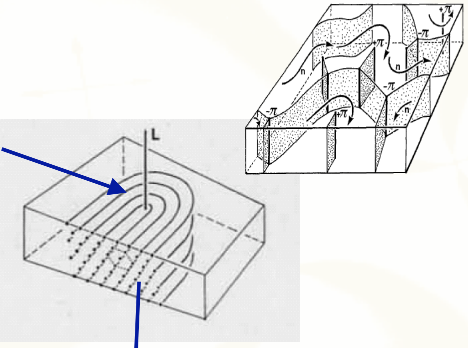
N = 146 bp, L = 50 nm, L/D = 25:1

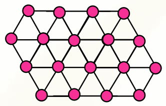


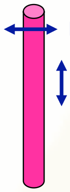
The highly concentrated liquid-crystalline phase of DNA is columnar hexagonal

F. Livolant*, A. M. Levelut†, J. Doucet‡† & J. P. Benoit‡

Nature (1989)







high n

low n

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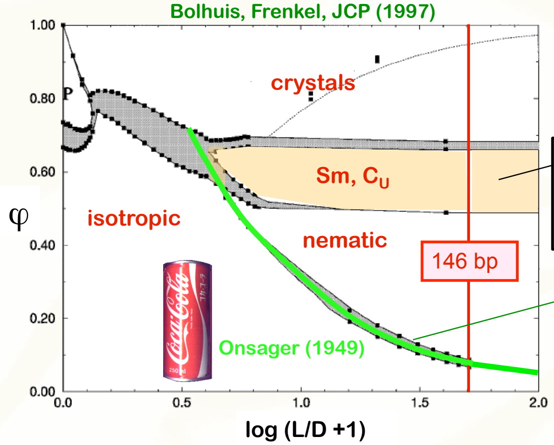
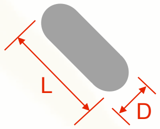
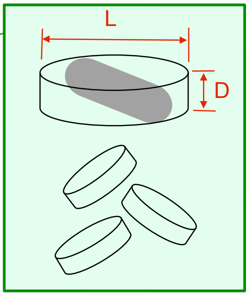
model: hard rods

Bolhuis, Frenkel, JCP (1997)





flexibility, polydispersity replaces smectic phase by columnar phase



nematic only for L > 5D

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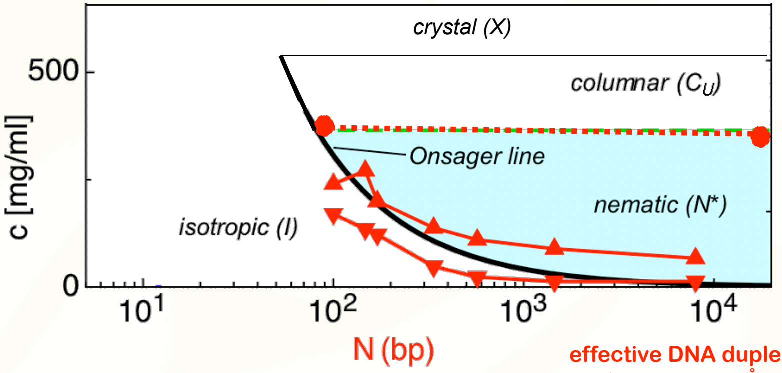
duplex DNA phase diagram



effective DNA duplex diamater = 40Å

Merchant, Rill, Biophysical Journal (1997)

“nanoDNA”

20bp	**5’-AACGCAAAGATCTTTGCGTT-3’**	**(L ~ 6.1 nm)**
16bp	**5’-CGCGAAAATTTTCGCG-3’**	**(~ 5.4 nm)**
14bp	**5’-ACGCGAATTCGCGT-3’**	**(~ 4.8 nm)**
12bp	**5’-CGCGAATTCGCG-3’**	**(~ 4.1 nm)**
12bp	**5’-AACGCATGCGTT-3’**	**(~ 4.1 nm)**
10bp	**5’-CGCAATTGCG-3’**	**(~ 3.4 nm)**
8bp	**5’-CGCATGCG-3’**	**(~ 2.7 nm)**
6bp	**5’-CGATCG-3’**	**(~ 2.0 nm)**

12bp **5’- CCTCAAAACTCC-3’ +**
5’- GGAGTTTTGAGG-3’

and many others!

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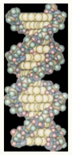
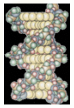
liquid crystals of nanoDNA

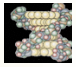
16 bp

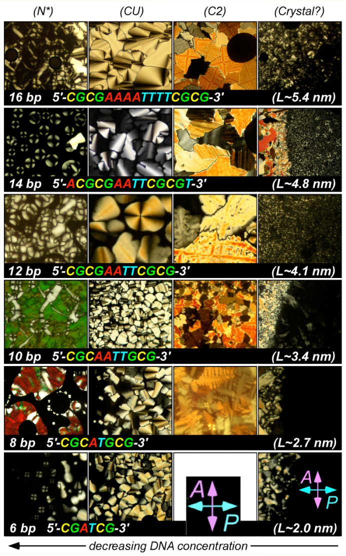


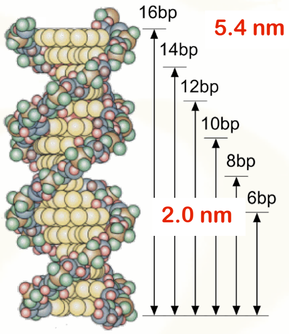
10 bp



6 bp







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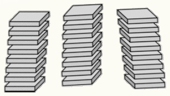
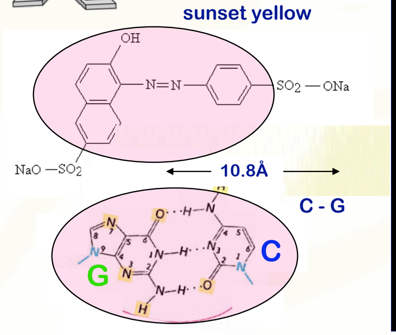
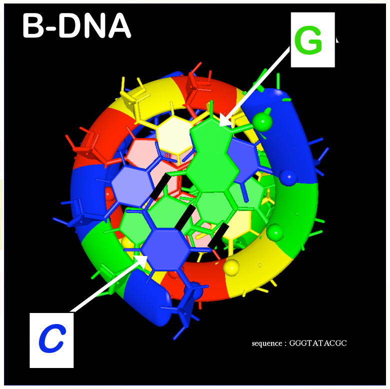
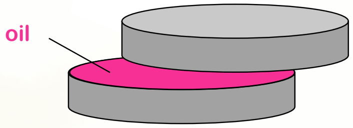
the end of DNA









ε ~ 2kT / 10Å^2

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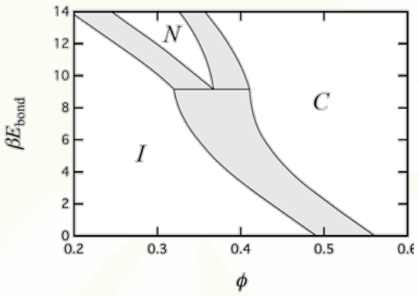
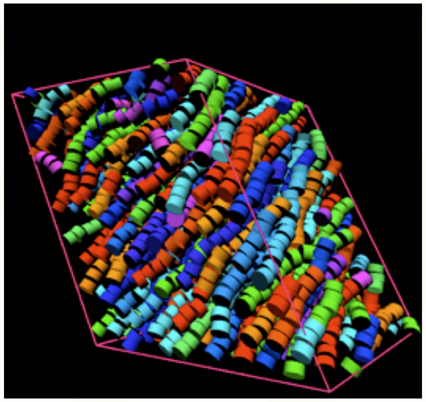
sticky ends → nematic & columnar phases

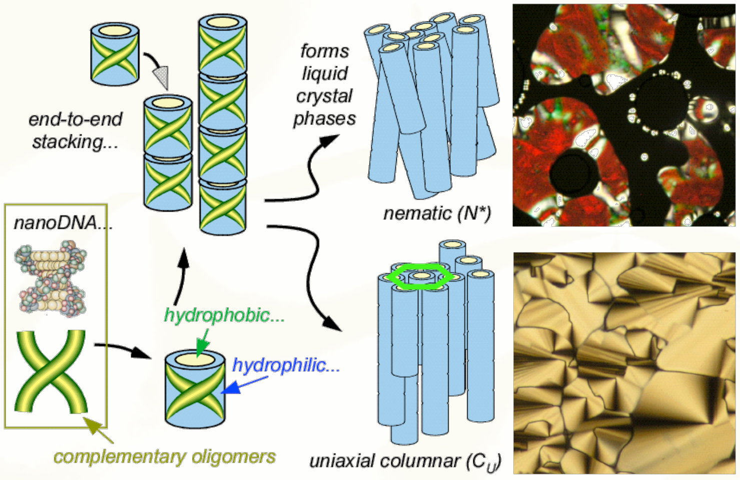


“living polymerization”

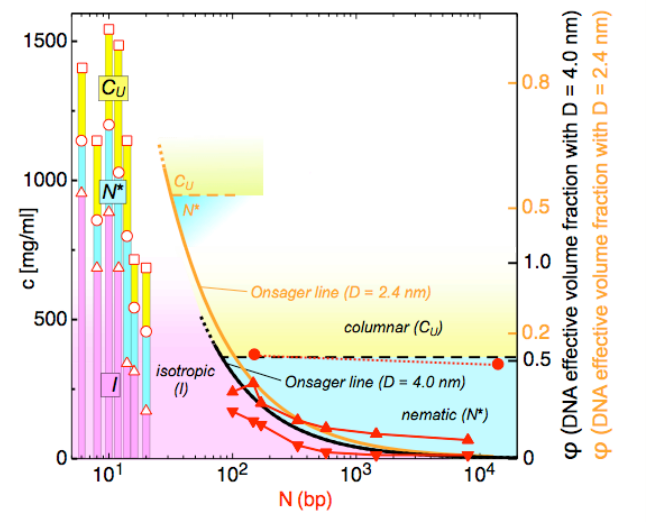


Kurablova, Betterton, Glaser,
Advanced Materials (2010)

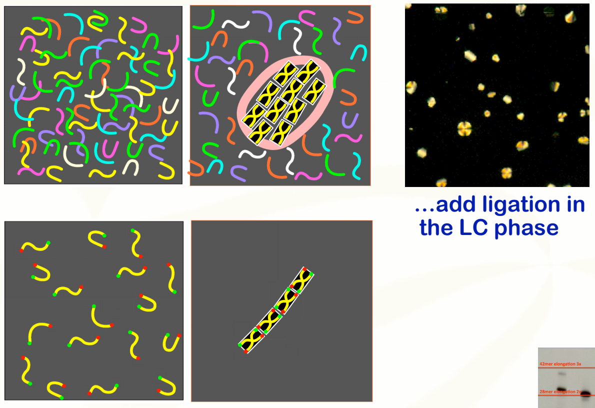
end-to-end adhesion



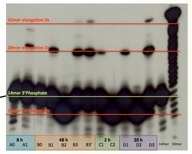
nanoDNA phase diagram



LC condensation of complementary strands

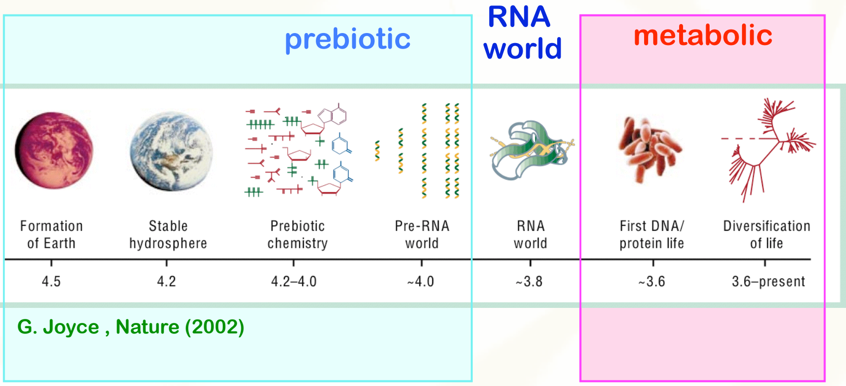


...add ligation in the LC phase



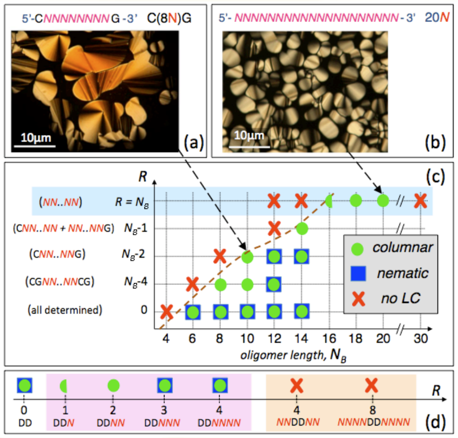
- **non enzymatic ligation**
  - water soluble carbodiimide
  - thiolene click chemistry (Chris Bowman)

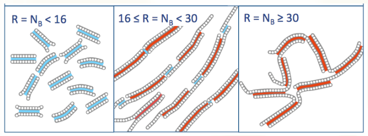
timeline

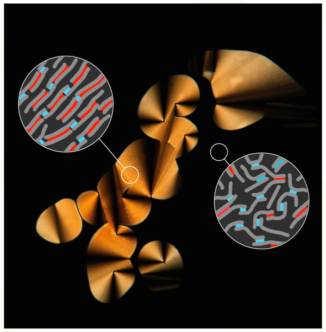


G. Joyce , Nature (2002)

random sequence DNA







<14 mers – association too weak: no LCs

14-20 mers – kinetic arrest into duplexes with random tails: gives LCs

>30 mers – kinetic arrest into a gel: no LCs

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the future