

Introductory remarks

Liquid crystals as quintessential *soft* matter.

Simultaneously transmit torques (solid) and flow (liquid).
NOT a soft solid, like a gel, but a true solid and a true fluid.

Contrast with glasses – transmits torque for “high” frequencies
while flows for “low” frequencies.

Very soft. kT is very important.

What is responsible for this remarkable behavior?

Introductory remarks

Classification of liquid crystals by symmetry, structure
and description of their macroscopic properties.

Classification of liquid crystals by materials, length scale, geometry,
molecular complexity.

Continuum description of elasticity and hydrodynamics.

Interaction with external fields.

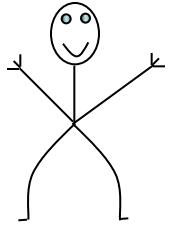
Characteristic defects.

Phase behavior.

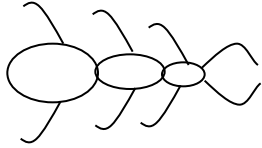
Introductory remarks

How does the field of liquid crystal research fit into soft matter?

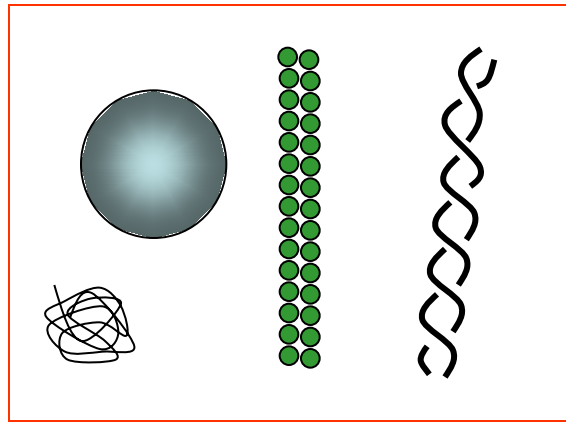
Historically, liquid crystals, colloids, polymers were studied by chemists.
1960's French physicists (around deGennes) revived liquid crystal research.



1m

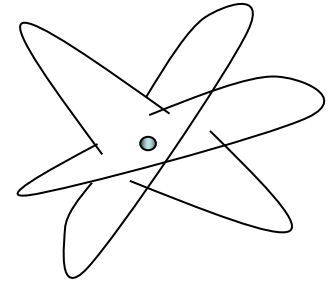
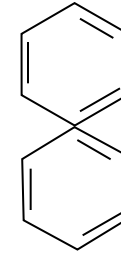


$10^{-2} - 10^{-4}$ m



$10^{-5} - 10^{-8}$ m

Colloids



$10^{-9} - 10^{-10}$ m

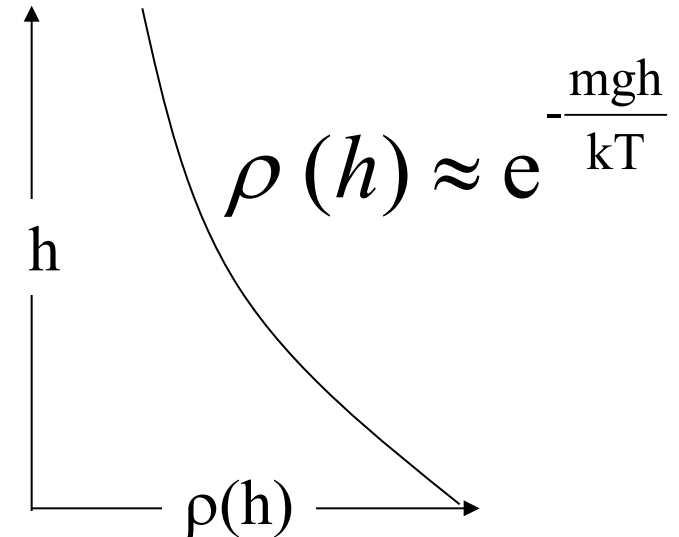
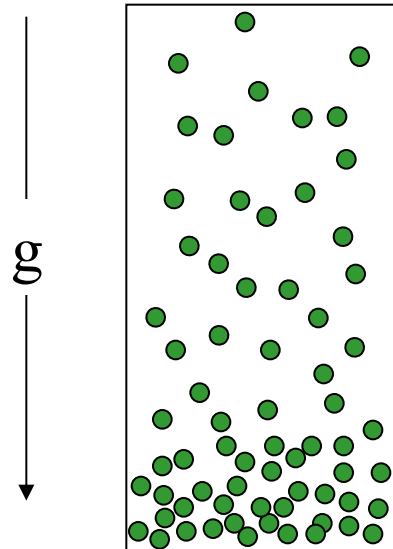
“quantum”

Thermal motion
prevents
sedimentation

yet

strongly couple
to external fields

liquid crystals



Introductory remarks

Recognition that energy, length and time scales are similar for
colloids, polymers, liquid crystals, emulsions, gels, membranes.

Consequently, same theoretical description.

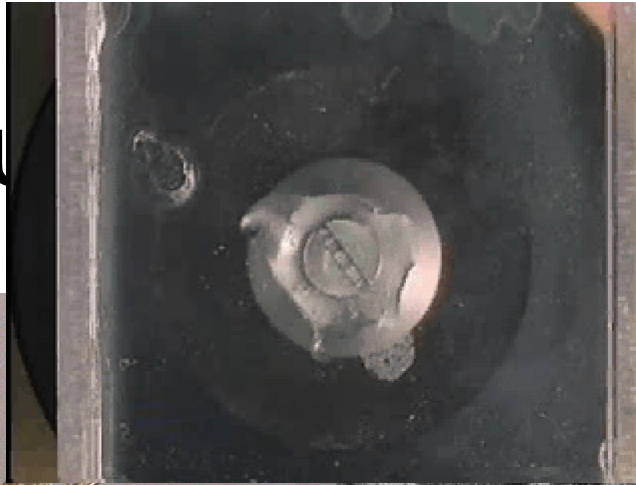
Personal history: irreversible aggregation of colloids w. G.B. Benedek in 1979,
x-ray diffraction of virus with D.L.D. Caspar in 1980,
2D colloids and liquid crystals for thesis w. R.B. Meyer 1981-86.

Feb 1984: Pieranski: Colloidal Crystals, Les Houches

Chaikin, Clark, Pieranski, Ackerson, Maret, Klein, JP Hansen, Charvolin,
Dubois-Violette, Pansu,

<http://www.elsie.brandeis.edu/>

Granular Colloidal



TMV



10,000,000 nm



http://www.uio.no/studier/emner/matnat/kjemi/KJM3100/v06/undervisningsmateriale/kjm3100_liquid_crystals_f.pdf

<http://www.uio.no/studier/emner/matnat/kjemi/KJM3100/v06/>

Chemistry of materials: Paul Norby, Kjemisk Institutt, Norway



The screenshot shows the official website of the University of Oslo (UiO). The header features the university's logo and name in blue. A navigation bar includes links for 'Om UiO', 'Studentliv', 'Forskning', 'For ansatte', 'IT-tjenester', 'Oppslagstavla', and 'Bibliotek'. A search bar is located on the right. Below the navigation bar, a yellow banner displays the word 'STUDIER' in blue. The main content area has a breadcrumb trail: 'Du er her: [UiO](#) > [Studier](#) > [Emner](#) > [KJM3100](#) >'. The title 'KJM3100 - Vår 2006 (Materialkjemi)' is prominently displayed. Underneath, there is a link for 'Beskrivelse av emnet'. The 'Forelesere' section lists 'Poul Norby', 'Bo Nyström', and 'Jaan Roots'. The 'Undervisning' section includes a link for 'Tid og sted'. The 'Forelesninger' section provides a list of topics: 'intro', 'Minerals', 'Metals', 'Pauling', 'Ceramics', 'Bond valence', 'composites', 'Glass', 'Colour', 'Colour 2', 'Colour: Patrick Woodward 1', 'Colour: Patrick Woodward 2', 'Semiconducting nanoparticles', 'Microporous and mesoporous materials', and 'Liquid Crystals'. A yellow box on the right contains the text 'Siste beskjeder:' followed by a message from '26.05' regarding missing material and a copy collection. At the bottom, another section for 'Forelesninger - Bo Nyström' lists topics like 'Gels and association complexes', 'Rheology of gels', 'Core-shell nanoparticles', and 'Polymer-cyclodextrin complexes'.

UNIVERSITETET I OSLO

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KJM3100 - Vår 2006 (Materialkjemi)

[Beskrivelse av emnet](#)

Forelesere
[Poul Norby](#) - [Bo Nyström](#) - [Jaan Roots](#)

Undervisning
[Tid og sted](#)

Forelesninger
[intro](#) - [Minerals](#) - [Metals](#) - [Pauling](#) - [Ceramics](#) - [Bond valence](#) - [composites](#) - [Glass](#) - [Colour](#) - [Colour 2](#) - [Colour: Patrick Woodward 1](#) - [Colour: Patrick Woodward 2](#) - [Semiconducting nanoparticles](#) - [Microporous and mesoporous materials](#) - [Liquid Crystals](#)

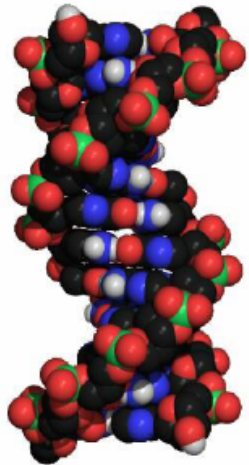
Forelesninger - Bo Nyström
[Gels and association complexes](#) - [Rheology of gels](#) - [Core-shell nanoparticles](#) - [Polymer-cyclodextrin complexes](#)

Siste beskjeder:

26.05: If any of you are still missing some of the material from the "pensum" list you may collect a copy from me. (Office: Ø148 in the Chemistry building)

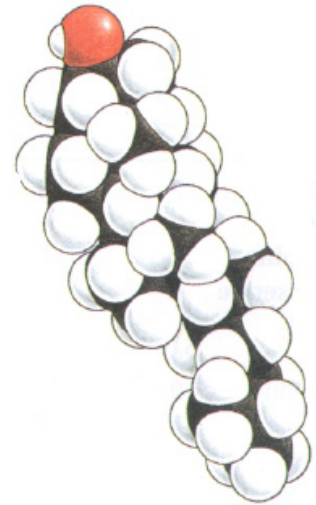
04.05: The class on May 20 will be moved

Johdatus pehmeän aineen fysiikkaan Tfy-3.363



**Ilpo Vattulainen
Laboratory of Physics and
Helsinki Institute of Physics**

E-mail: Ilpo.Vattulainen@csc.fi



The Biological and Soft Matter Physics Group
www.fyslab.hut.fi/bio/

http://fig.if.usp.br/~school06/palfy_1.pdf

Fundamental Aspects of Liquid Crystals

P. Palfy-Muhoray

Liquid Crystal Institute
Kent State University, Kent, OH

work supported by NSF-EC DMR 0132611

21/02/2006



Summer School on
Soft Matter Physics





International
Centre for
Theoretical
Physics



<http://fig.if.usp.br/~school06/>



Ministério
da Ciência
e Tecnologia

Summer School on Soft Matter Physics

Instituto de Física/USP - São Paulo/SP
February, 13-24, 2006

The Programme consists of research
addresses and courses, primarily directed to
graduate students and young researchers.



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An Introduction to Liquid Crystals Postgraduate Lectures

This series of lectures was first given in Autumn 2004 by members of the Continuum Mechanics Group in the Department of Mathematics (Prof. Mikhail Osipov, Prof Iain Stewart, Dr Andre Sonnet, Dr Nigel Mottram and Dr Geoff McKay).

- 1. Basic thermodynamics applied to liquid crystals:** [slides](#) (pdf)
Basic concepts of thermodynamics are briefly discussed including phases, 1st and 2nd order phase transitions, internal and external thermodynamic variables, thermodynamic potentials and their minimisation under different boundary conditions, the concept of the order parameter is introduced, and illustrated using simple liquid crystal phases (nematic, smectic A and C). A relationship between the form of the tensor order parameter and the symmetry of the phase is considered. Finally Landau-de Gennes theory of phase transitions between these phases is briefly discussed.
- 2. Fluid dynamics of liquid crystals:** [slides](#) (pdf)
Some simple ideas about Newtonian and Non-Newtonian behaviour in fluids will be discussed. Brief mention will be made of the Bingham and Herschel-Buckley models for the shear stress and the non-Newtonian properties of such materials. The specialised case of anisotropic fluids will also be discussed and a simple shear problem will be investigated to demonstrate non-Newtonian behaviour.



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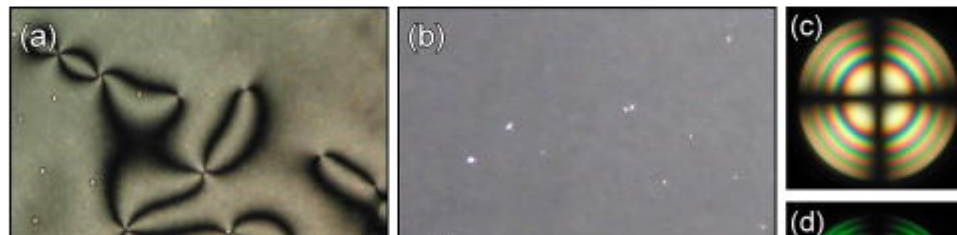
Liquid Crystal Textures in the Microscope: A Short Tutorial

The optical properties of liquid crystal phases often directly reflect the symmetry of their structures. Anisotropy of the refractive index, or birefringence, is one of the characteristic physical properties of liquid crystals, and it allows for the visualization of the macroscopic molecular orientation. In thin liquid crystal sample cells placed between two crossed polarizers under an optical microscope, a variety of textures and birefringence colors will be observed. These textures and colors not only look beautiful but also provide a lot of information about the macroscopic structure of the LC phases. Although there are many experimental techniques available to investigate the structure and physical properties of LC phases, microscope observations often give enough information to determine the structure even if a well-aligned domain is not obtained.

[<TOP>](#) [<Nematic>](#) [<Cholesteric>](#) [<Blue Phase>](#) [<SmA>](#) [<SmC>](#) [<SmCA>](#) [<SmCP>](#)

The Nematic phase

In a planar cell, where the molecular director aligns parallel to the glass surface, with no rubbing treatment a *schlieren* texture organized around point disclinations, disclination lines and inversion walls is observed [see Figure 1 (a)]. In a homeotropically aligned texture, where the molecular director is normal to the glass surface, no birefringence is observed [see Figure 1 (b)] because the phase is uniaxial [see Figure 1 (c) and (d)] and the optic axis is normal to the substrates. Birefringence is visible when the sample is tilted. Flickering originating from fluctuations of the $\mathbf{n}$ -director is often observed in both homeotropic and planar cells.



<http://research.yale.edu/boulder/Boulder-2002/notes.html>

The screenshot shows a Microsoft Internet Explorer browser window. The title bar reads "July 2002 Summer School Lectures - Microsoft Internet Explorer". The address bar contains the URL "http://research.yale.edu/boulder/Boulder-2002/notes.html". The search bar shows the text "quid crystal meyer boulder". The main content area of the browser displays the following text:

BOULDER SCHOOL FOR CONDENSED MATTER AND MATERIALS PHYSICS

Physics of Soft Condensed Matter

July 1-26, 2002, Boulder, Colorado, USA

Bob Meyer

- [Complete Slides](#)
- Lecture 1 - [Liquid Crystals - Elasticity, Static Equilibrium, Textures](#)
- Lecture 2 - [Optics of thin layers of liquid crystals](#)
- Lecture 3 - [Chirality - Lack of Mirror Symmetry](#)
- Lecture 4 - [Liquid Crystal Gels - Liquid & Rubber in one material!](#)

Paul Chaikin

- [Lecture Notes](#)

Doug Durian

At the bottom of the browser window, the text "Lecture 1 Introduction" is partially visible.

<http://dept.kent.edu/spie/liquidcrystals/index.html>

Liquid Crystals: a Simple View on a Complex Matter - Microsoft Internet Explorer

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Address <http://dept.kent.edu/spie/liquidcrystals/index.html> Go Links

Google Search 194 blocked Check AutoLink AutoFill Options

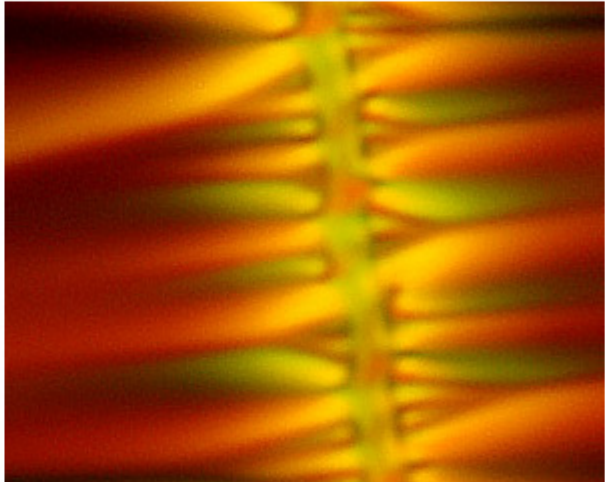
Liquid Crystals: *a Simple View on a Complex Matter*

[Next](#)

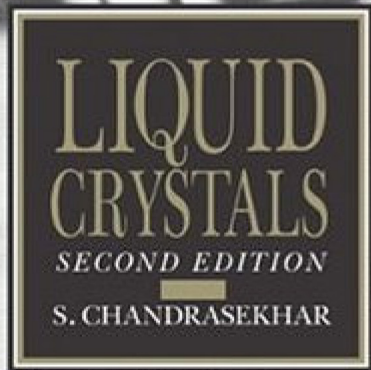
presentation by [B. Senyuk](#)

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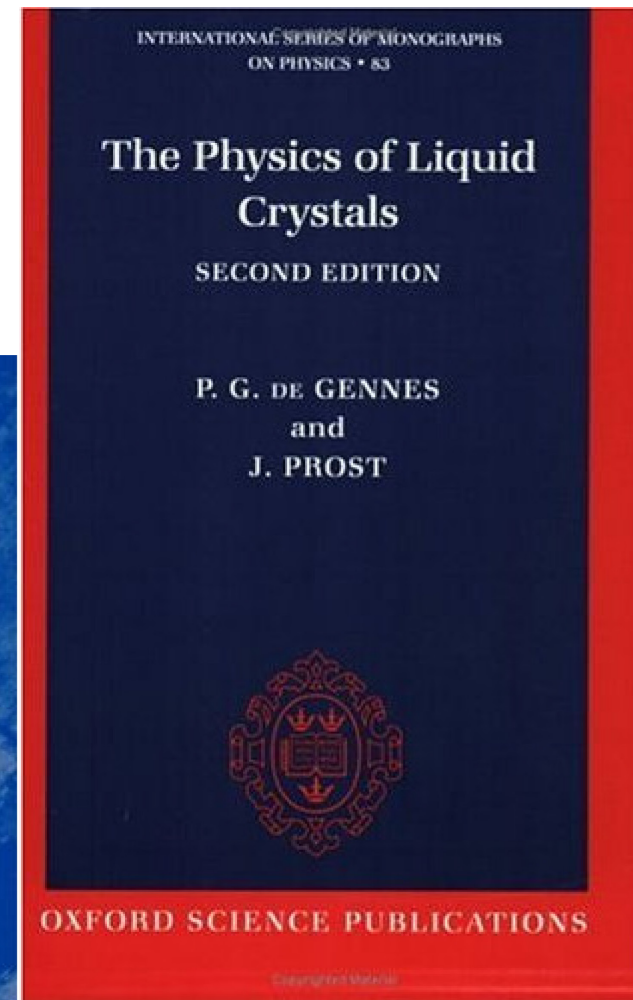
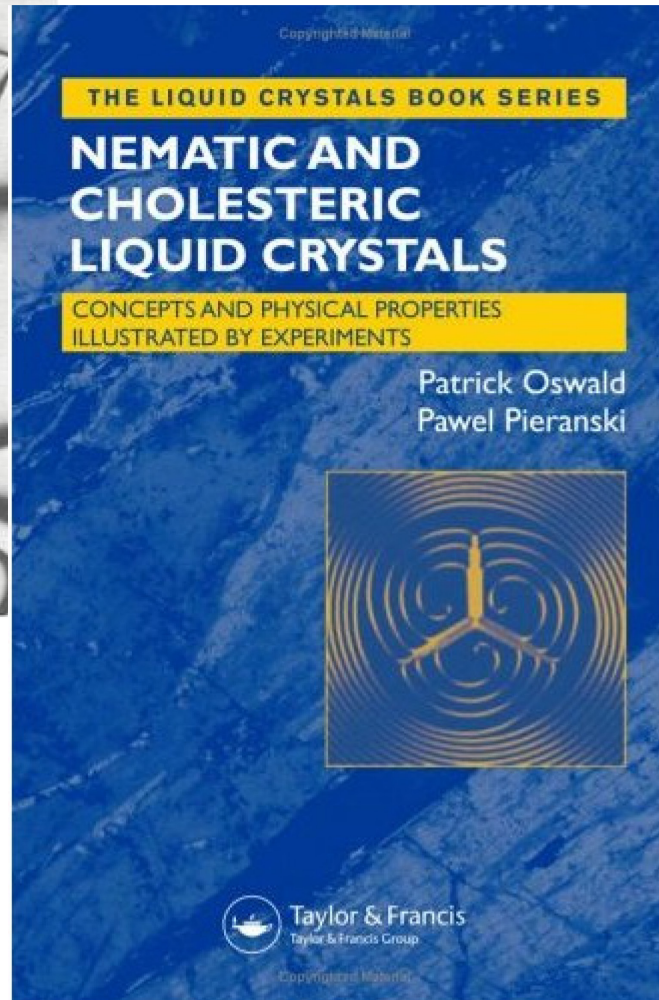
- [1. Introduction](#)
 - [What are Liquid Crystals?](#)
 - [Why Liquid Crystals?](#)
 - [A brief history of Liquid Crystals](#)
- [2. General Remarks](#)
 - [Classification](#)
 - [Building blocks](#)
 - [Liquid Crystal State](#)
- [3. Director and Order Parameter](#)



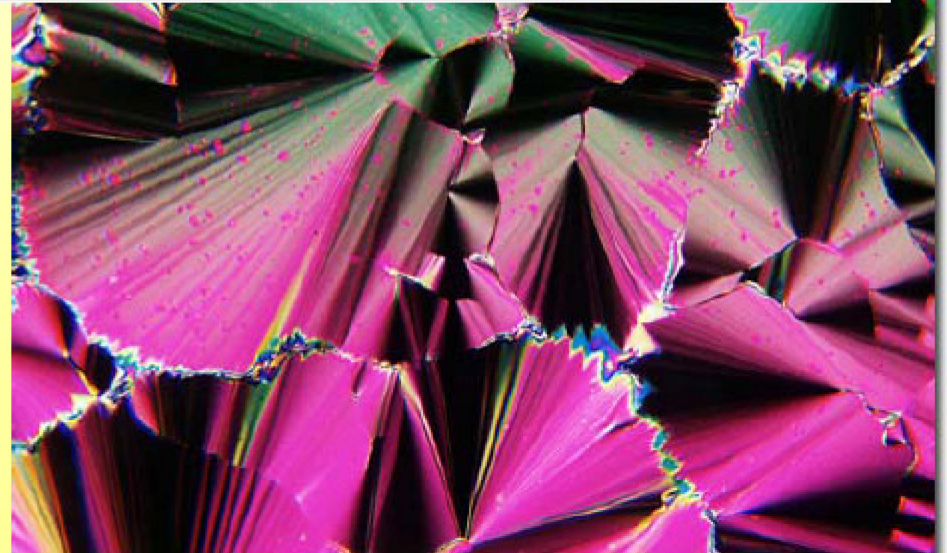
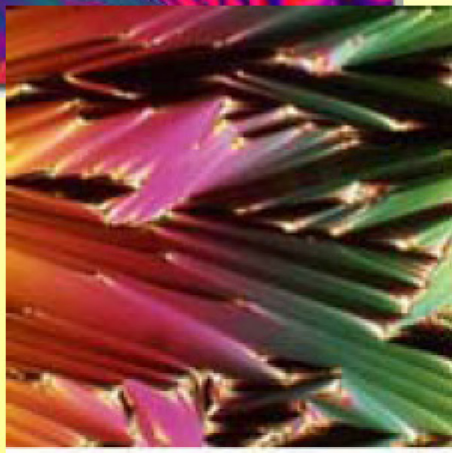
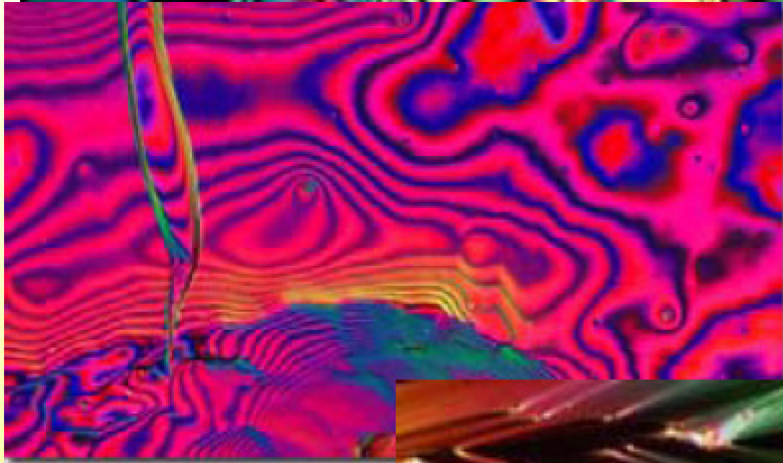
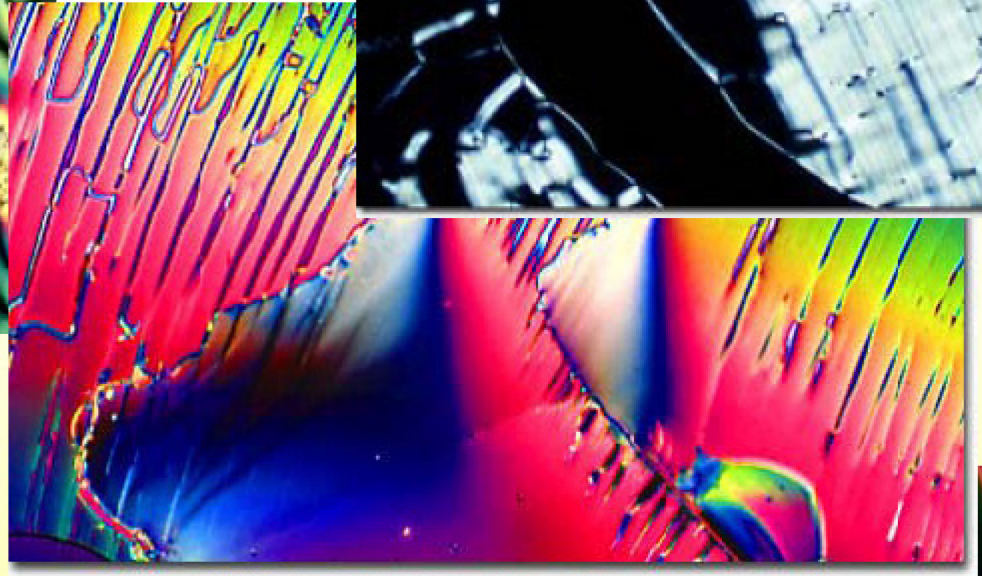
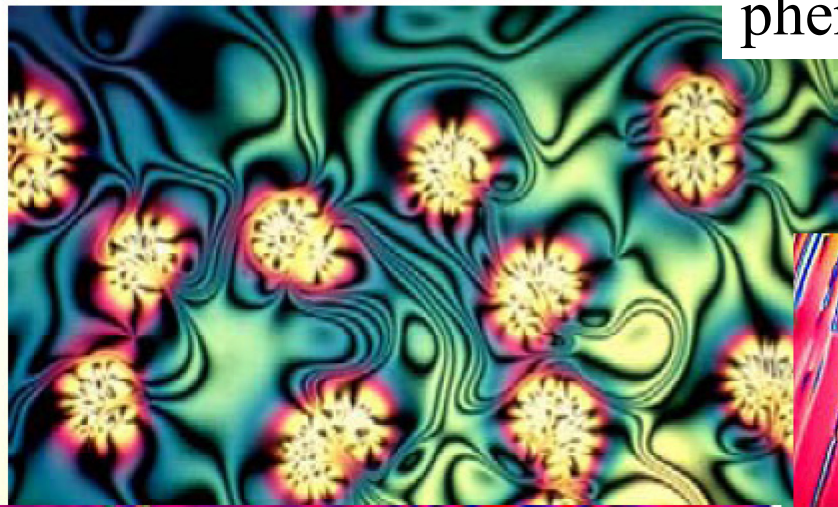
Books



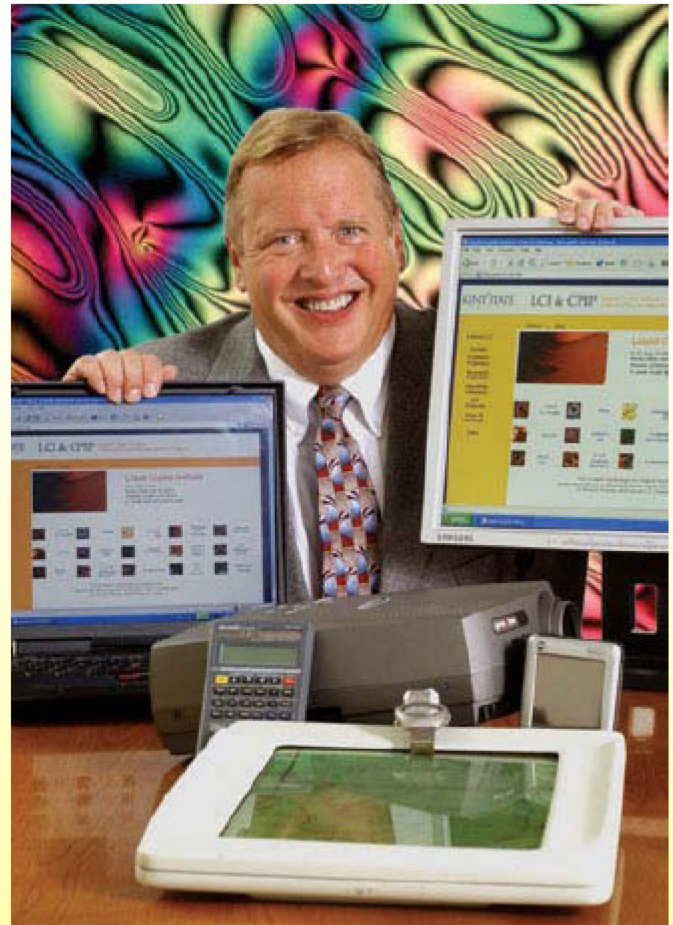
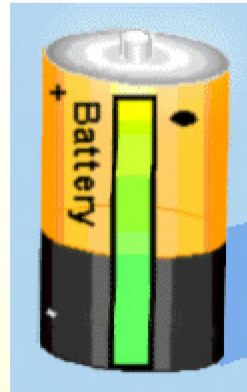
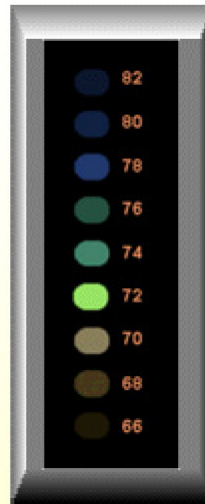
Cambridge University Press



phenomenology



Applications



LCD flat panel: \$50B in 2005

www.switchlite.com/applications.html

Liquid crystals - history

Several scientists observed liquid crystal behaviour without understanding the implications or yjr underlying structure.

From 1850 – 1888:

- 1) Microscopy studies of biological specimens: e.g. covering of nerve fibers. Soft flowing forms and polarizing effects in liquid states...
- 2) Crystallization studies: **Otto Lehmann**: Heating stage on a microscope with polarizing filters. Crystallization studies during cooling. Observed formation of an “amorphous state” between liquid and crystalline state.
- 3) Unusual melting behaviour in stearin. (W. Heintz ~1850): Cloudy at 52°C, opaque at 58°C and becomes clear at 62.5°C.

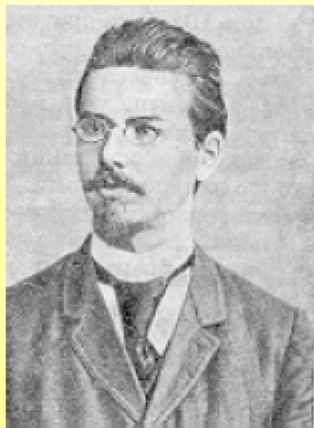
The discovery

An Austrian botanist, Friedrich Reinitzer, studied cholesterol in plants. In 1888 he reported **two melting points** in a compound related to cholesterol: Melts to a cloudy liquid at 145.5°C , turned to a clear liquid at 178.5°C . (cholesteryl benzoate)

What is this? Might it be a form of matter different from solids or liquids?

By asking the question, instead of just observing, he qualified to be remembered as the discoverer of liquid crystals.

Otto Lehmann became the leading figure in the early days of liquid crystal research.



Friedrich Reinitzer
(1857 - 1927)



Otto Lehmann
(1855 - 1922)

Lehmann:
Soft crystals (that are almost fluid)
Floating crystals
Crystalline fluids
Liquid crystals

Otto Lehmann

Microscope with heating stage and polarizing filters (1889)

From a letter to Reinitzer:

"...my new results confirm your [previously] declared view, that the [substance] consists of very soft crystals ... It is absolutely homogeneous, and another liquid - as you assumed formerly - is not present ... It is of a high interest for the physicist that crystals exist which are of such a considerable softness that one could almost call them liquid."

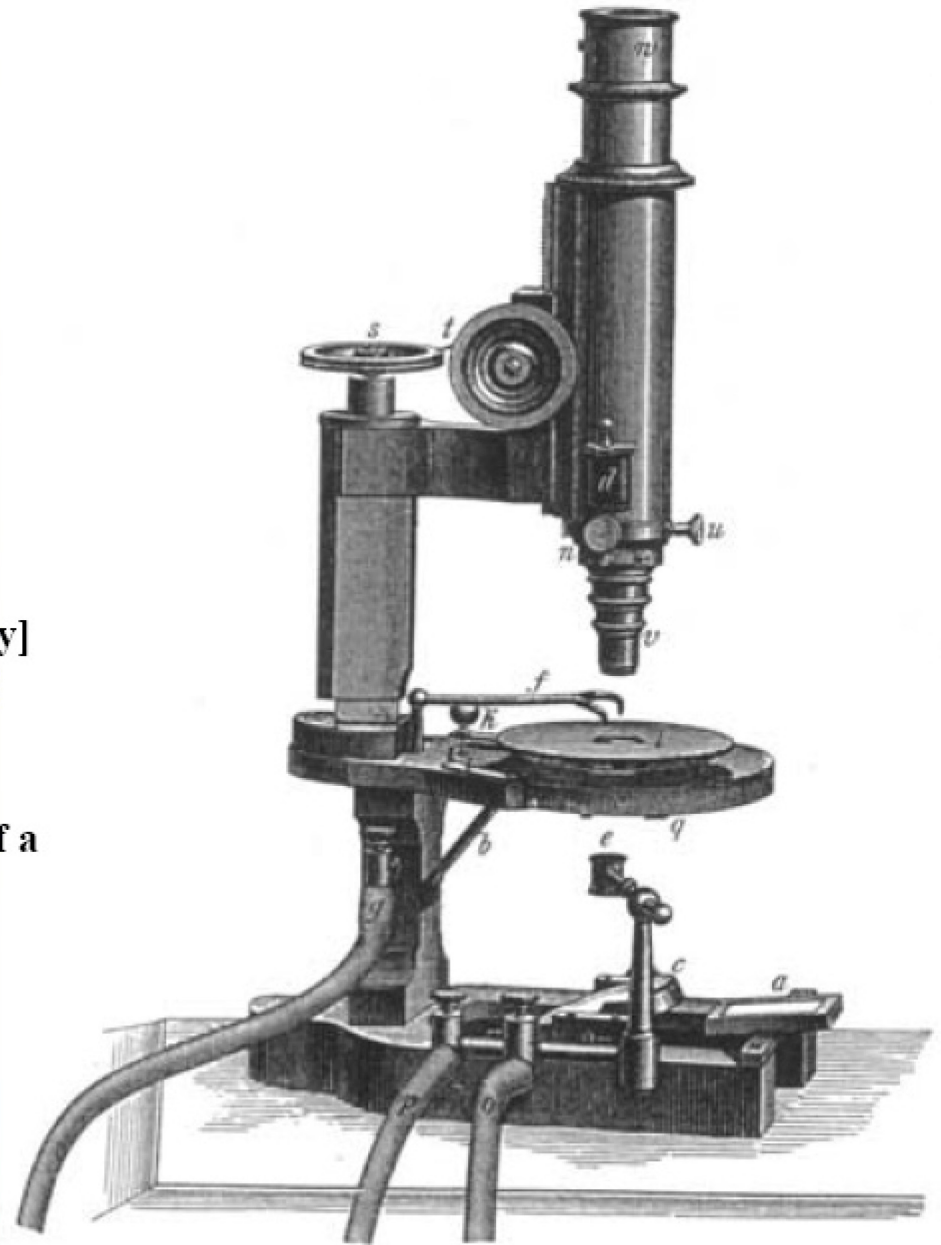
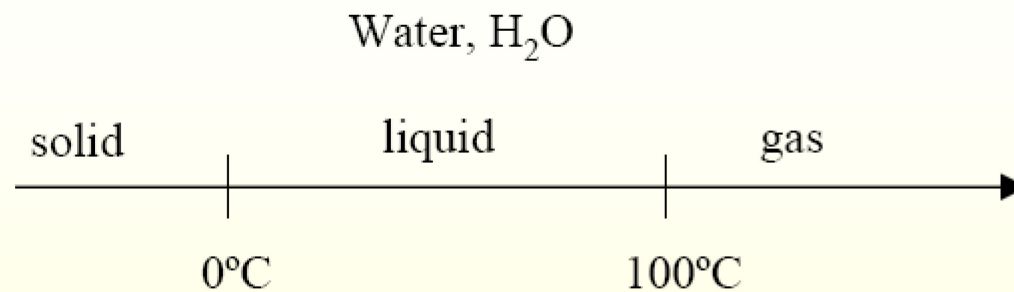
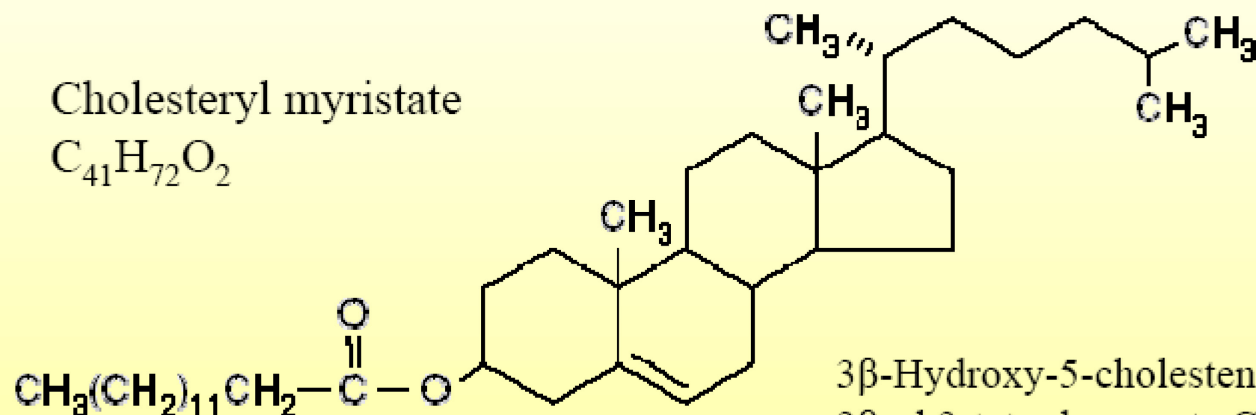
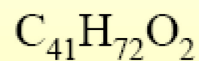


Fig. 20.

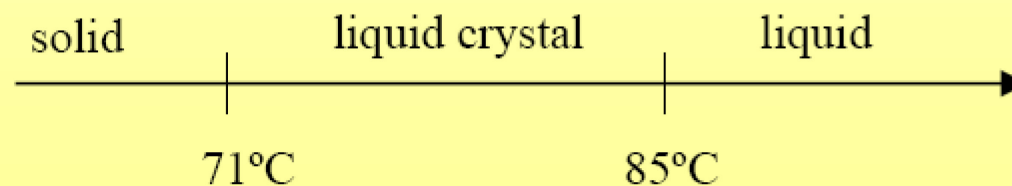
Types and classification of liquid crystals



Cholesteryl myristate



3 β -Hydroxy-5-cholestene 3-tetradecanoate 5-Cholesten-
3 β -ol 3-tetradecanoate Cholesteryl tetradecanoate



Otto Lehmann: Fliessende Kristalle: “flowing crystals”

Über fliessende Kristalle, Zeitschrift für Physikalische Chemie, 1889.

If one trusts the interpretation of the experimental observations, this is so far the only case when a crystalline substance, showing considerable birefringence, has such a weak mechanical strength that it can hardly resist the action of its own weight.

Forty years of debates between view that *liquid crystals* were chemically and physically homogeneous phases vs. view that optical turbidity was a result of either demixing impure substances or incomplete melting of the crystalline phase.

George Friedel (1922): “mesomorphic states”.

States are intermediary (*meso*-morphic) between those of crystals and liquids.

230 space groups allowing for the classification of all possible crystalline structures in 3D.

The same substance can display crystalline polymorphism depending on temperature and pressure (ice IX, etc.).

Analogously mesomorphic polymorphism is a characteristic of liquid crystals

Modern definition of mesophases;

Broken symmetries; short- and long-distance order.

Symmetry of a system of particles can be lower than that of the interaction Hamiltonian.

In a homogeneous and isotropic space the hamiltonian must be invariant with respect to

$$G = t \otimes SO_3$$

t – the group of 3D translations $t = x\hat{i} + y\hat{j} + z\hat{k}$

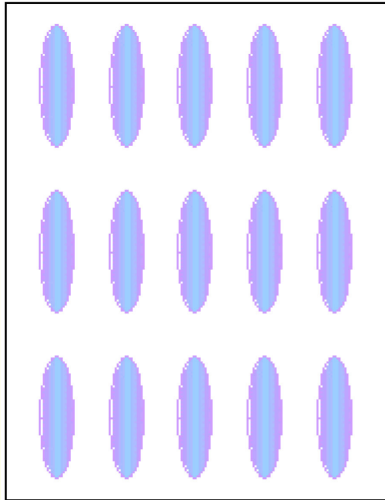
SO_3 – the group of space rotations

In a gas or liquid there is no symmetry breaking, but in a crystal both translational and orientational symmetries are broken.

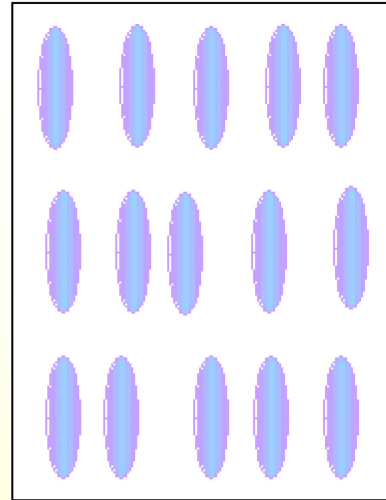
$$\langle \rho(r) \rangle = \rho_o + \sum \rho(q) e^{iqr}$$

In a crystal, density is only invariant with respect to the elements of one of the 230 possible space groups.

Symmetry breaking is *less important* in mesophases than in 3D crystals:
liquid crystals are *intermediaries* between 3D crystals and the liquid isotropic phase.

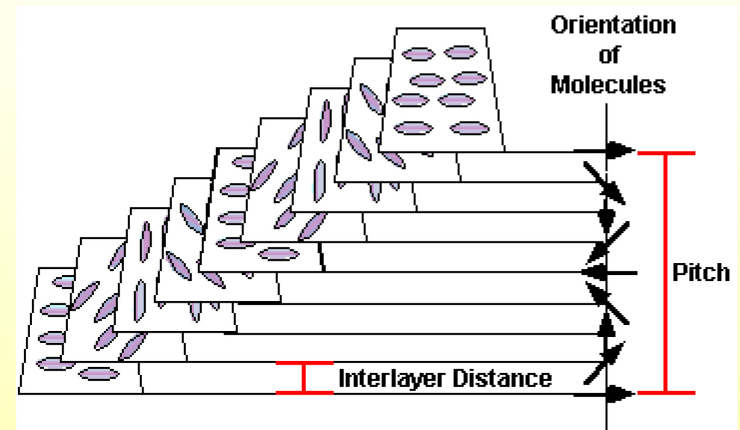


Crystalline Solid

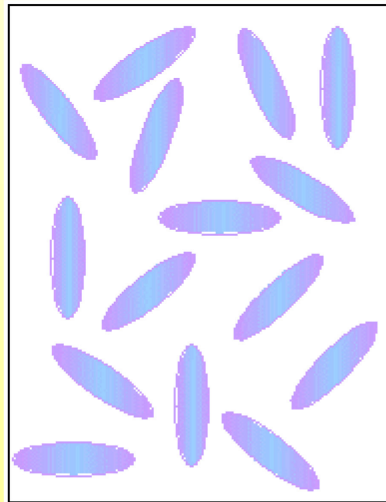


Smectic

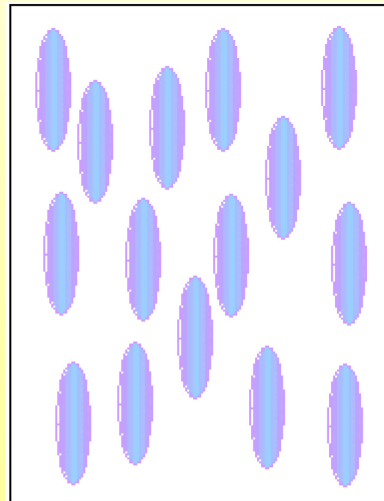
Liquid Crystal:



Cholesteric
or
twisted- nematics
or
Chiral nematics



Isotropic Liquid



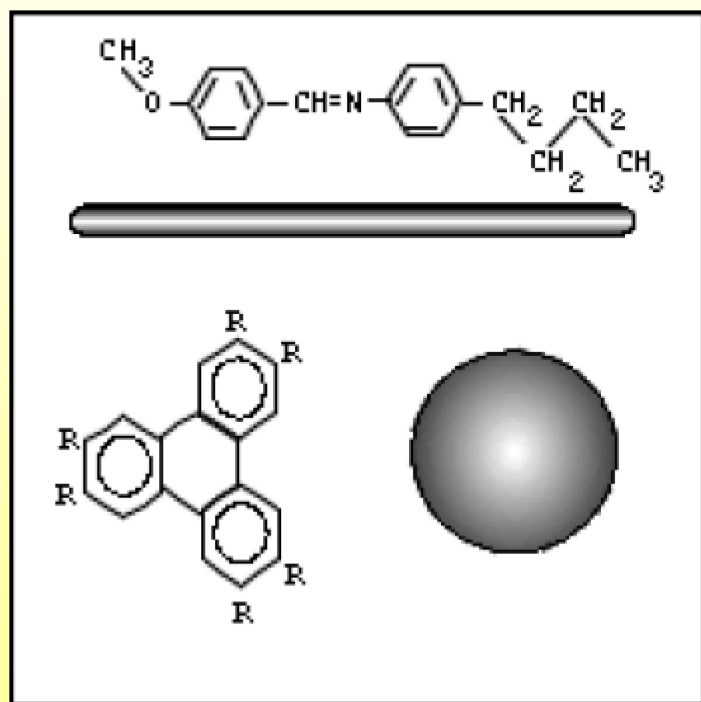
Nematic

Molecules

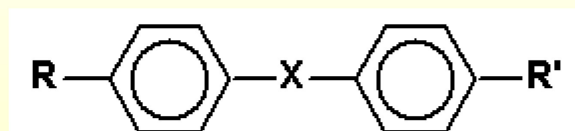
**~1 of 200 molecules
form liquid crystals**

Which molecules may form liquid crystals?

- 1) Elongated shape (anisotropic)
- 2) Must have some rigidity in its central region. Flexible (cooked spaghetti-like) molecules do not form a liquid crystal state.
- 3) Flexible ends seems to be an advantage



Calamatic:

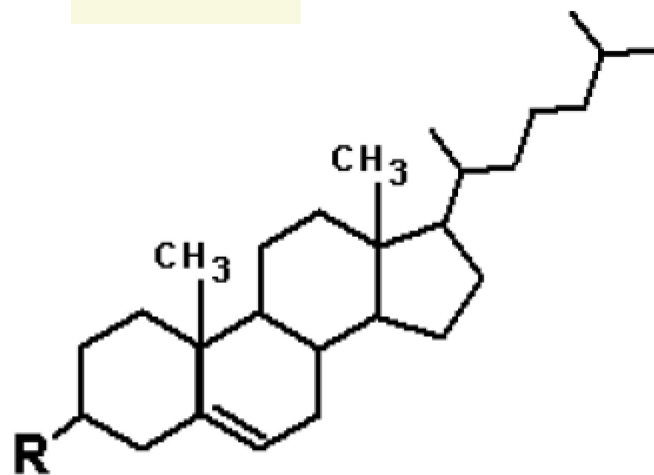


Bridging Group X

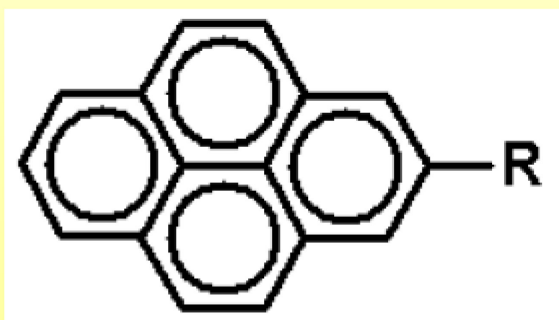
- N = N -
- N = NO -
- CH = CH -
- C $\equiv$ C -
- CH = N(O) -
- CH = N -
- O - CO -

End Groups R, R'

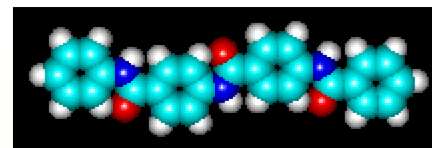
- $\text{C}_n\text{H}_{2n+1}$ n = 1 to 9
- $\text{OC}_n\text{H}_{2n+1}$ n = 1 to 9
- C $\equiv$ N
- $\text{OOC} - \text{OC}_n\text{H}_{2n+1}$ n = 1 to 9



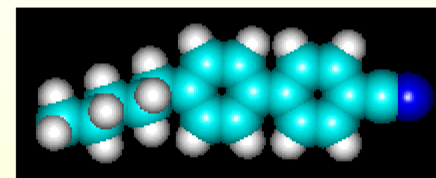
Cholesterol-derivatives



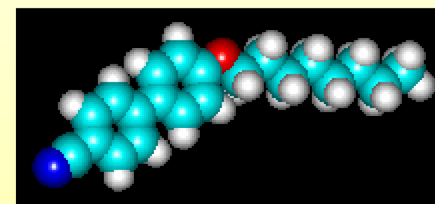
pyrene-derivatives



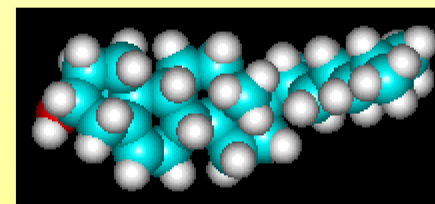
Kevlar - polymeric liquid crystal



5 -CB



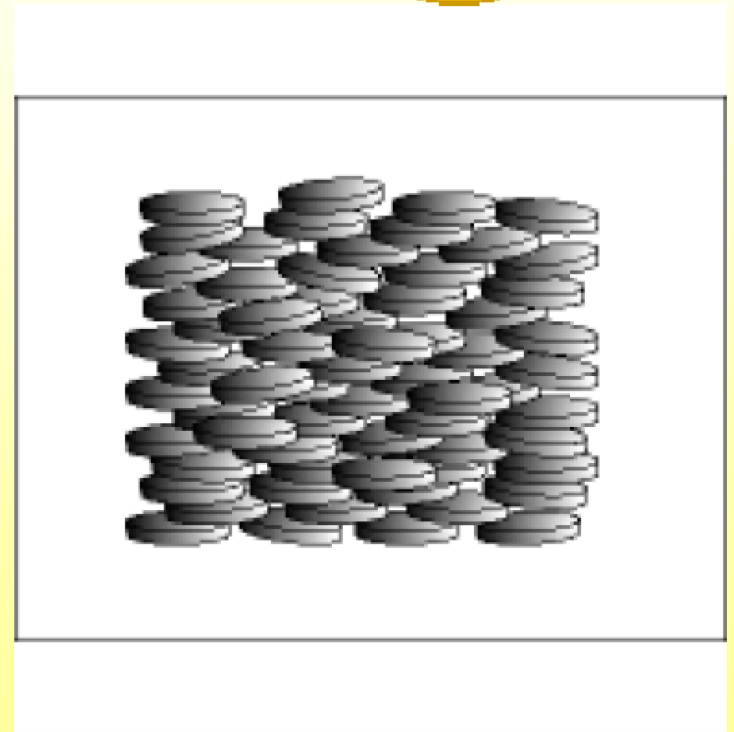
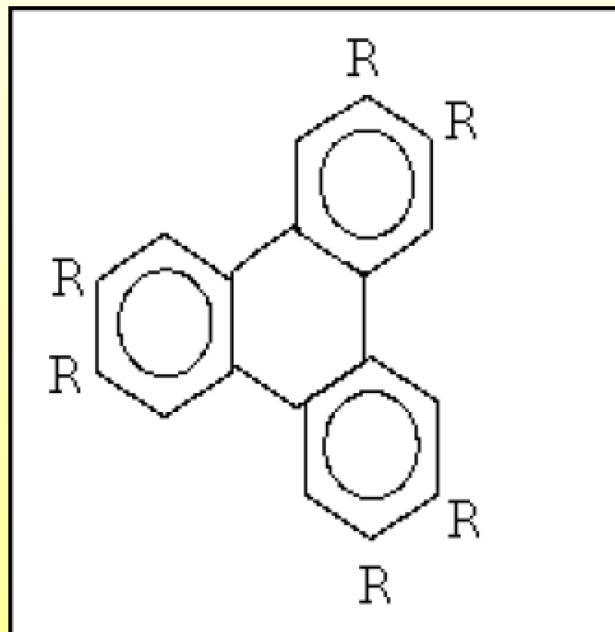
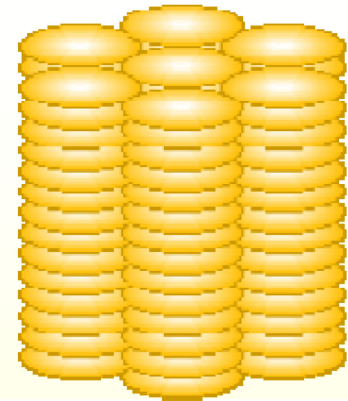
OOCBP



Cholesterol

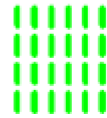
Discotic phases

Disc-shaped molecules
Columnar organized liquid crystals
Nematic or smectic organization



Hybrid molecular form and molecular frustration

octane



crystal



-91 °C



isotropic liquid

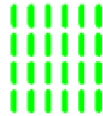
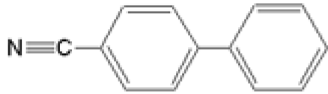


+98 °C

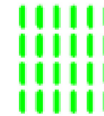


gas

4-cyanobiphenyl

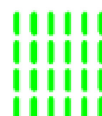


crystal



88 °C

8CB: octane + 4-cyanobiphenyl



crystal Solid



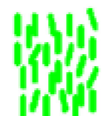
21.5 °C



Smectic A



33.5 °C



Nematic



40.5 °C



Isotropic

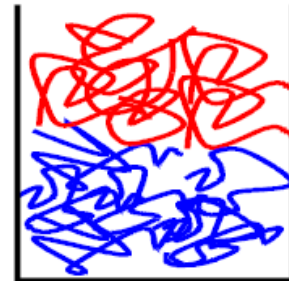
Block co-polymers
liquid crystalline block copolymers
self-assembling amphiphilics

Block copolymer self-assembly

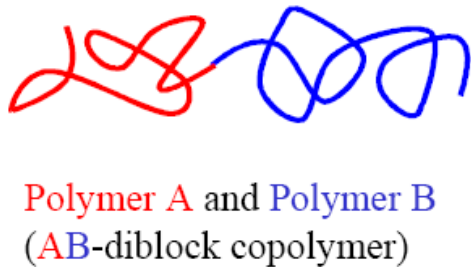
Homopolymers



Macrophase separation...



Block copolymers



Microphase separation

Typical microphase domain size 10 – 100 nm



<http://dept.kent.edu/spie/liquidcrystals/index.html>

Liquid Crystals: a Simple View on a Complex Matter - Microsoft Internet Explorer

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Liquid Crystals: *a Simple View on a Complex Matter*

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presentation by [B. Senyuk](#)

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