FACULTY OF ENGINEERING
AND ARCHITECTURE

ELECTRONICS AND INFORMATION SYSTEMS DEPARTMENT
LIQUID CRYSTALS AND PHOTONICS RESEARCH GROUP

LIQUID CRYSTALS AND LIGHT EMITTING MATERIALS FOR PHOTONIC APPLICATIONS

Kristiaan Neyts April 2018 Lecture series at WAT in Warsaw

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WAT

nb-photonics
Center for Nano- and Biophotonics
Ghent University

Liquid Crystals and Photonics

GHENT UNIVERSITY, LIQUID CRYSTALS AND PHOTONIC GROUP

LCDs
OLEDs
solar cells
piezo-electrics
electrophoresis

Liquid Crystals and Photonics

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GHENT IN FLANDERS, BELGIUM, EUROPE

Liquid Crystals and Photonics

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OVERVIEW

- Introduction (2h)
- Electrical and optical properties of materials (6h)
- Liquid crystal properties (10h)
- Display applications (6h)
- Photonic applications (6h)

OVERVIEW

materials

electrical & optical properties

applications: displays photonics

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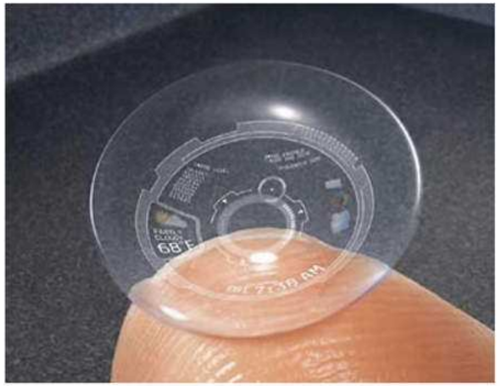
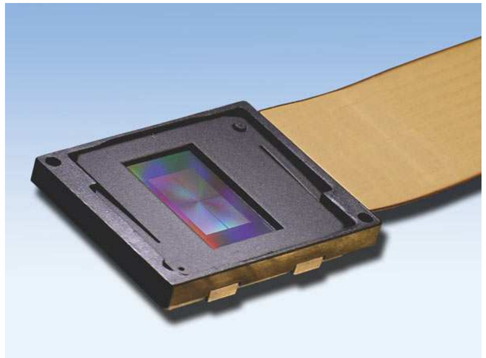
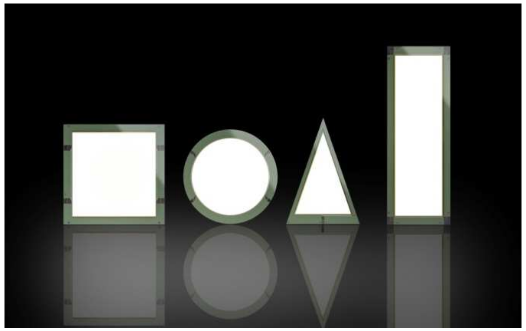
FROM MATERIALS TO APPLICATIONS

LCDs





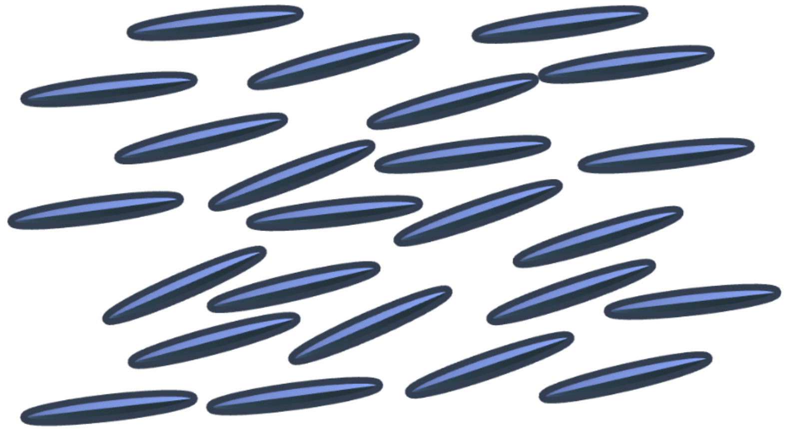
OLEDs



WHAT IS A LIQUID CRYSTAL?

it is a liquid
... you can pour it from a bottle!

the properties depend on
the orientation



... like in a crystal!

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WHAT IS ANISOTROPY?

...different properties in different directions...

Wood is anisotropic. It contains fibers that transport water

fibers are strong

to cut the fibers a saw is needed

link between fibers is weak
wood can be cleaved
by inserting a wedge

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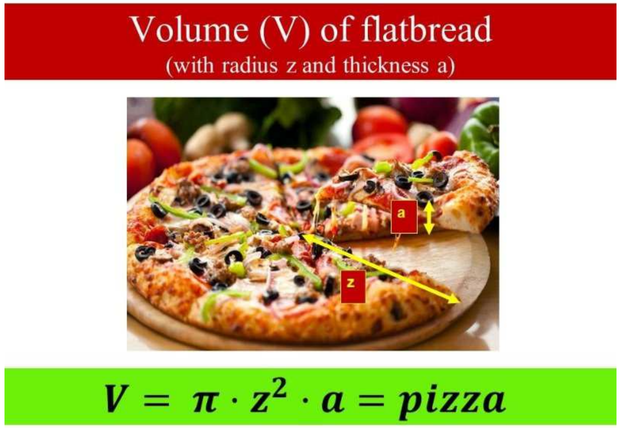
WHAT IS ANISOTROPY?

another example: cheese forms threads when stretched



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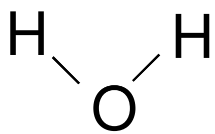
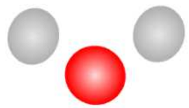
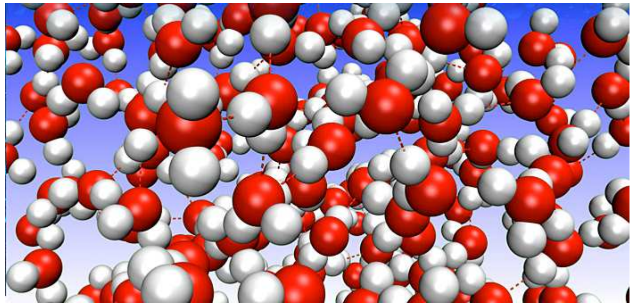
WHAT IS ORIENTED IN A LIQUID CRYSTAL?

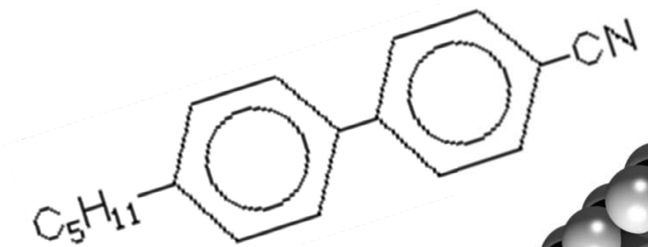
water consist of small H_2O molecules with random orientation

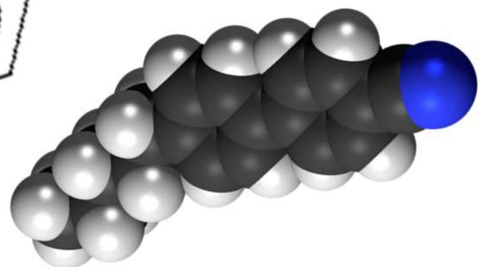


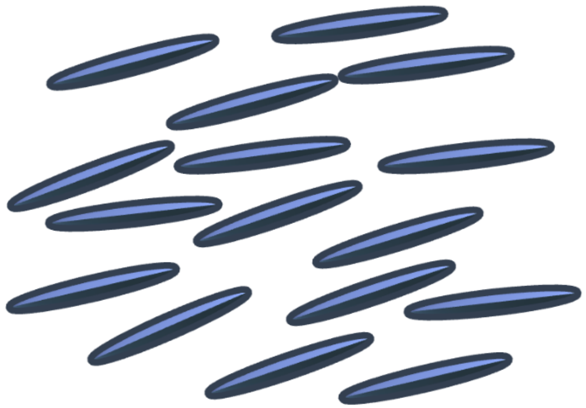




liquid crystal consists of long molecules preferring parallel orientation







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LIQUID CRYSTALS

Liquid crystal molecules and phases

Thermotropic liquid crystals

intermolecular interaction ⇔ thermal energy

anisotropic molecular interaction

liquid crystal ⇔ liquid

discovery in 1888

pure material with 2 phases

LC (turbid) ⇔ liquid (clear)

(variable anisotropy in space)

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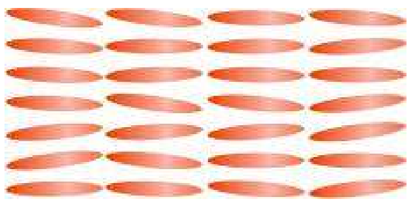
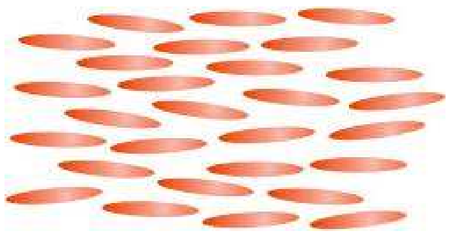
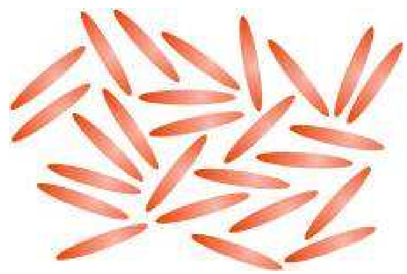
LIQUID CRYSTALS

Introduction: the fourth state of matter

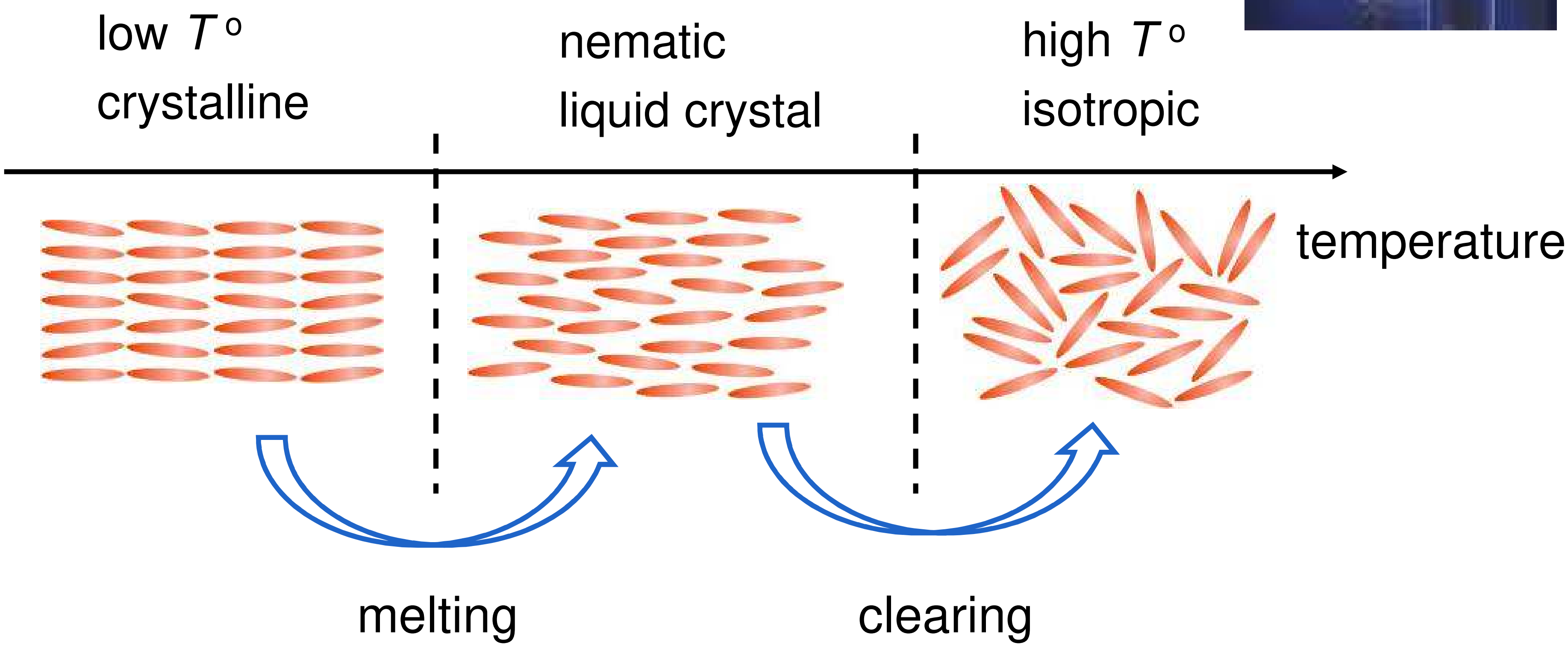
solid	mesophase = liquid crystal	liquid
fixed position fixed orientation	random position fixed orientation	random position random orientation
can be anisotropic	can be anisotropic	isotropic







Introduction: the fourth state of matter



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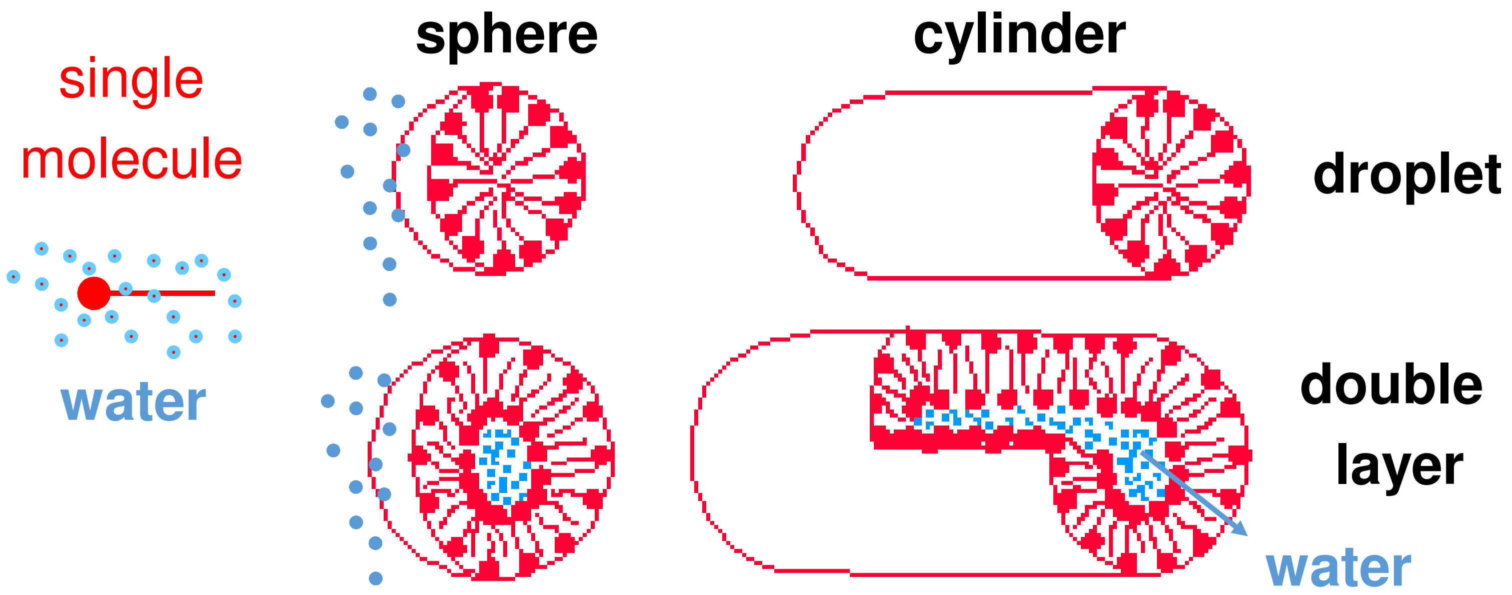
LYOTROPIC LIQUID CRYSTALS

Lyotropic liquid crystals

molecules in a solvent at higher concentration

polar (hydrophilic) and non-polar (hydrophobic)



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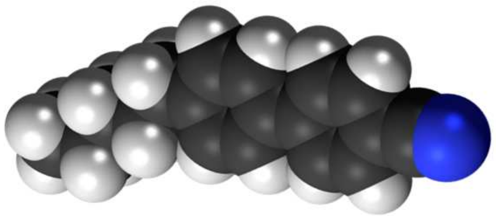
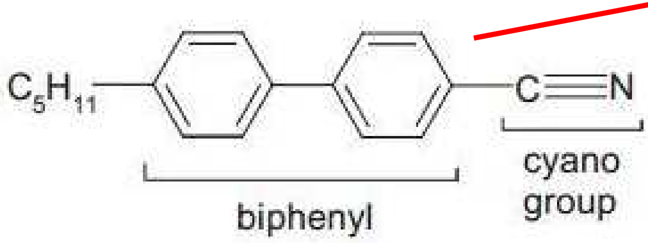
NEMATIC MESOGENS

small elongated organic molecules



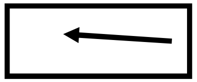
d~2 nm

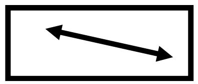


phenyl rings

terminal group

molecular shape  

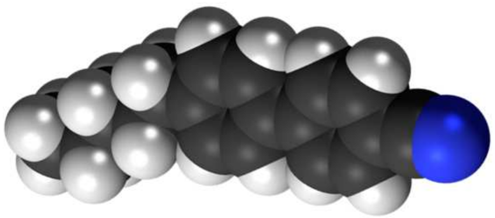
permanent dipole moment  $\vec{p}$

absorption of light: transition dipole  $\vec{\mu}$

polarizability tensor: easier to polarize in the plane $\bar{\bar{\alpha}}$

NEMATIC MESOGENS

molecular properties (WAT knowledge)



stronger dipole moment

→ higher dielectric constant

more double bonds

→ higher refractive index

longer molecules

→ higher clearing temperature

→ more viscous

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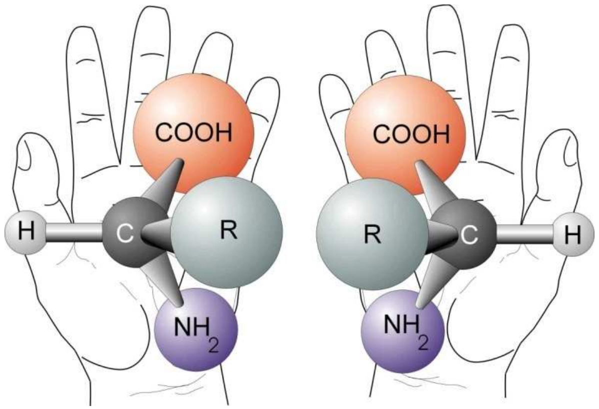
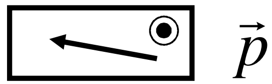
NEMATIC MESOGENS

Chirality

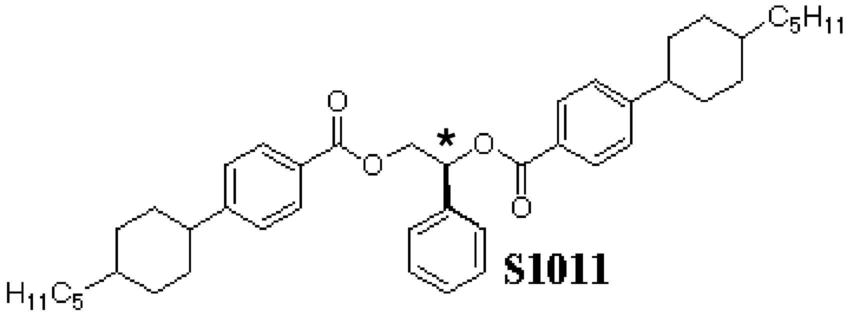
molecules without mirror plane symmetry



2 enantiomers



dipole moment
has an out-of-plane component



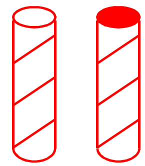
S1011

CHIRAL NEMATIC PHASE

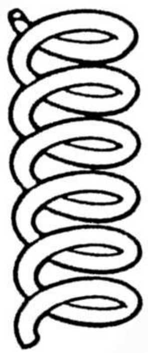
molecules with chirality (cholesteric)

not the same as their mirror image

example: sugar



right handed screw, spring, corkscrew



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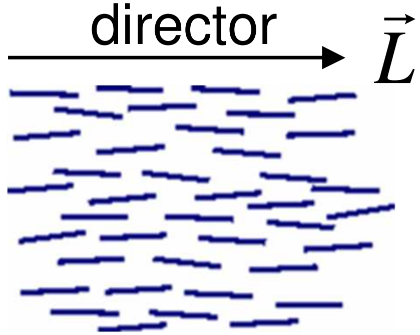
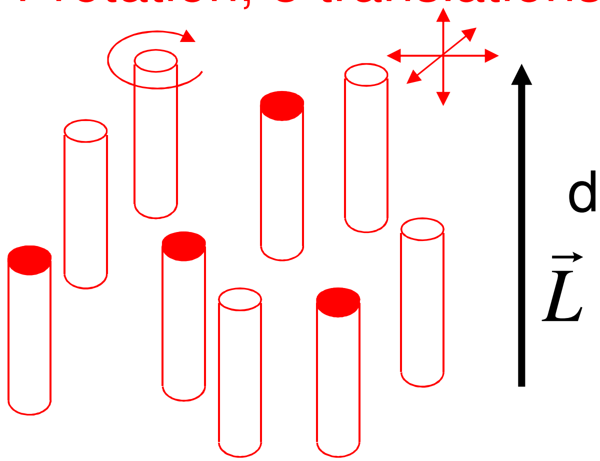
NEMATIC PHASE

nematic order



director
$\vec{L}$ and $-\vec{L}$
equivalent

free: 1 rotation, 3 translations



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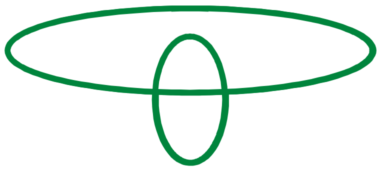
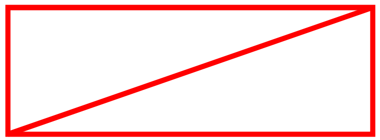
SYMMETRY ELEMENTS

A material may remain unchanged under a symmetry element

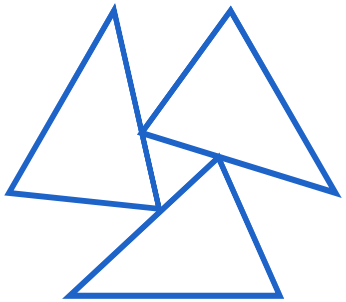
examples: mirror plane m



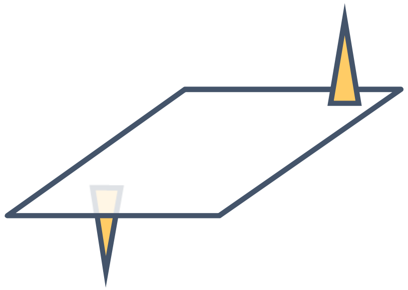
2-fold rotation axis C_2



3-fold rotation axis C_3



inversion symmetry I



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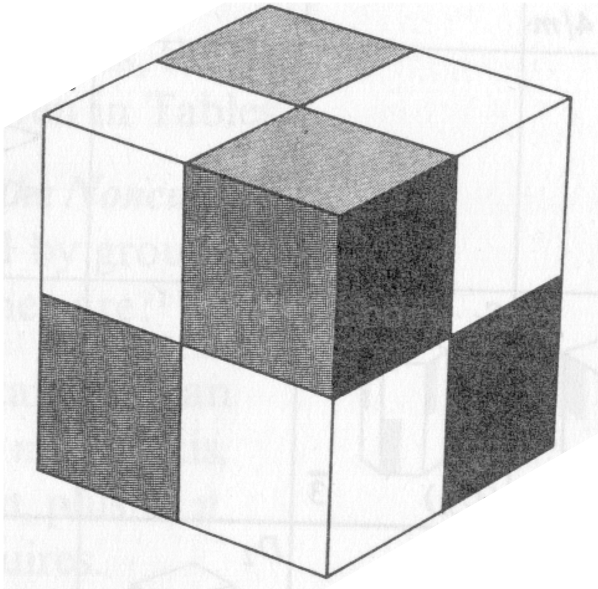
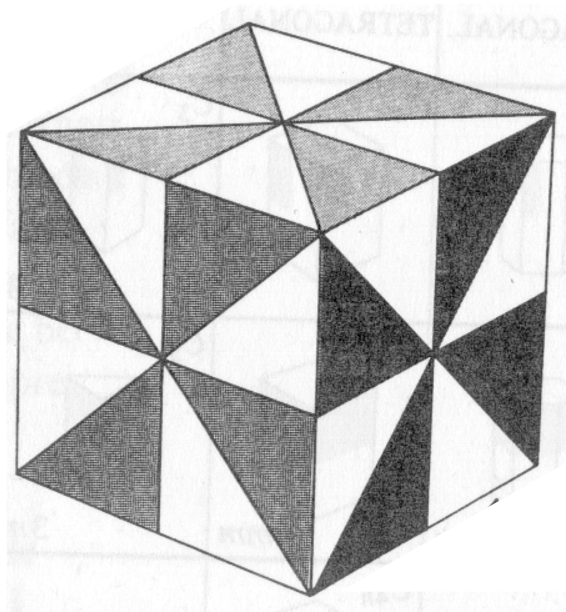
SYMMETRY ELEMENTS

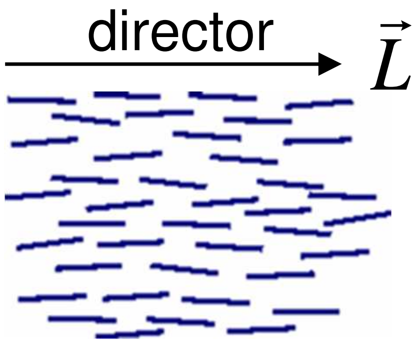
find the symmetry elements of the two crystal structures

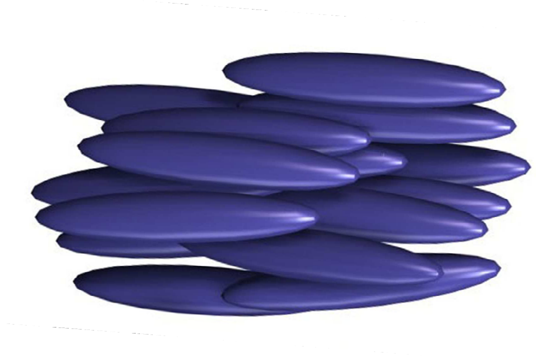




NEMATIC PHASE

nematic ordering: uniaxial symmetry

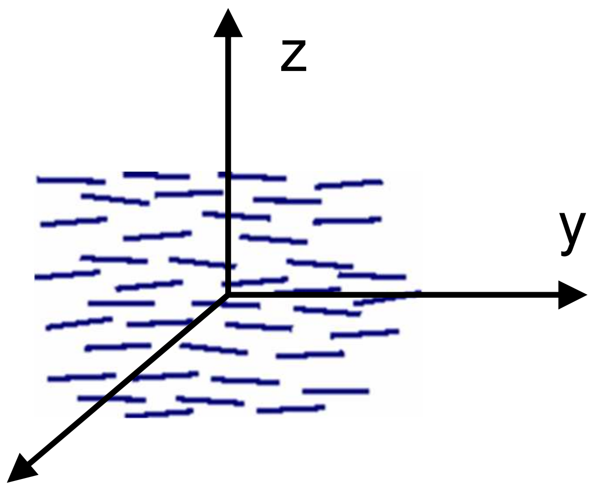




Mirror symmetry?

Rotation axis symmetry?

Inversion symmetry?



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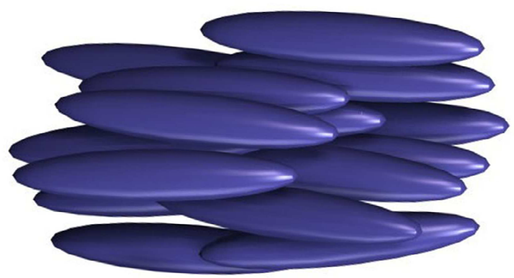
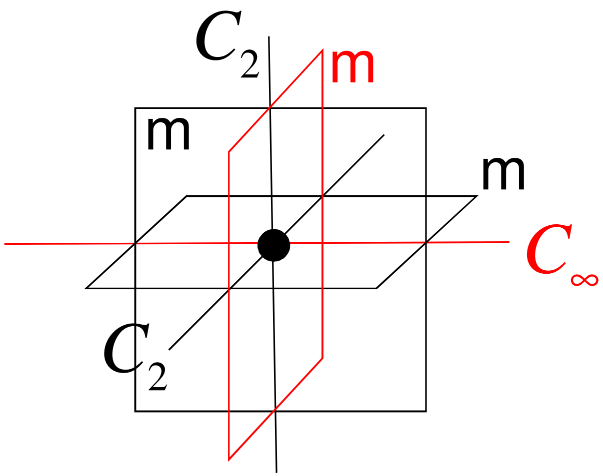
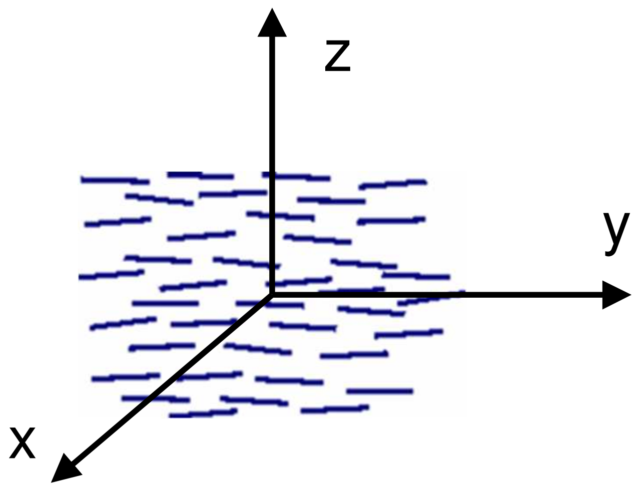
NEMATIC PHASE

nematic ordering: uniaxial symmetry







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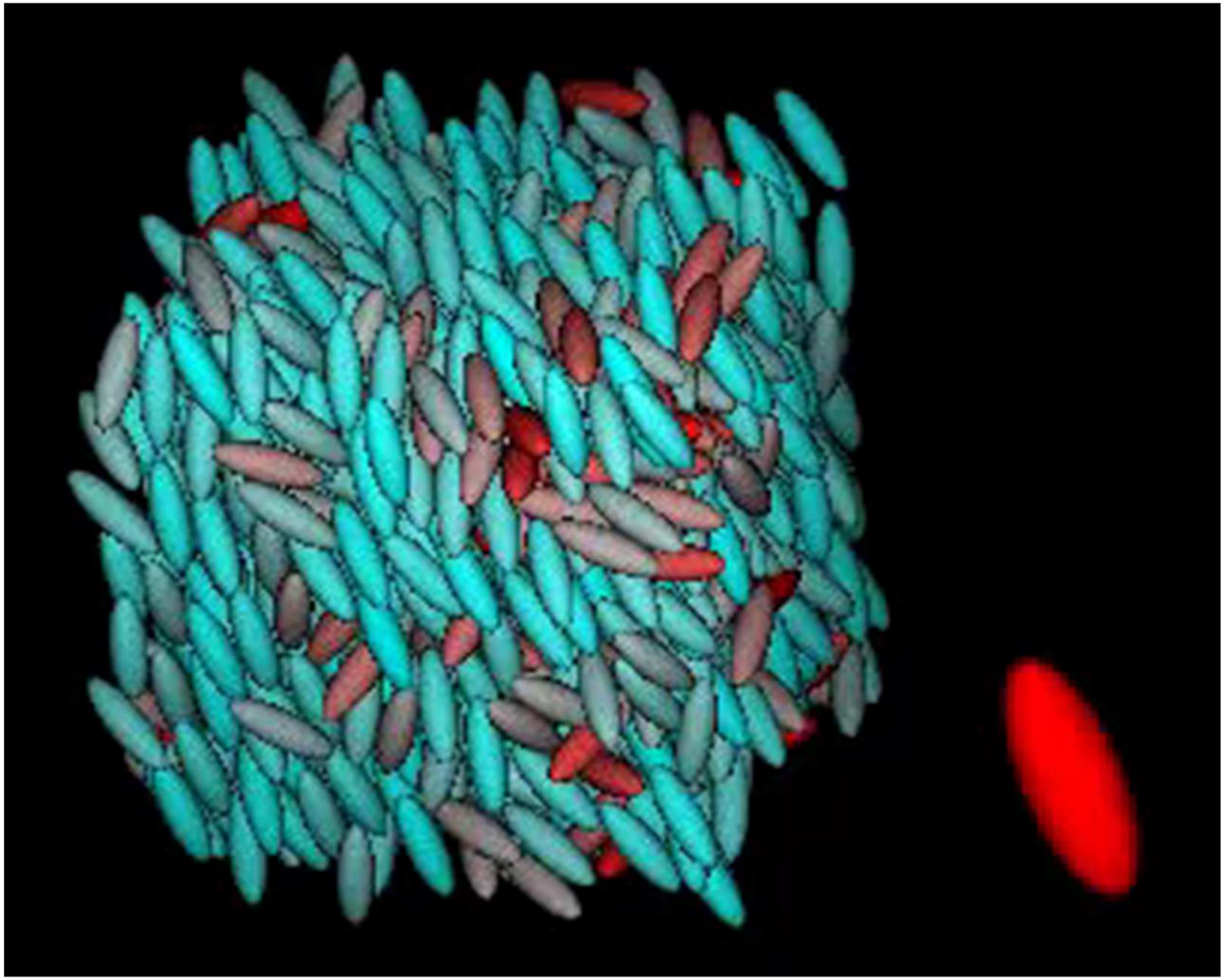

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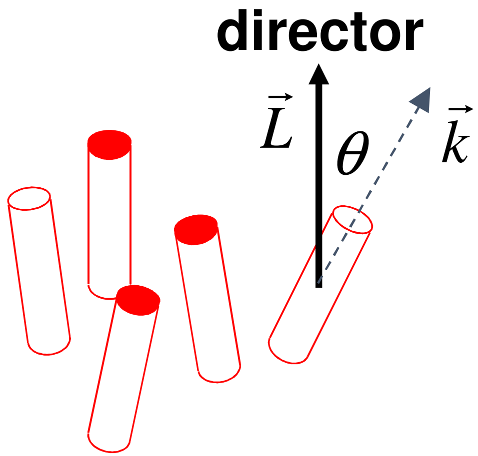
ORDER PARAMETER FOR NEMATIC PHASE

thermal motion, molecule deviation angle θ

order parameter S

$$S = \frac{1}{2}\left\langle 3\left(\vec{k}\cdot\vec{L}\right)^2 - 1\right\rangle$$

$$= \frac{1}{2}\left\langle 3\cos^2\theta - 1\right\rangle$$



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perfect alignment: *S=1*

for isotropic orientation:

$$\left\langle \cos^2\theta \right\rangle = \frac{2\pi\int_0^{\pi}\cos^2\theta\sin\theta d\theta}{4\pi} = \frac{1}{3}$$

isotropic: *S=0*

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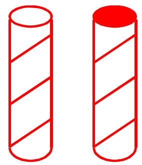
CHIRAL NEMATIC PHASE

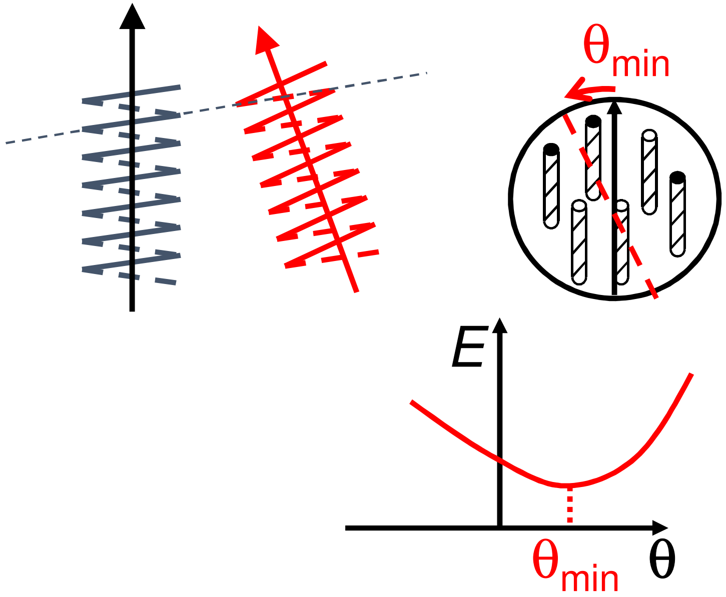
nematic layer does not have mirror plane

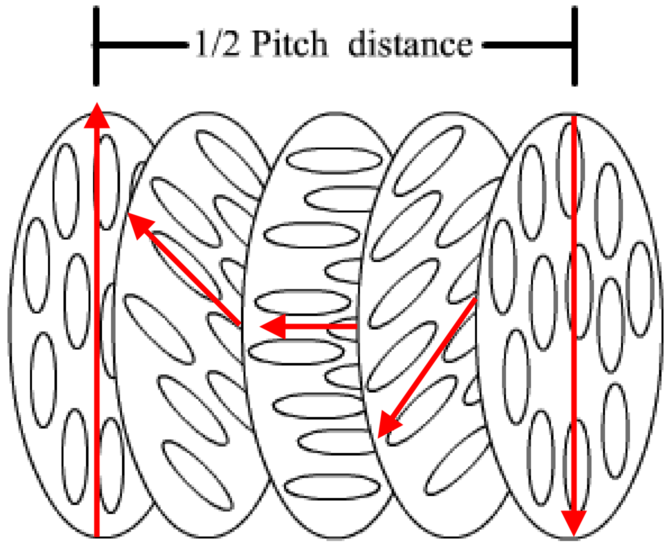
minimal energy for next layer at θ_{min}



example: chiral structure

first layer second layer





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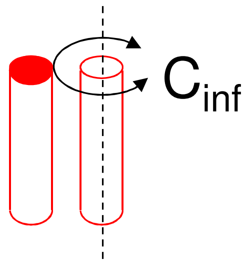
SMECTIC A PHASE

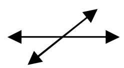
smA: molecules arranged **in planes**

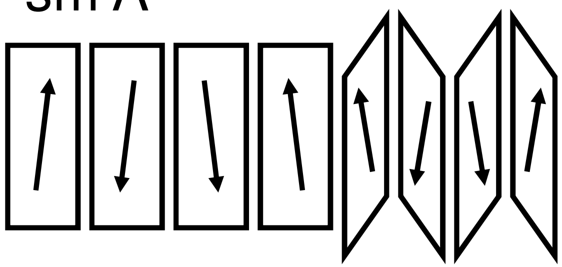
$\vec{L}$ perpendicular to planes

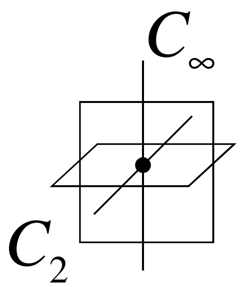
uniaxial symmetry

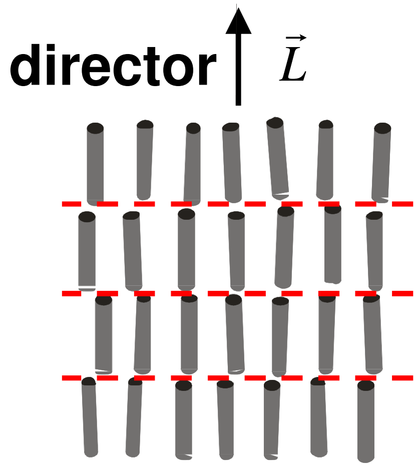
freedom: 1 rotation, 2 translations











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SMECTIC A* PHASE

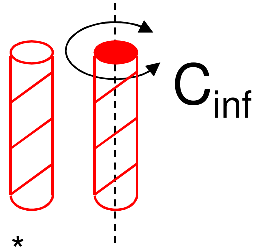
smA*: chiral molecules

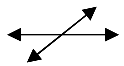
perpendicular to planes

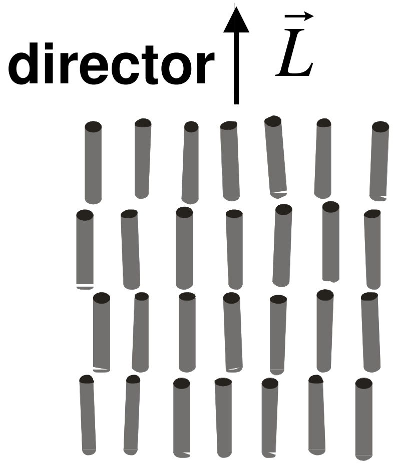
no mirror planes

uniaxial symmetry

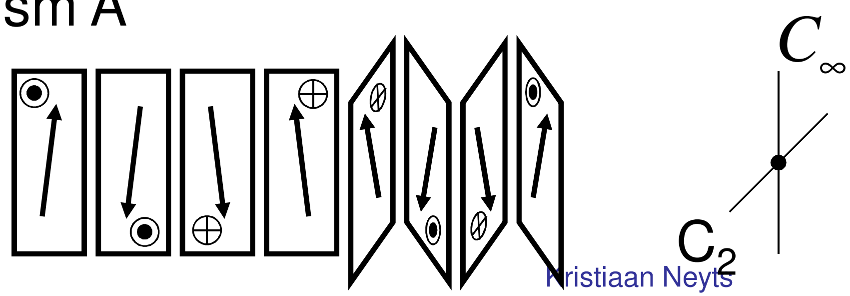
freedom: 1 rotation, 2 translations







sm A*



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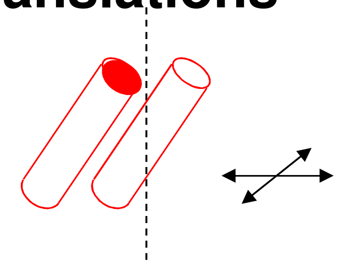
SMECTIC C PHASE

smC: molecules arranged in planes

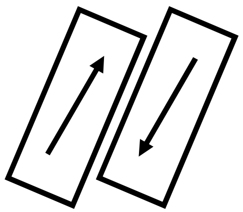
angle θ with layer normal

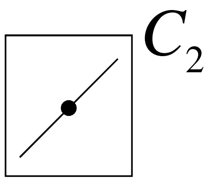
biaxial symmetry

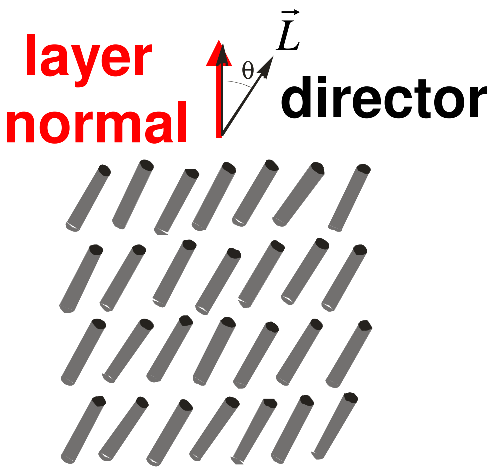
2 translations



smC: no axial rotation







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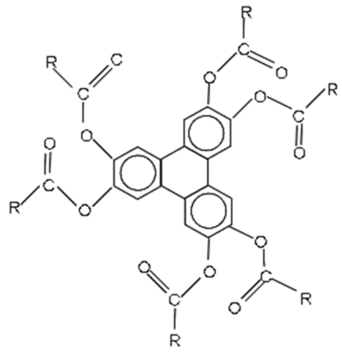
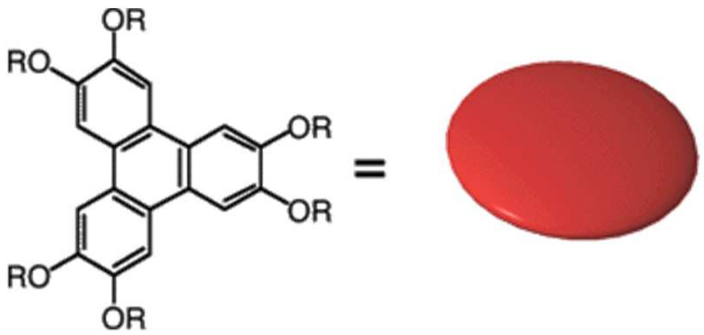
DISCOTIC MESOGENS

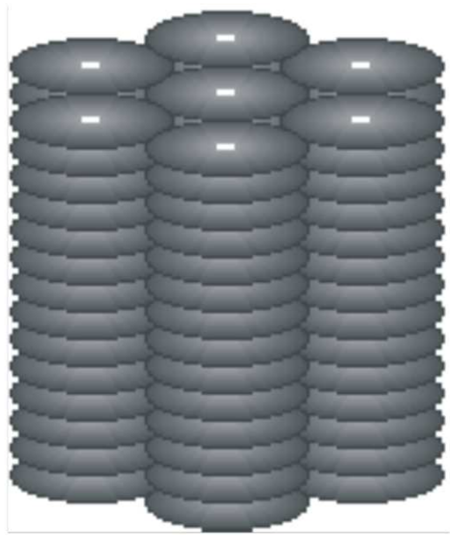
Discotic mesogens

molecules with disc shape

nematic and columnar phases







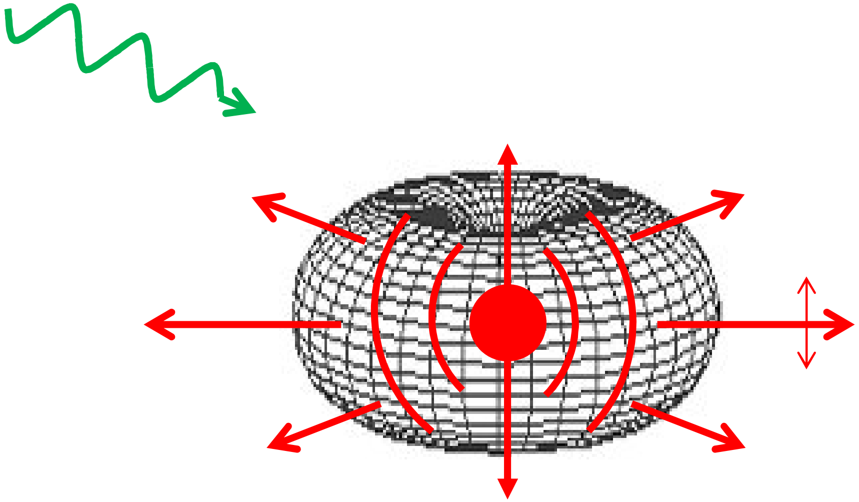
LIGHT EMITTING MATERIALS

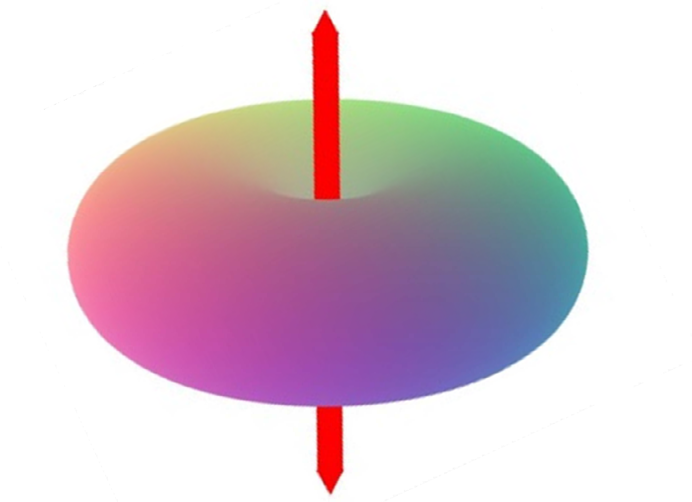
Material with a two electronic levels

The material can be
- an organic molecule
- a semiconductor
- a quantum dot
- a crystal

LIGHT EMITTING MATERIALS

excitation by absorption of a photon





emission from a dipole transition

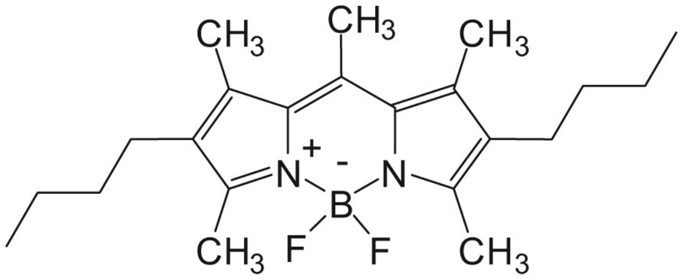
probability ~ electrical dipole antenna radiation (linear pol)
dipole may have different orientations

LIGHT EMITTING MATERIALS

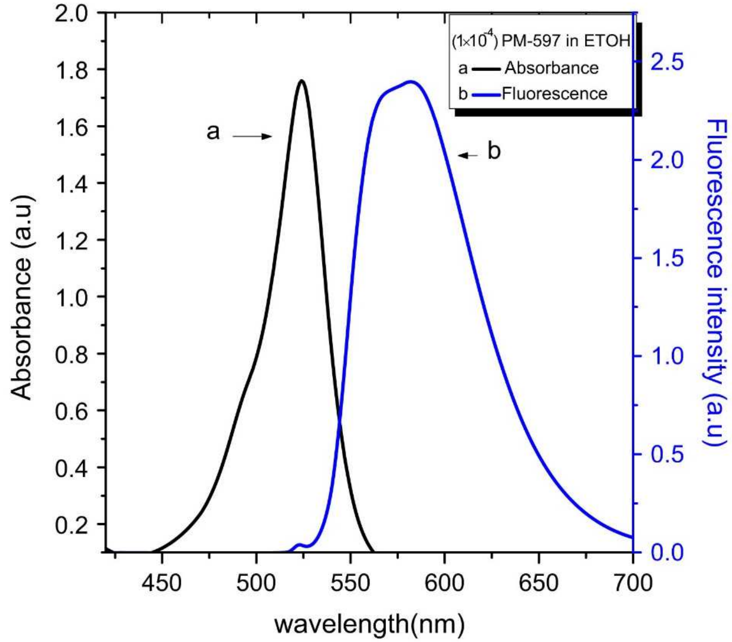
organic emitter dye PM597

absorbs green light

emits orange and red light



PM 597



Liquid Crystals and Photonics

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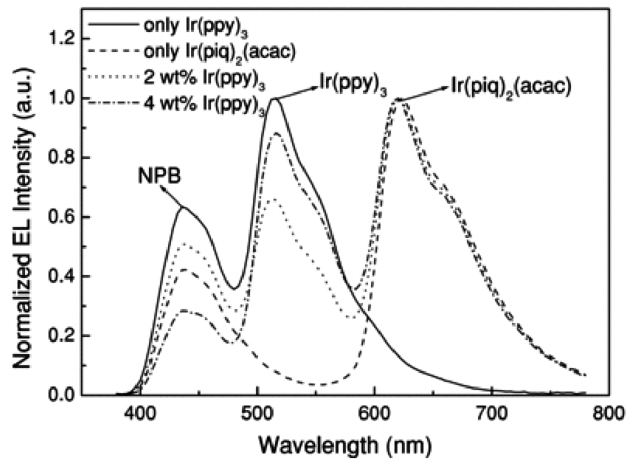
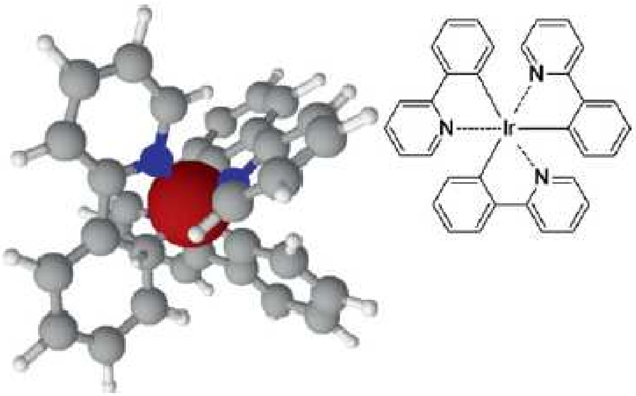
LIGHT EMITTING MATERIALS

organic emitters

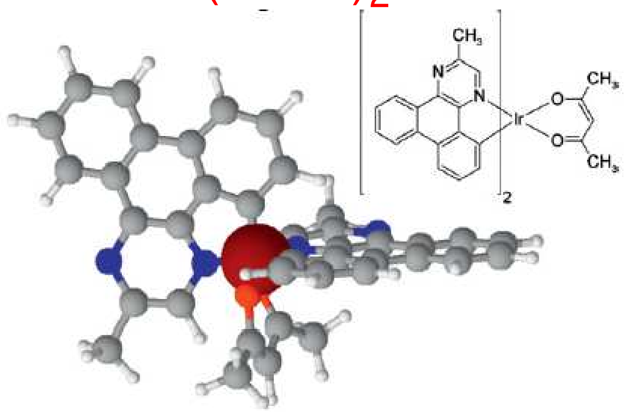
phosphorescent dopants
with very high efficiency
(phosphorescent)



$Ir(ppy)_3$



$Ir(MDQ)_2acac$



Liquid Crystals and Photonics

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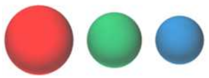
QUANTUM DOTS

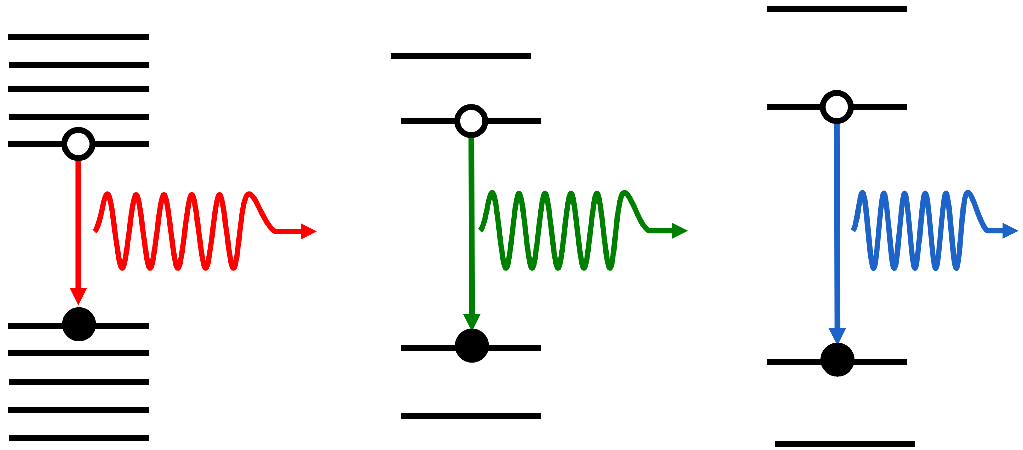
Quantum Dots (QDs)

emit a narrow spectrum
λ related to the radius



CdSe

CdSe most efficient
InP as alternative



bulk CdSe	Q-dot CdSe	small Q-dot CdSe

Liquid Crystals and Photonics

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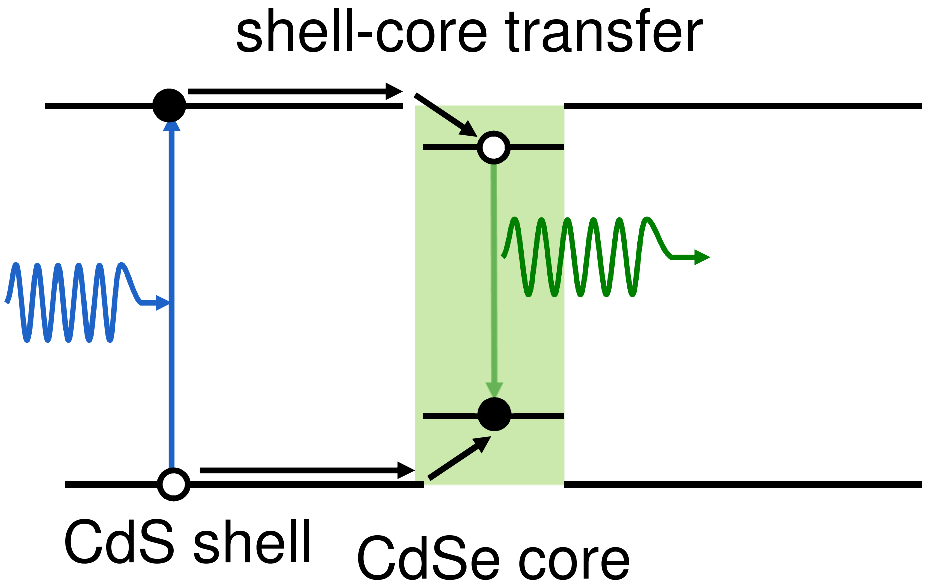
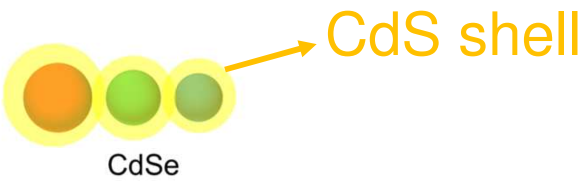
QUANTUM DOT CORE-SHELL PARTICLES

Quantum Dots (QDs)

emit a narrow spectrum
λ related to the radius





CdSe core in CdS shell

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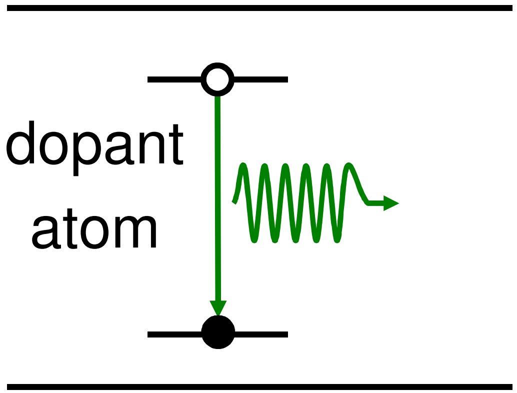
CRYSTALLINE PHOSPHORS

Phosphors

Dopant atoms in a crystal



blue LED with yellow phosphor

GaN **$Y_3Al_5O_{12}:Ce^{3+}$**

OVERVIEW FOR NEXT LECTURES

Electrical and optical properties of materials (6h)

Polarizability of dielectric materials

Conductors and semiconductors

Light propagation

Polarized light

Spontaneous and stimulated emission

Liquid Crystals and Photonics

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PLAN FOR LECTURE 2 (APRIL 5TH)

Electrical and optical properties of materials (6h)

Polarizability of dielectric materials
Conductors and semiconductors
Light propagation
Polarized light
Spontaneous and stimulated emission

Liquid Crystals and Photonics

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