COMMONWEALTH OF AUSTRALIA

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Soft Matter: Nematics – Properties and Applications

Lecture 25

Soft Matter: Onsager Theory and the Statistical Mechanics of Nematics

Lecture 26

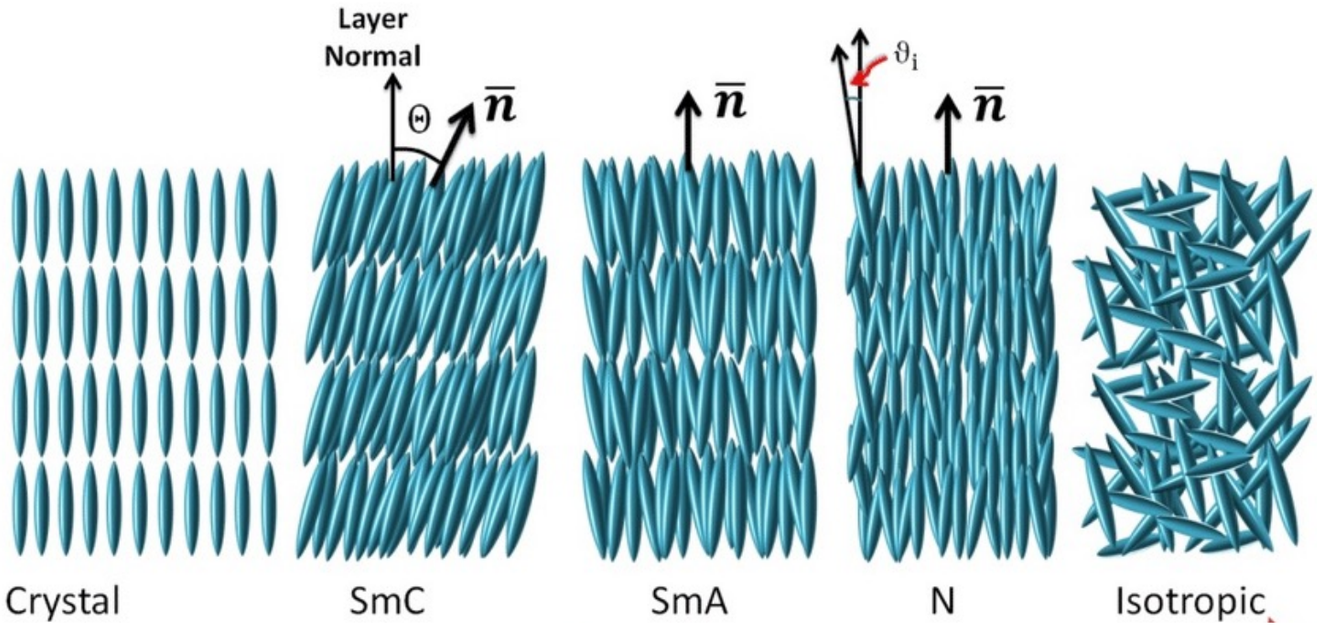
Soft Matter: Nematics – Properties and Applications

Lecture 27

Liquids: Diffusion and Randomness

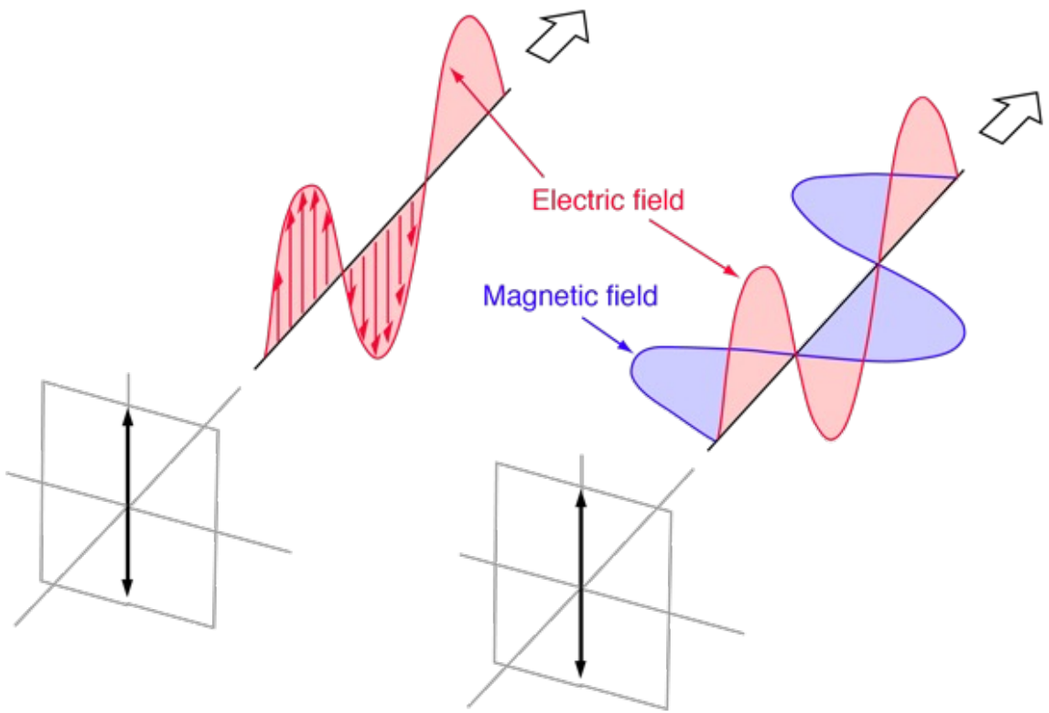
Reminder: Mesophases: anisotropy

10.3390/nanoZ100305



- Some of these phases have one, two or three different axes of symmetry over macroscopic distances. This is called anisotropy.
- As a consequence, physical and mechanical properties (e.g. electrical and thermal conductivity, light polarisation) can also depend on the direction in which they are measured.

Polarised light

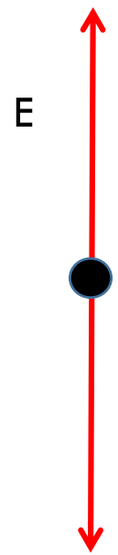


hyperphysics.phy-astr.gsu.edu/hbase/phyopt/polclas.html

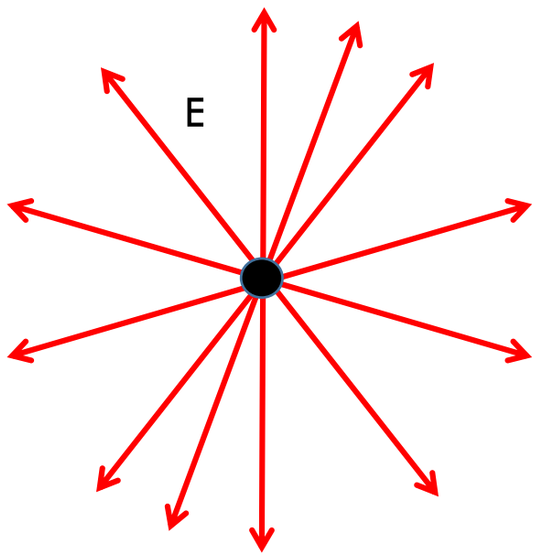
- Polarisation is a property of waves that can oscillate in more than one orientation.
- In electromagnetic radiation (i.e. light) the propagation vector (white arrow), electric field vector (red), and magnetic field vector (blue) are mutually perpendicular.
- If all the photons in a light beam have electric field vectors in the same direction, we say that the light is "polarised".

Unpolarised light

Q1



Polarised light



Unpolarised light

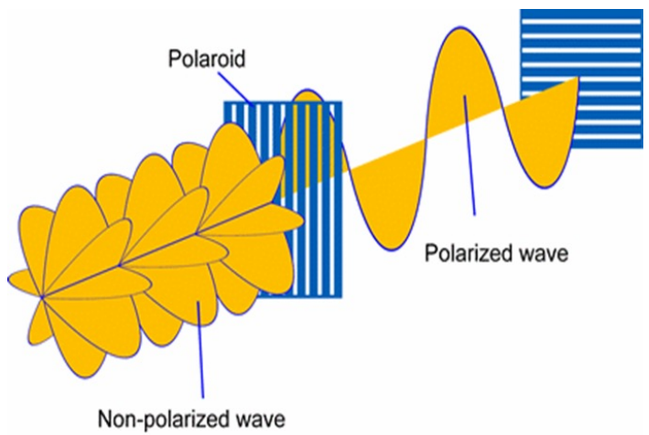
- In the diagrams on the left, we are looking along the direction that the light is moving
- When many beams of light travel in the same direction, they may not all have the same polarisation.
- This is called unpolarised light, and almost all light sources generate light like this.

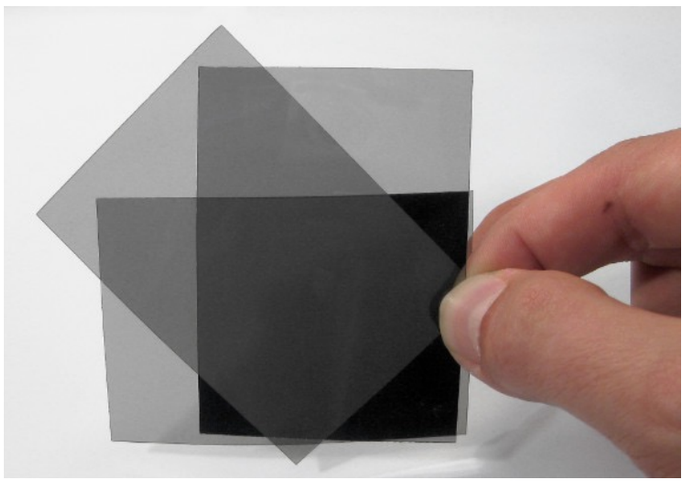
How can we polarise light?

- Light can be polarised by:
  - Reflection
  - Refraction
  - Scattering
  - **Transmission**

do not need any anisotropy in the material, because of the different angles of incidence, surface, and measurement

- **Transmission** through an anisotropic material can achieve <u>filtering</u>.
- Crossed filters block all light because filter #1 lets only one polarisation through and this is then blocked by filter #2





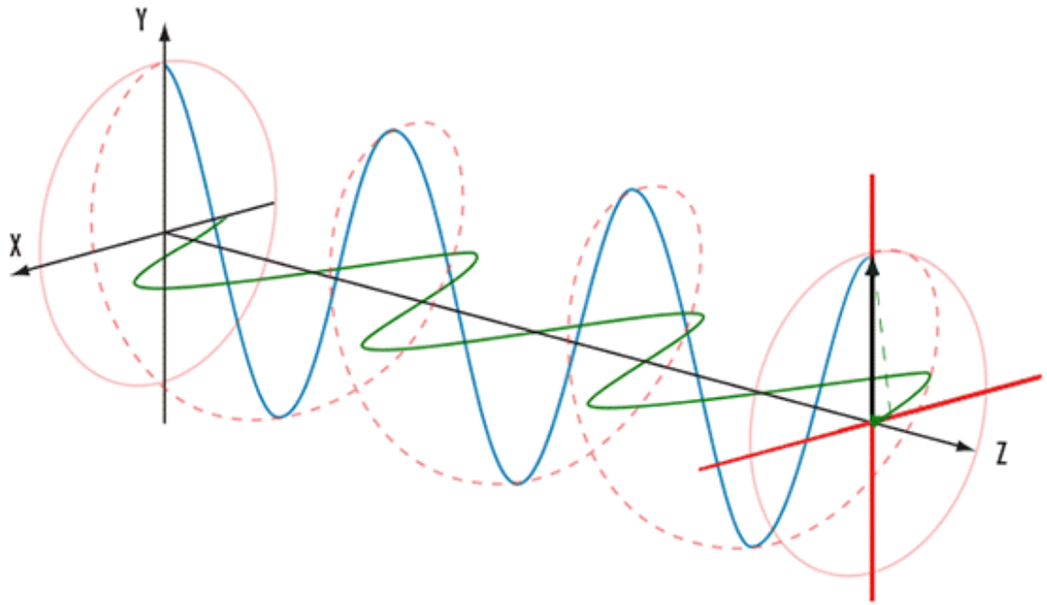
A common analogy is passing through a grate, but actually the conductive direction is the direction that absorbs light waves.

https://www.sciensation.org/hands-on_experiments/e508Zp_twistingLight.html

Circularly (or elliptically) polarised light

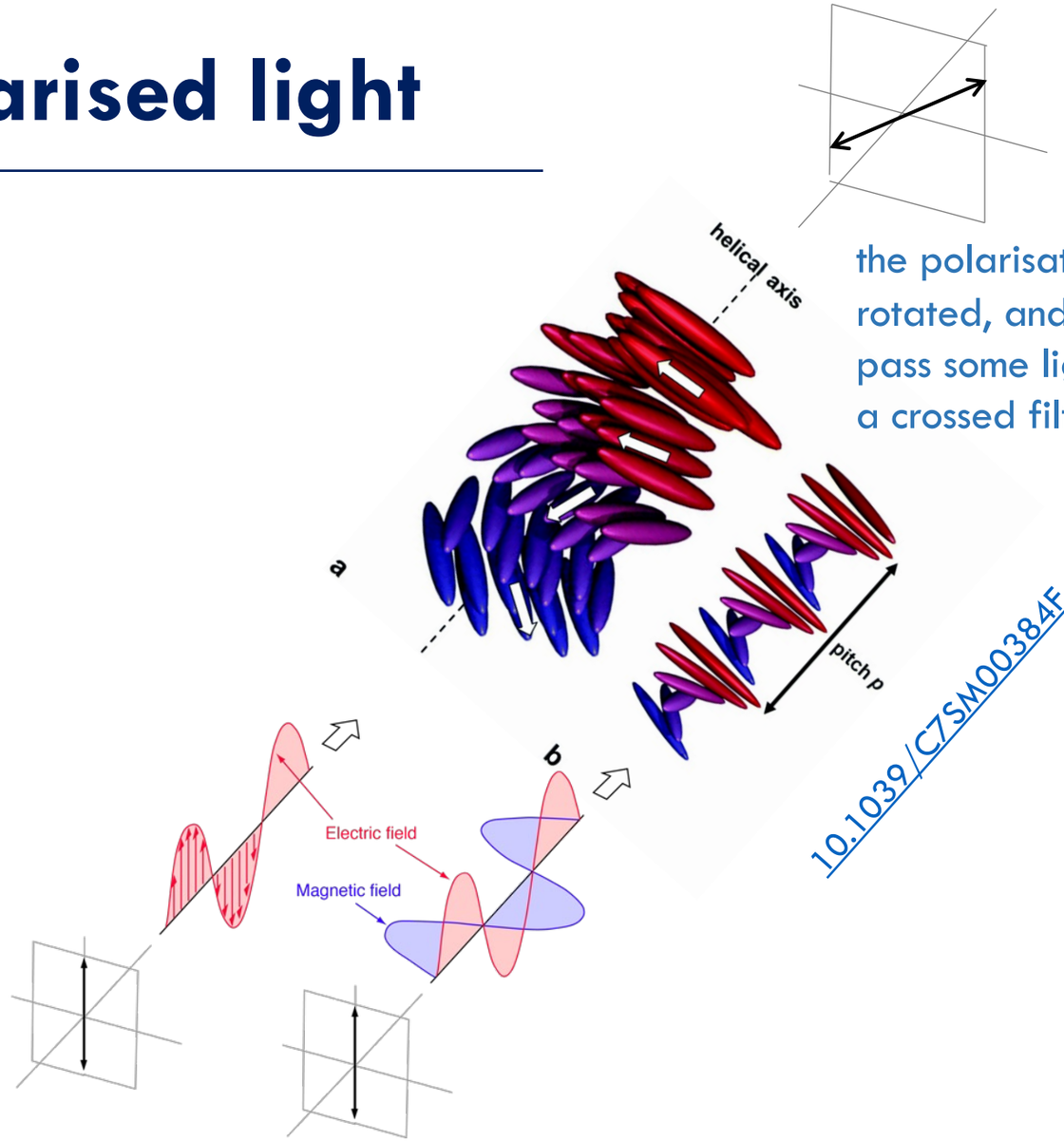
Q2

- If two perpendicularly polarised beams of light are combined, and are out of phase with one another, the resulting electric field vector spirals around the axis of propagation.
- If the phase difference is one quarter of a wave ($\pi/2$), the cross section is a circle, so it is called "circularly polarised". Otherwise, it is elliptical.
- You can analyse how this will interact with filters or materials by considering the two components separately, then adding them at the end.



Mesophases and polarised light

- We know that a solution of a chiral molecule can rotate the plane of polarisation of light as it passes through the solution
- Similarly, if we put a chiral phase between crossed filters, it also rotates the polarisation of the light
- Recall the cholesteric (chiral nematic), which can have a pitch on the order of the wavelength of visible light



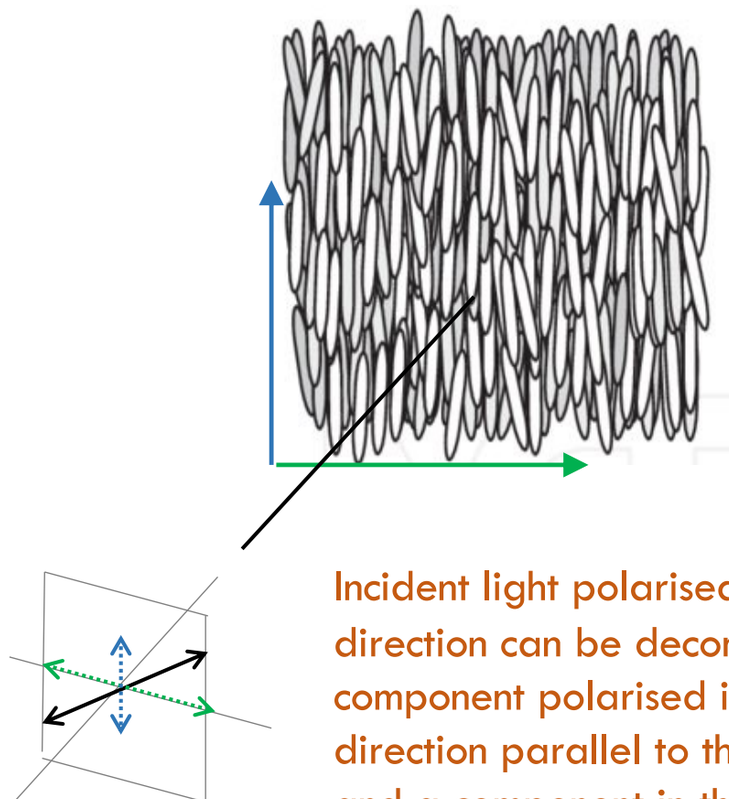
the polarisation has rotated, and can now pass some light through a crossed filter

10.1039/C7SM00384F

hyperphysics.phy-astr.gsu.edu/hbase/phyopt/polclas.html

Mesophases and polarised light

- How about when polarised light hits an achiral phase?
- The electrons oscillate and collectively propagate the electric field wave at a slower speed (higher refractive index).
- These oscillations are different for each polarisation (here either across the molecules or along them), thus the two polarisation components will travel at different speeds and get out of phase.
- This is called “birefringence”.

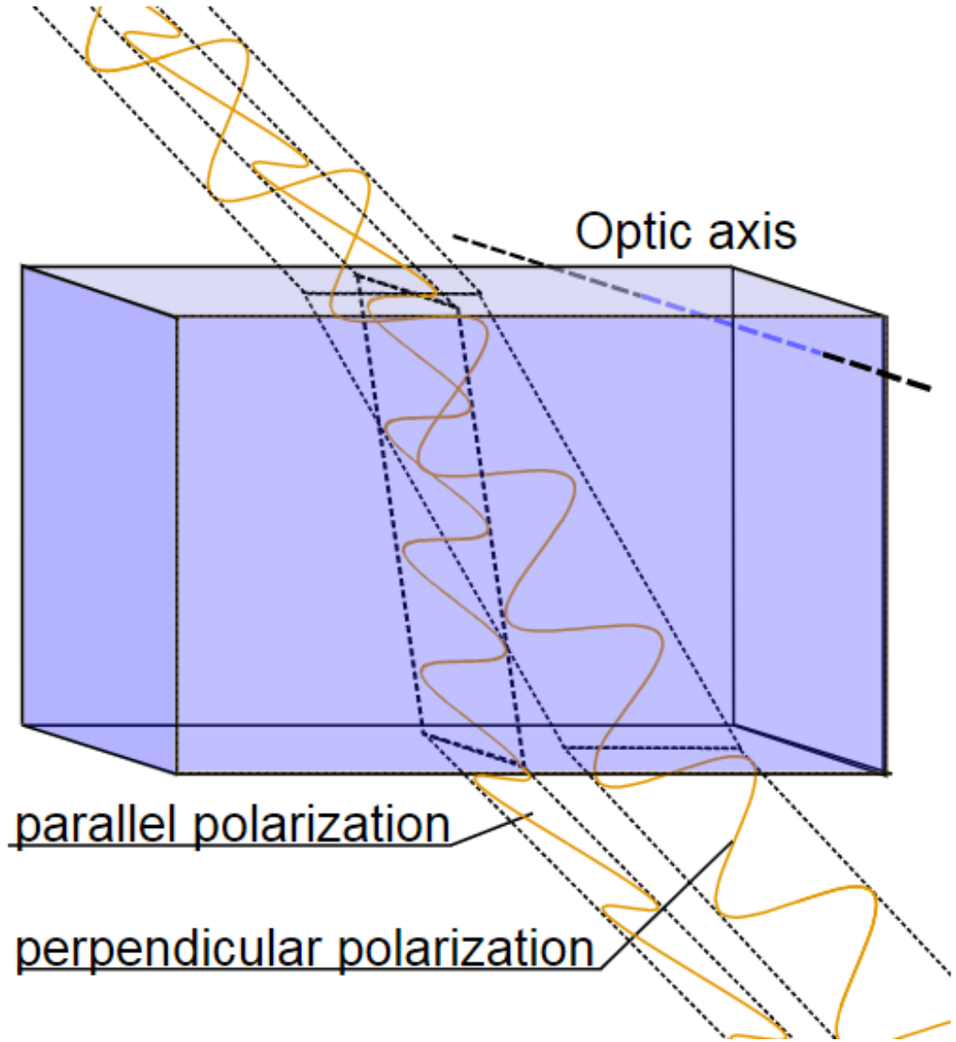


Incident light polarised in the **black** direction can be decomposed into a component polarised in the **green** direction parallel to the molecules and a component in the **blue** direction perpendicular to the molecules

10.5772/60776

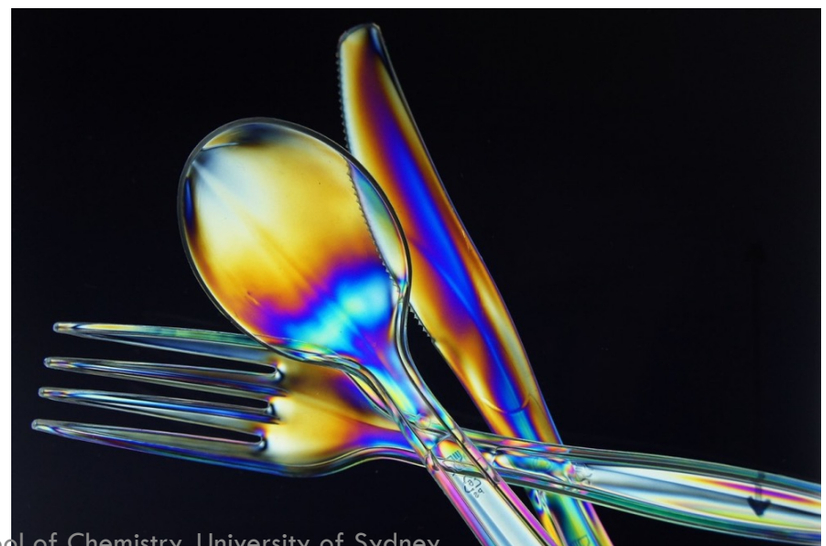
Birefringence

- Birefringence gets even more interesting when the angle of the beam is not normal to the surface of the material.
- The angle of refraction depends on the refractive index, so the two polarisation components from a single beam are split into two.

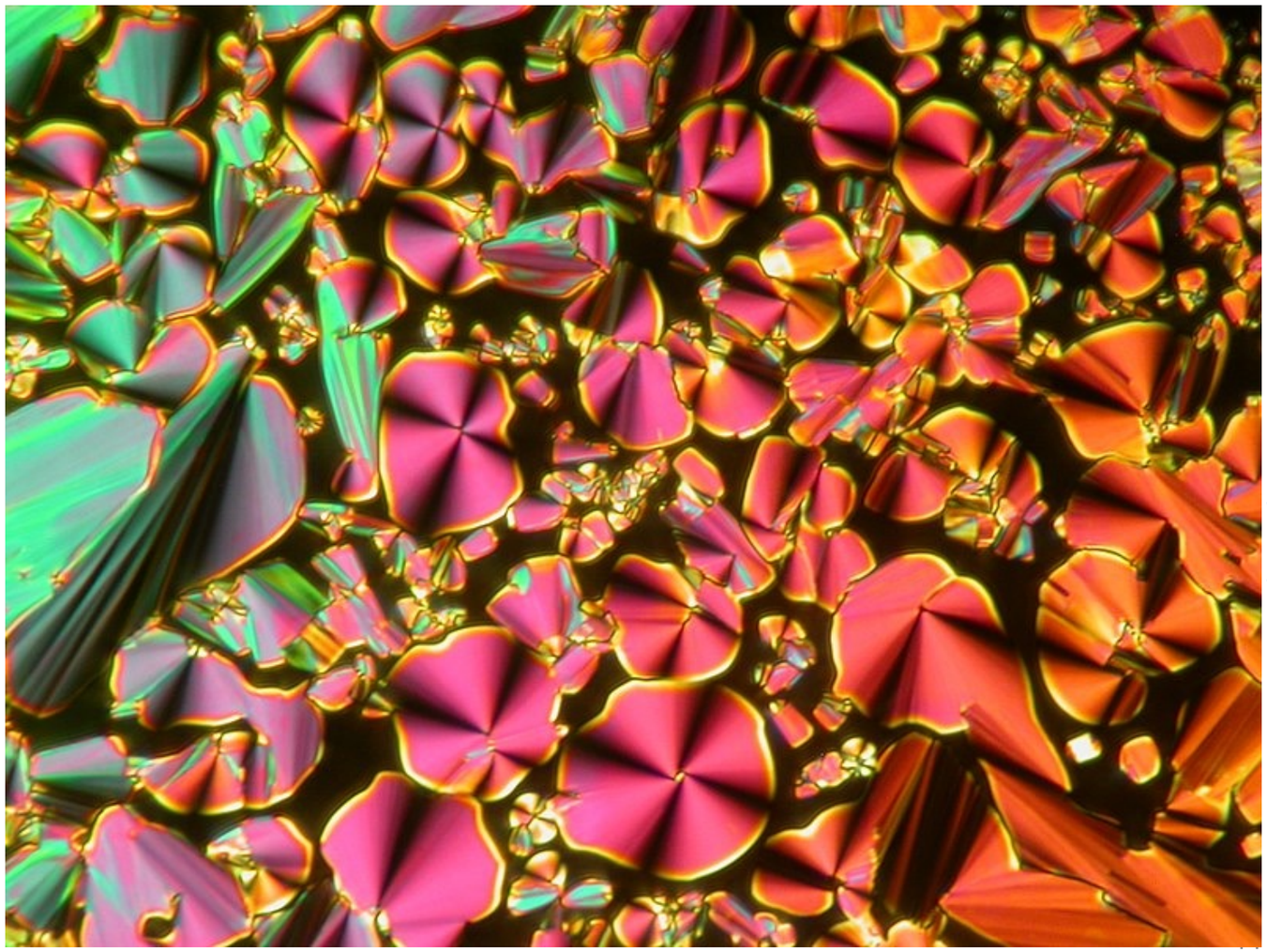


Birefringence

- The amount of birefringence can vary for different wavelengths, meaning that they go out of phase a different amount.
- Studying mesophases between crossed polarisers is therefore very colourful.



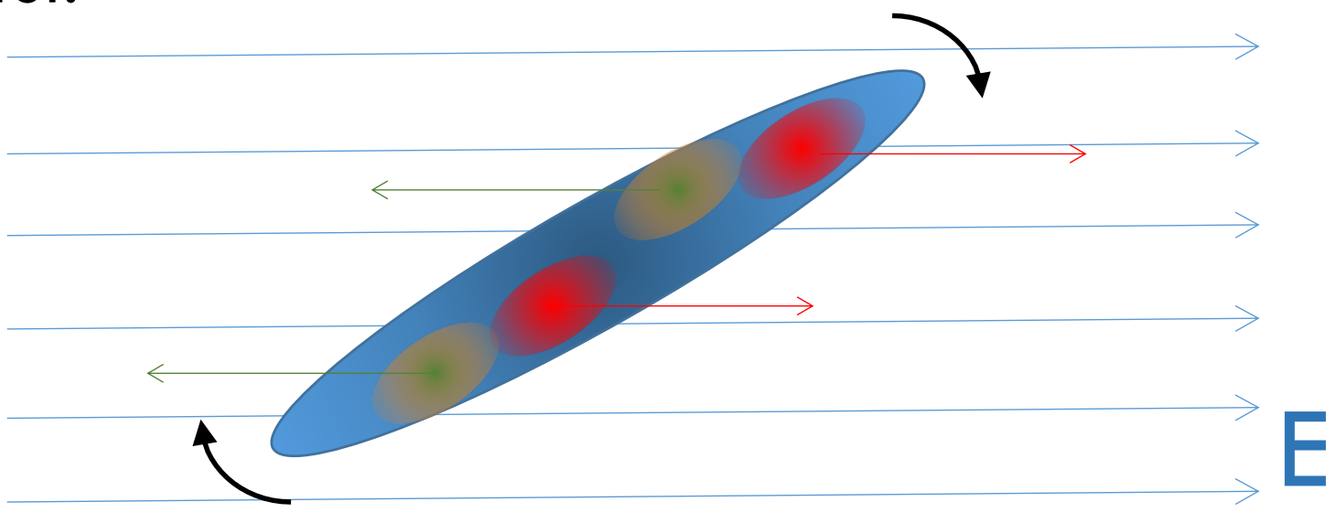
commons.wikimedia.org/wiki/File:Food_Polarization-Dierking.jpg



commons.wikimedia.org/wiki/File:Liquid_crystal_textures_2.jpg

Mesophases and electric fields

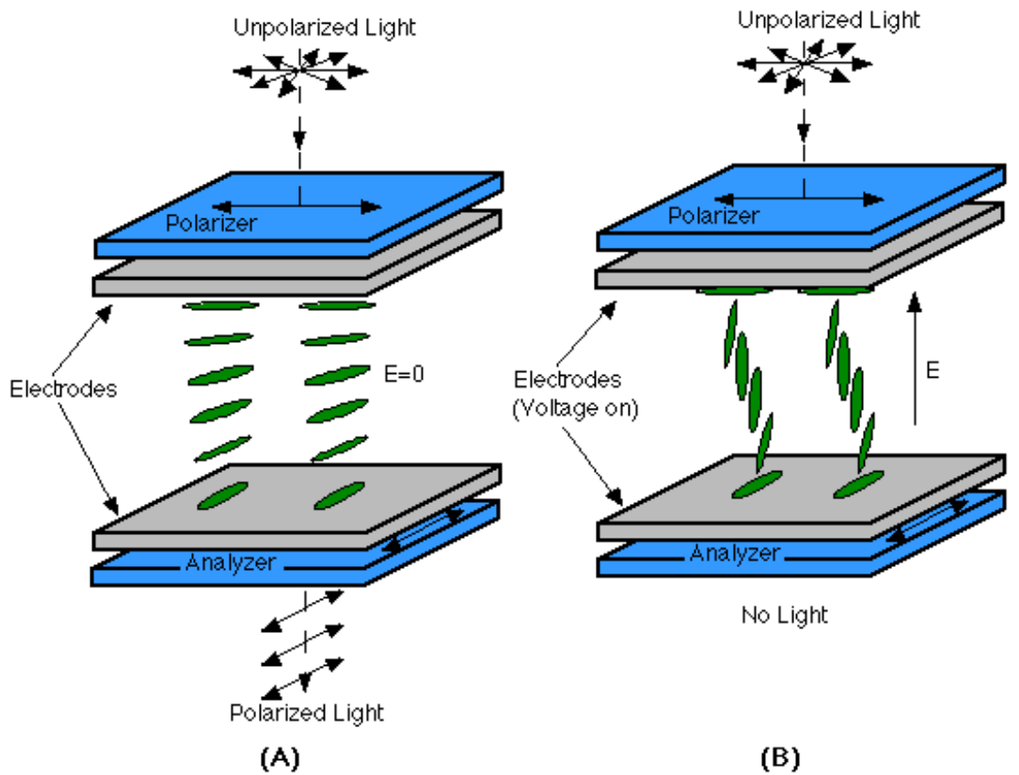
- The charge distribution or polarisability of the molecules means that the structure of mesophases can be altered by the application of an external electric field.
- Even a small torque on every molecule adds up to realign the director.



Mesophases and electric fields

Q3

- The new equilibrium can be established very quickly (although the kinetics depend on the temperature and molecular interactions).
- Together with polarised light, this provides for tunable or switchable transmission.

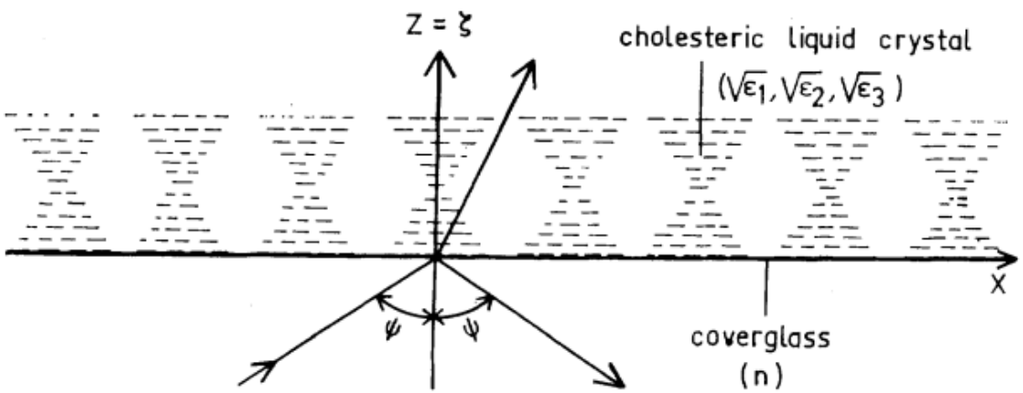


Molecular alignment in the no-field case can be chosen by the alignment of structural patterns on the upper and lower surfaces

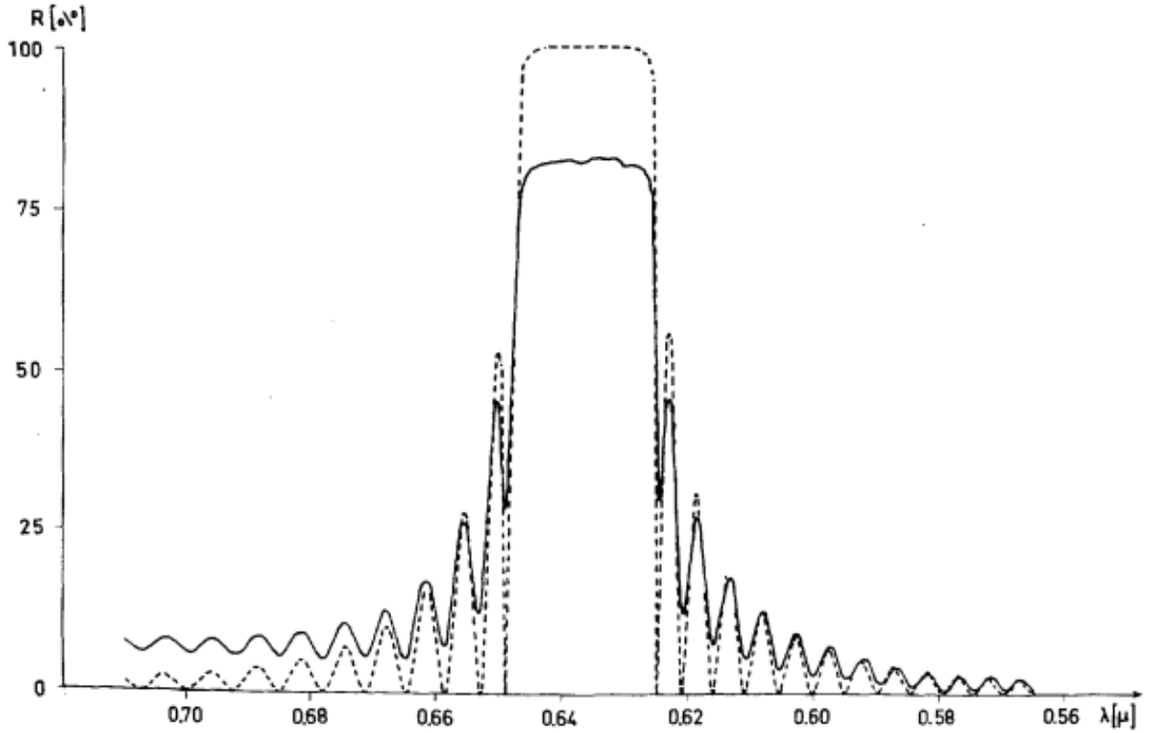
bly.colorado.edu/lcphysics/lcintro/tnlc.html

Mesophases: selective reflection

- The periodicity of cholesteric phases causes some wavelengths to reflect off surfaces but others to transmit. This selects colours from white light.
- This is similar to the Bragg reflections which we discussed earlier in the course



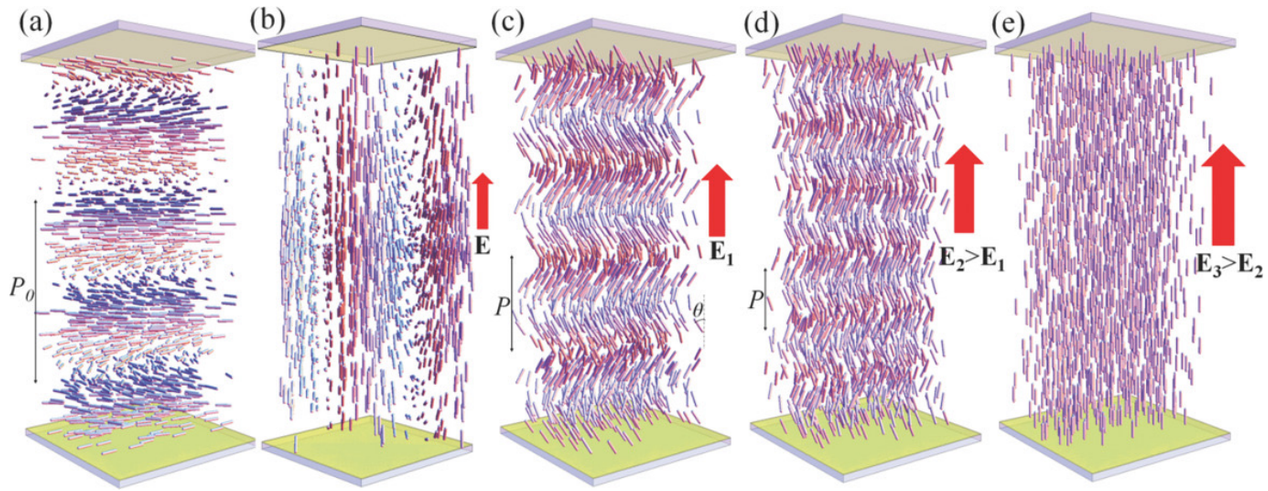
Light propagates in the (x,z)-plane from an isotropic medium of refractive index n into the liquid crystal



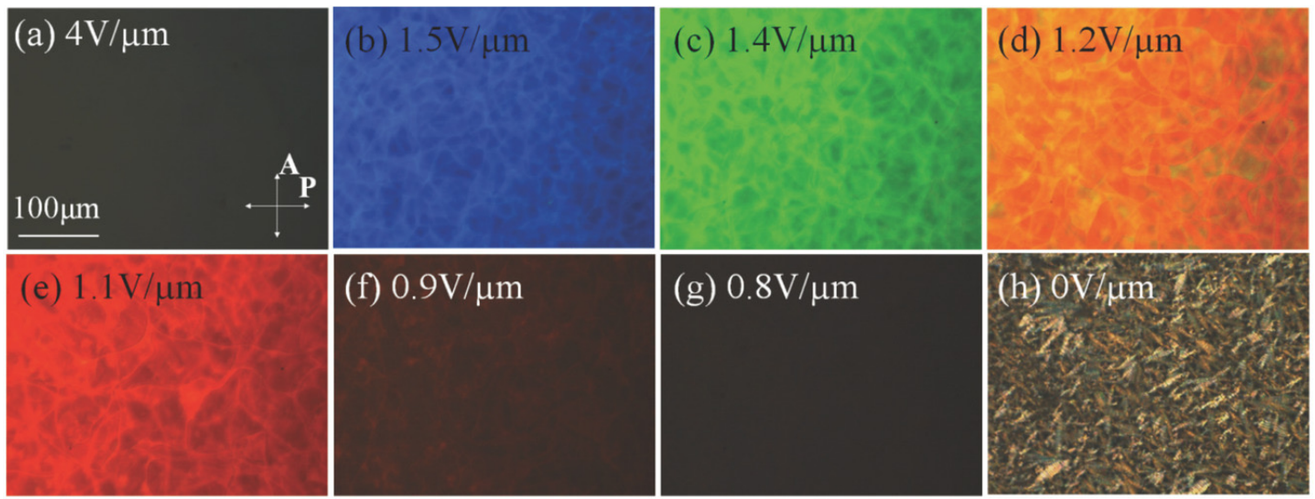
Reflection spectrum at normal incidence, measured and calculated with pitch p=0.427μm and layer thickness 21.0μm

10.1080/15421407108083534

Optoelectronic tuning



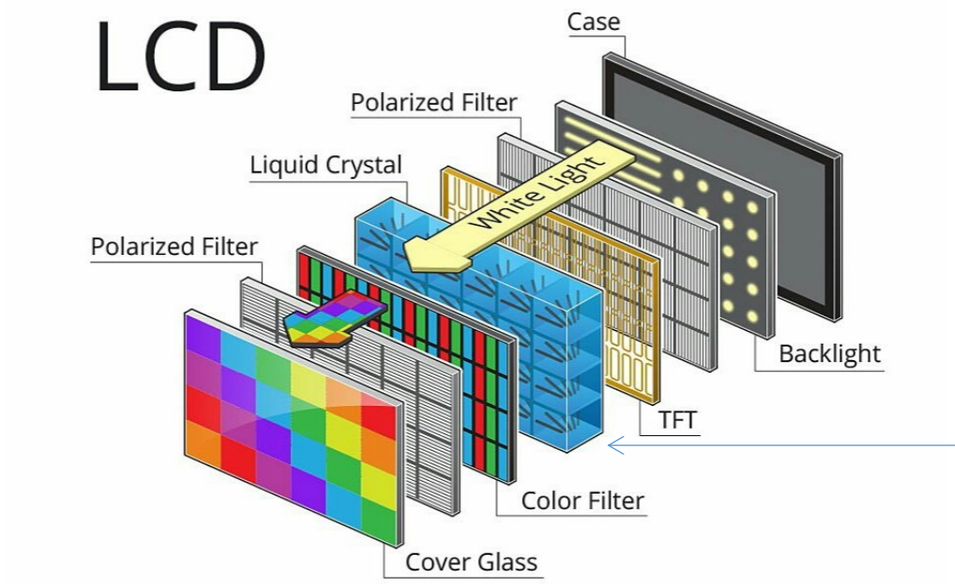
Electrically Tunable Selective Reflection of Light from Ultraviolet to Visible and Infrared by Heliconical Cholesterics



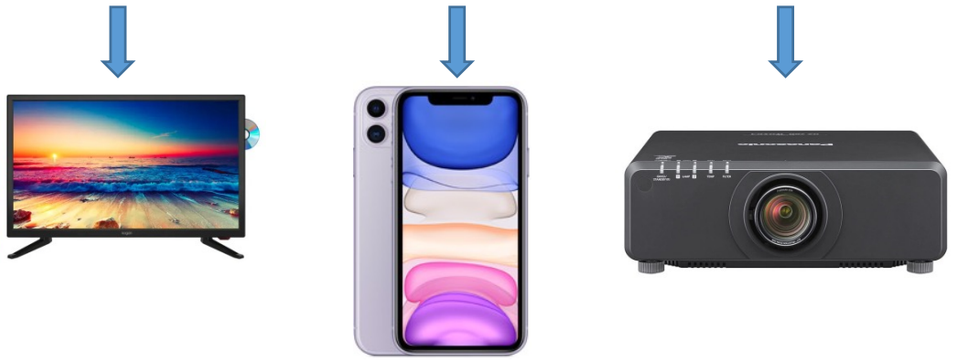
- Applied electric fields can adjust the behaviour of the cholesteric, and thus tune the selective reflection
- The upper diagrams show how gradually increasing the E field changes the structure of the liquid crystal
- The lower diagrams show how the coverglass reflects different components of white light in each case

Advanced Materials, Volume: 27, Issue: 19, Pages: 3014-3018, First published: 27 March 2015, DOI: (10.1002/adma.201500340)

Devices



myqacorner.blogspot.com/2017/01/liquid-crystal-display.html



The most important action is in here. Each pixel has transparent addressable electrodes on either side to enable optoelectronic switching.

Learning outcomes

After this lecture you should be able to

- Describe the nature of polarised and unpolarised light
- Explain how polarised light interacts with anisotropic mesophases
- Explain how birefringence and selective reflection can occur in anisotropic mesophases
- Explain how electric fields can influence the optical behaviour of mesophases
- Reflect on the role of fundamental chemical physics in modern devices

Further reading

- https://chem.libretexts.org/Bookshelves/Analytical_Chemistry/Book%3A_Physical_Methods_in_Chemistry_and_Nano_Science_(Barron)/07%3A_Molecular_and_Solid_State_Structure/7.09%3A_The_Analysis_of_Liquid_Crystal_Phases_using_Polarized_Optical_Microscopy
- http://layer.uci.agh.edu.pl/Programy/Physics2000/Phys2000/laptops/polarizing.html
- https://www.lockhaven.edu/~dsimanek/14/polaroid.htm