UNIVERSITY OF CAMBRIDGE

Liquid crystals

Lecture 12

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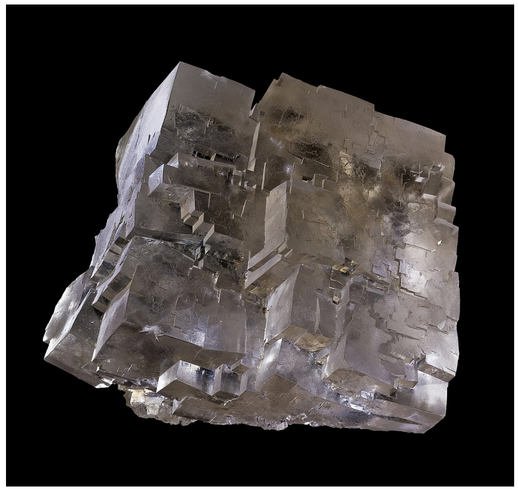
Course B: Materials for Devices

Professor M does Science

http://www.tcm.phy.cam.ac.uk/~bm418/

Solid vs liquid

crystalline solid



- Atoms are ordered in regular pattern
- Periodic lattice: long-range order
- Anisotropic

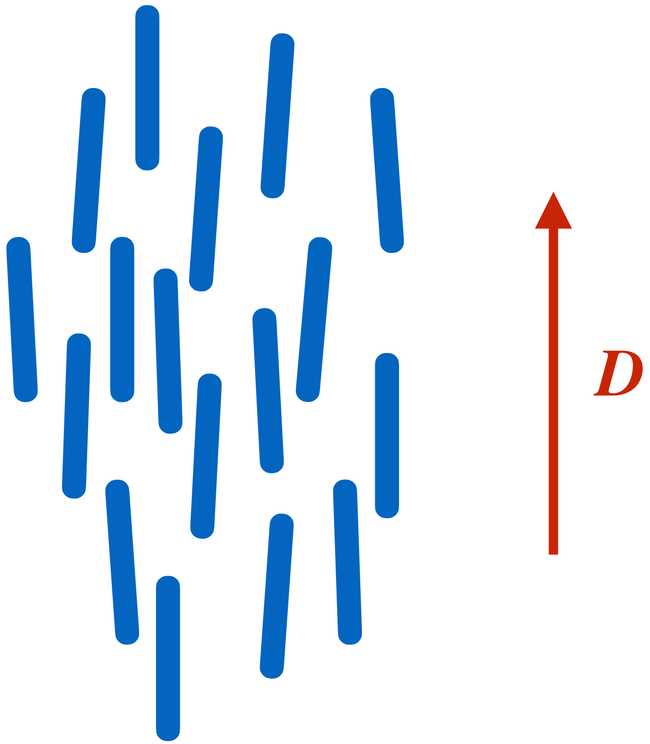
liquid

- Atoms are not ordered
- Isotropic

Liquid crystal

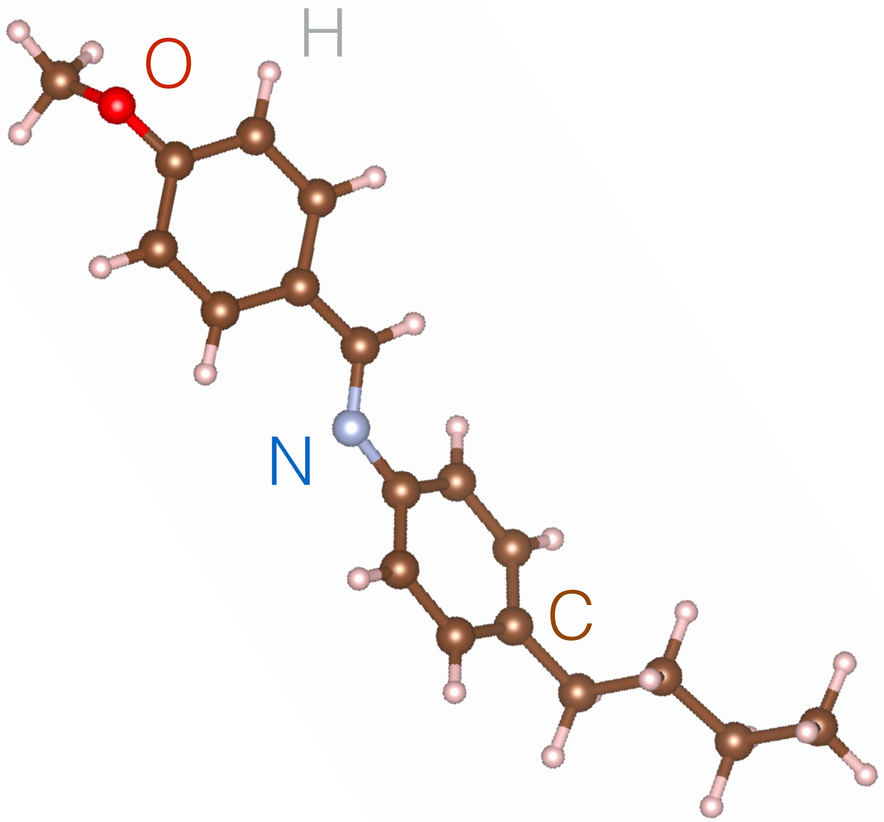
- Liquid crystal: state of matter with properties intermediate between crystalline solid and conventional liquid

Nematic liquid crystal



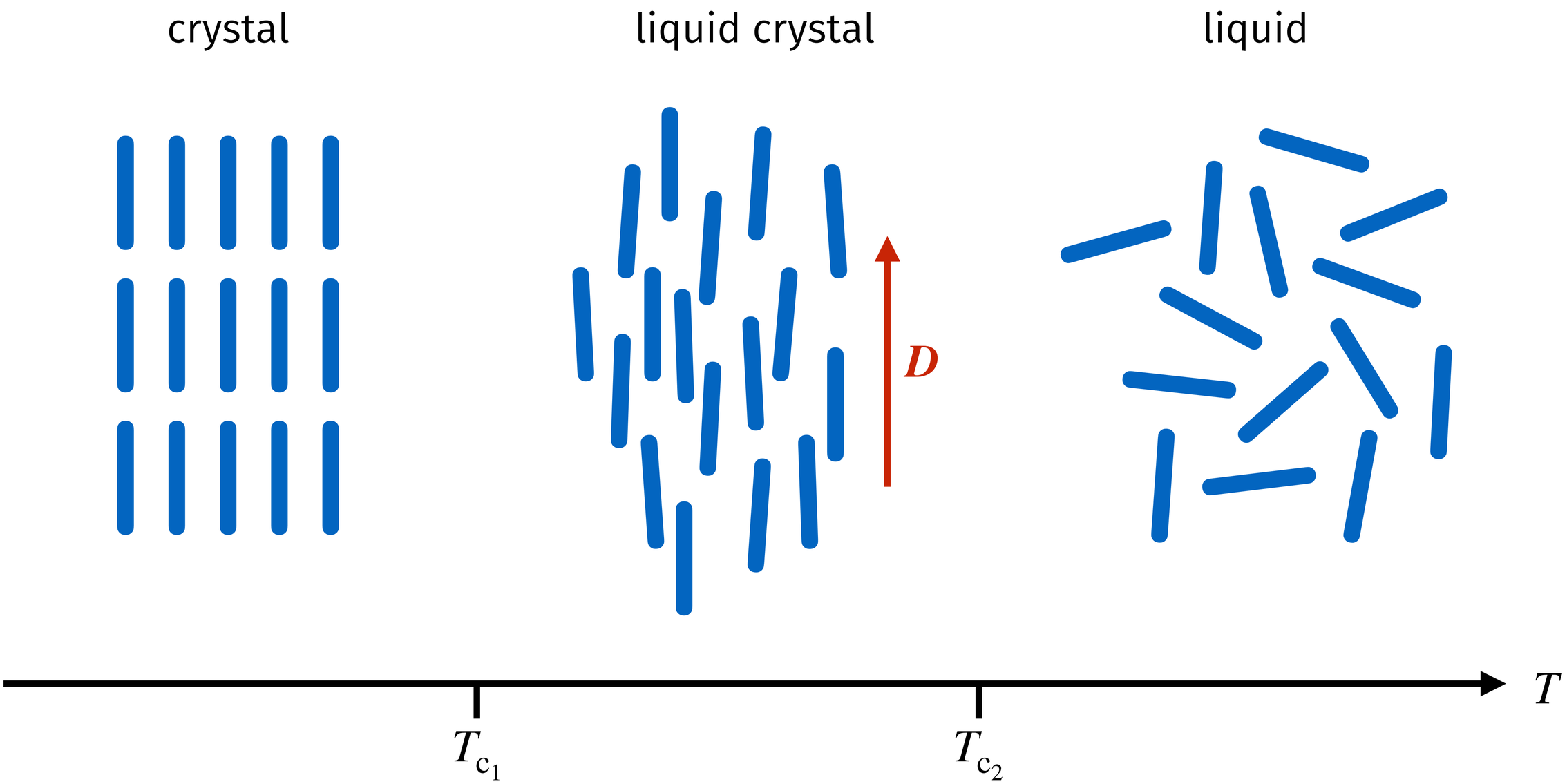
- Organic rod-like molecules
- Centres of mass of molecules have no long range order: they flow like a liquid
- Molecules tend to align along some common axis, the *director* $\boldsymbol{D}$: leads to anisotropic properties like a crystal

Nematic liquid crystal



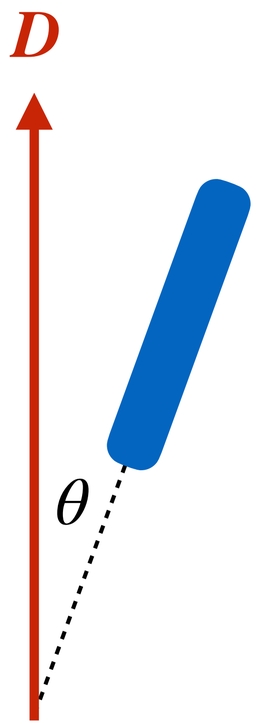
- N-(4-Methoxybenzylidene)-4-butylaniline (MBBA)
- First nematic liquid crystal at room temperature

Nematic liquid crystal phase diagram



Nematic liquid crystal: order parameter

- *See discussion of order parameter*

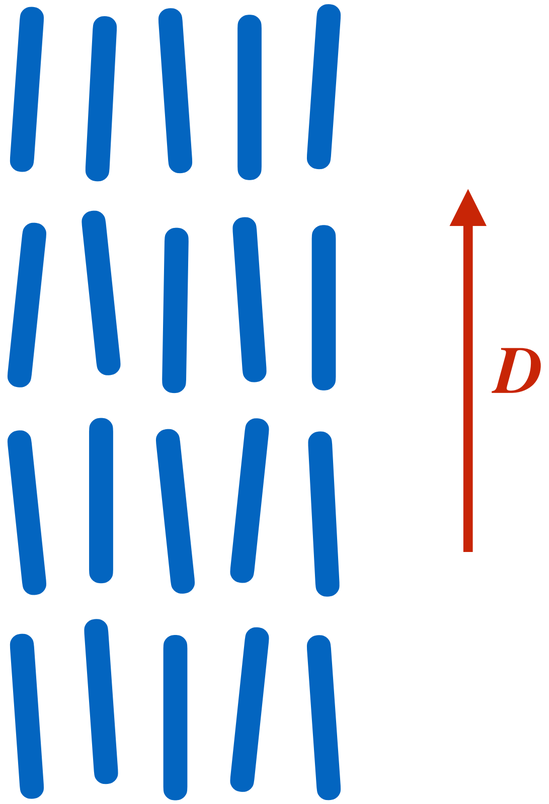


$$Q = \frac{1}{2}\langle 3\cos^2\theta - 1\rangle$$

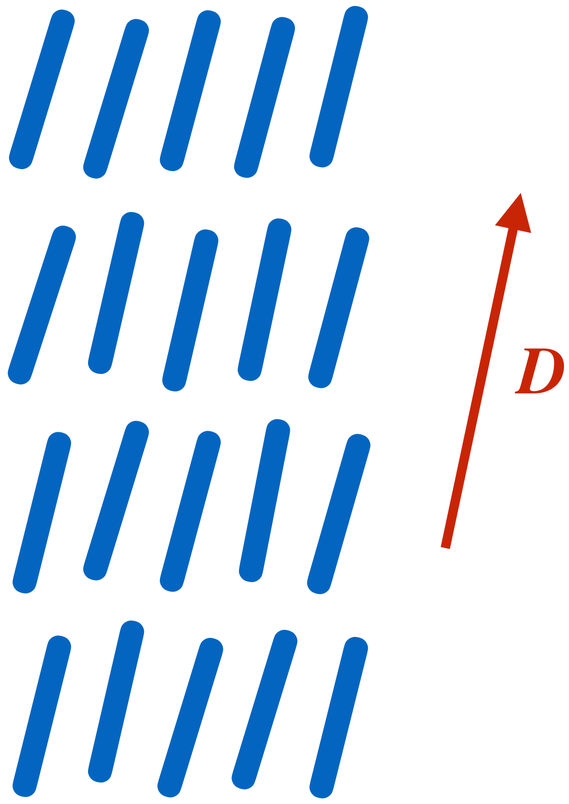
- All molecules aligned: $Q = 1$
- Randomly oriented molecules: $Q = 0$

Smectic liquid crystals

- Smectic liquid crystal: molecules organise in layers

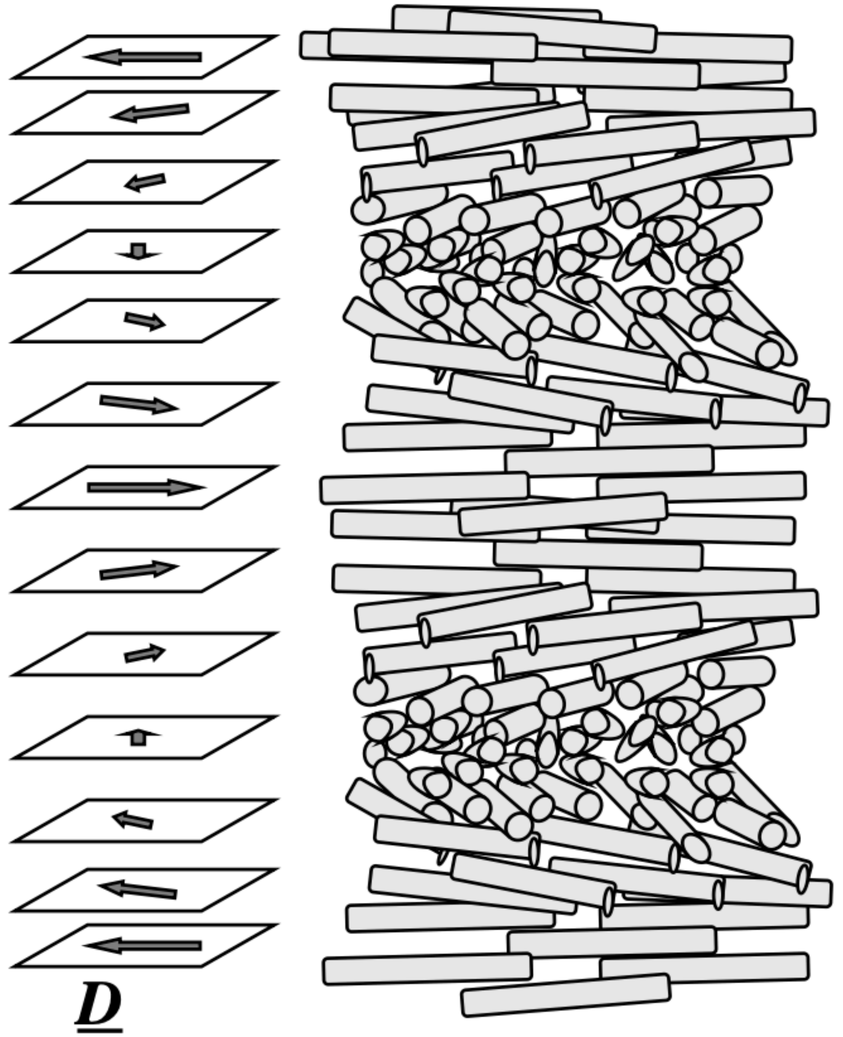


Smectic A



Smectic C

Chiral nematic (cholesteric) liquid crystals



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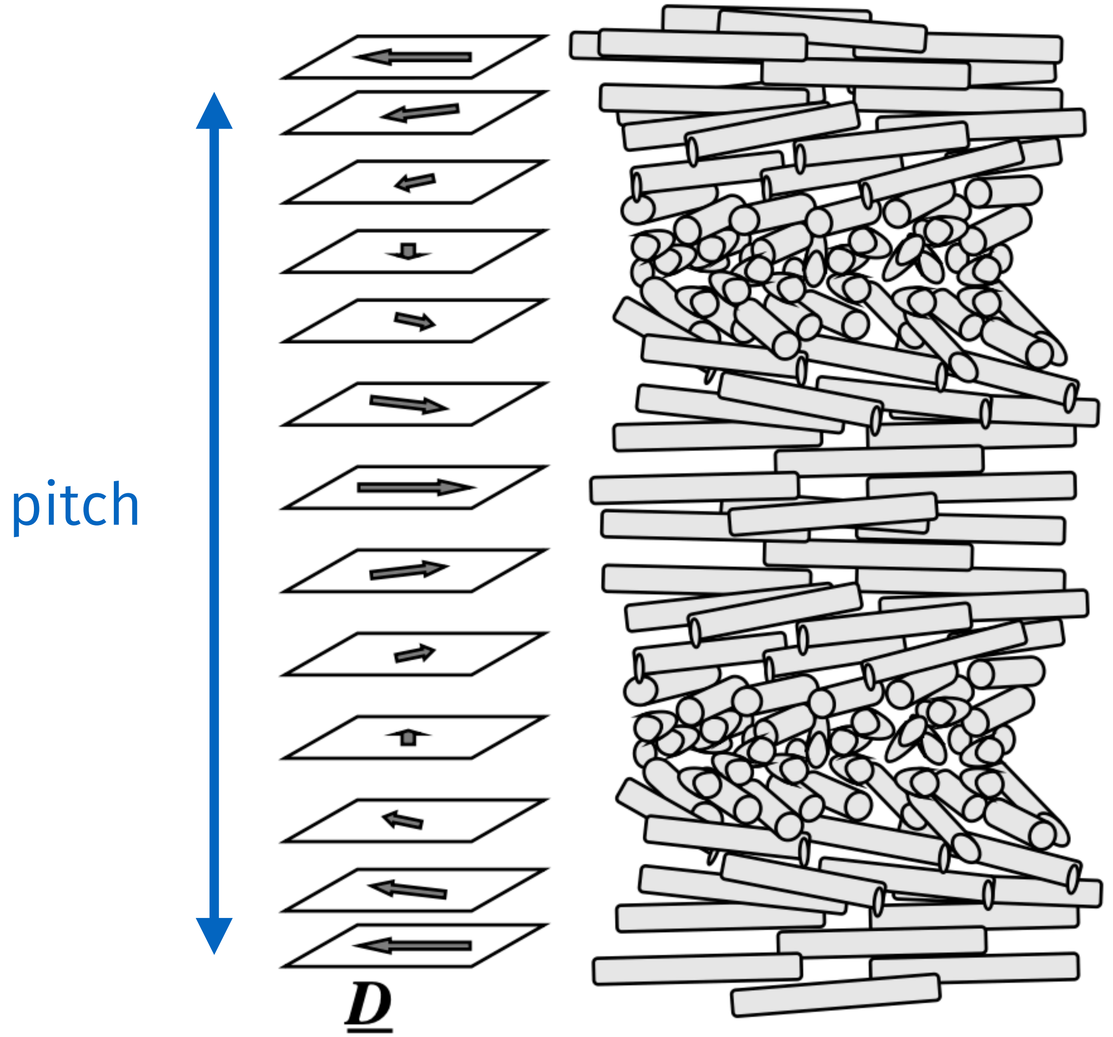
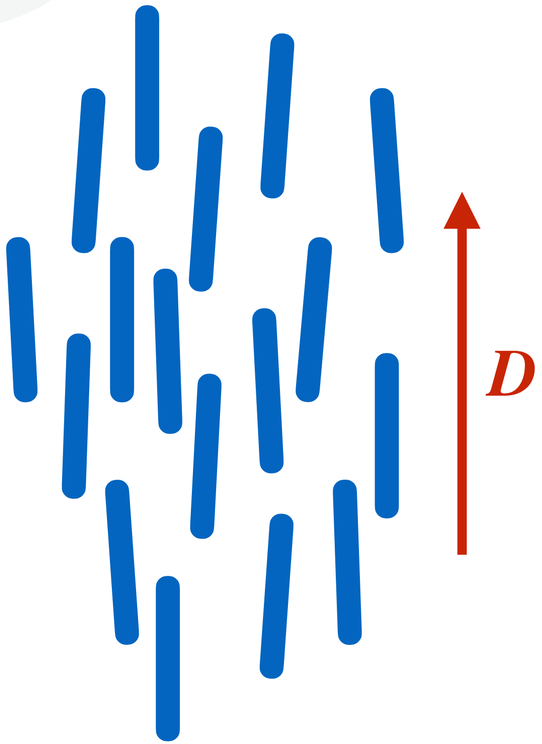
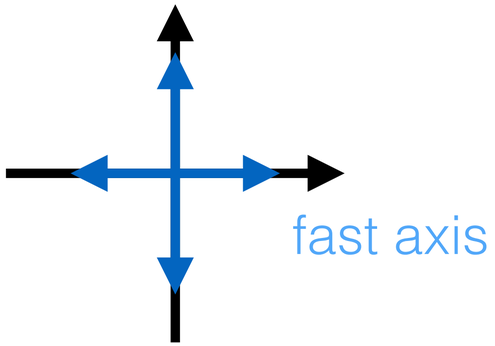


Birefringence in liquid crystals



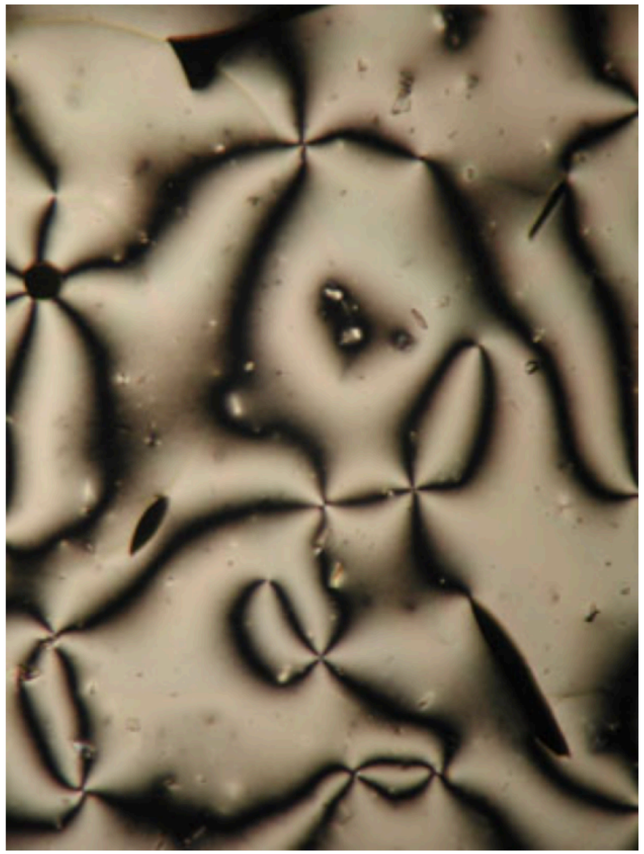
slow axis



fast axis

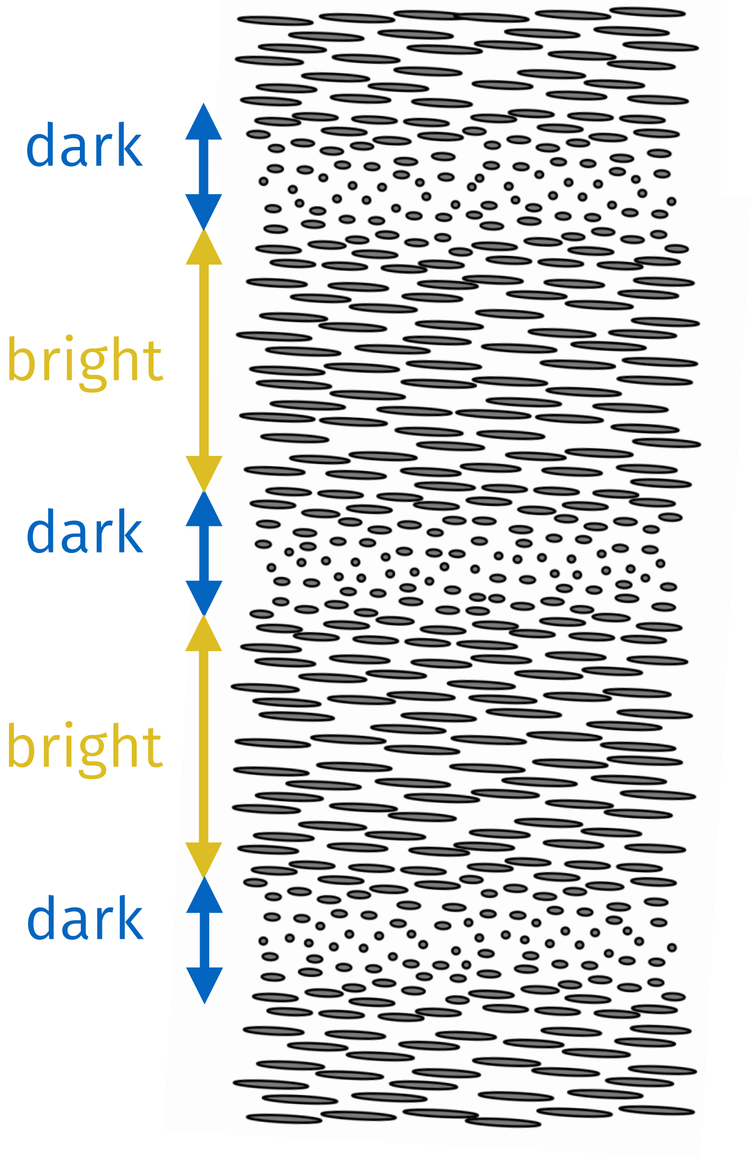
- Permitted vibration directions are parallel and perpendicular to director $\boldsymbol{D}$)
- For example, component of light travelling along the molecules (parallel to $\boldsymbol{D}$) would have a larger refractive index
- For light with propagation direction along $\boldsymbol{D}$: no birefringence as section looks isotropic (polarisation always perpendicular to director)

Birefringence in liquid crystals



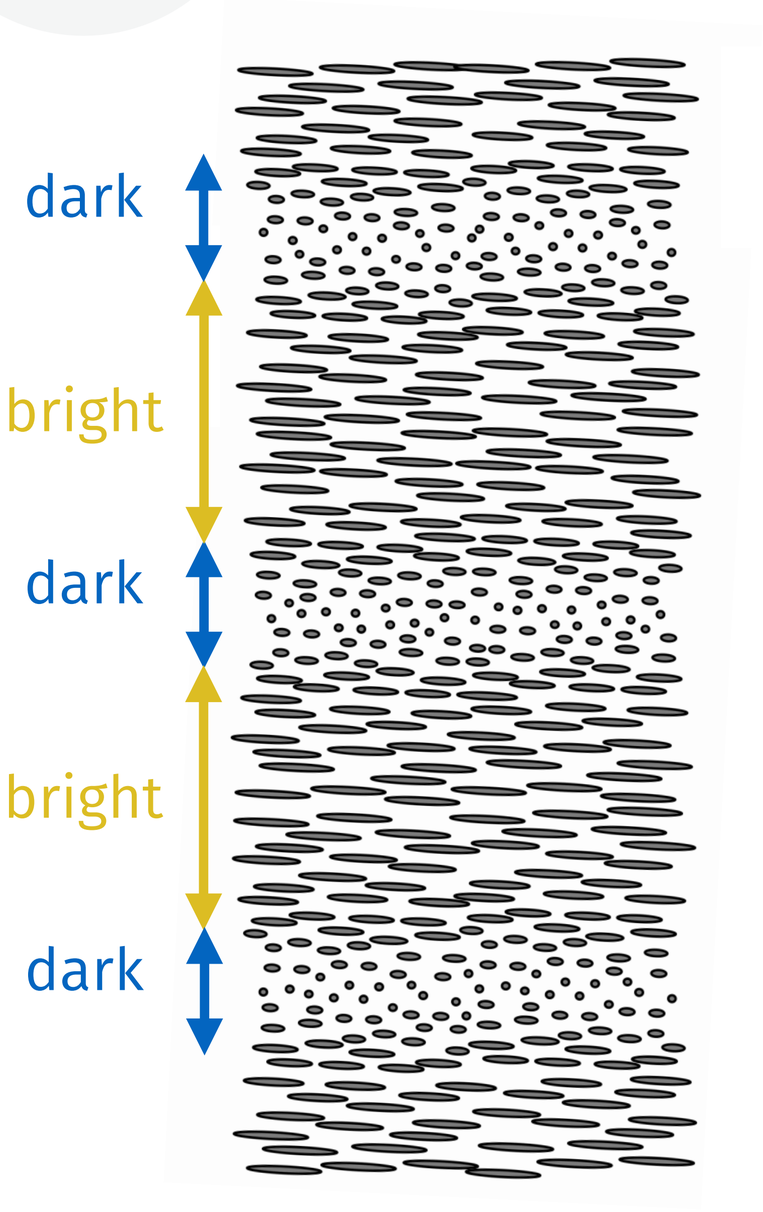
- Real liquid crystal samples have domains: director $\boldsymbol{D}$ points in different directions in each domain
- Domain boundaries are called *disclinations*
- A liquid crystal sample observed between crossed polarisers shows the structure on the Figure:
  - Bright regions: domains
  - Dark boundaries: director aligned with one of the cross polarisers (or parallel to light propagation direction)

Birefringence in liquid crystals



- Direction of propagation of light perpendicular to helix axis (e.g. into the page).
- Sample between crossed polarisers:
  - Dark: light propagating along $\boldsymbol{D}$
  - Bright: strong birefringence for light not propagating along $\boldsymbol{D}$

Birefringence in liquid crystals



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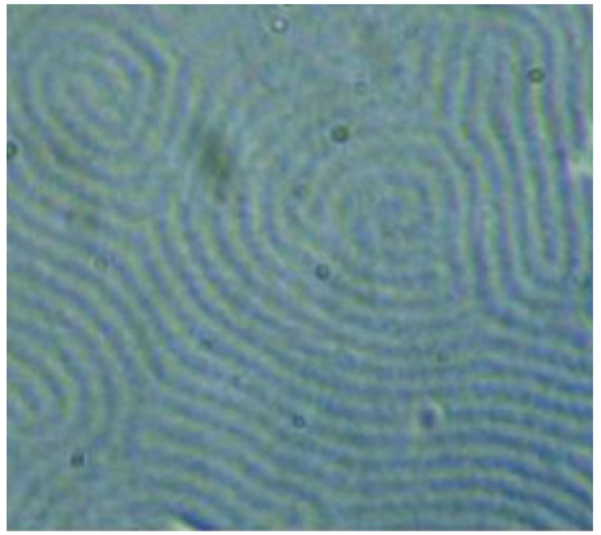
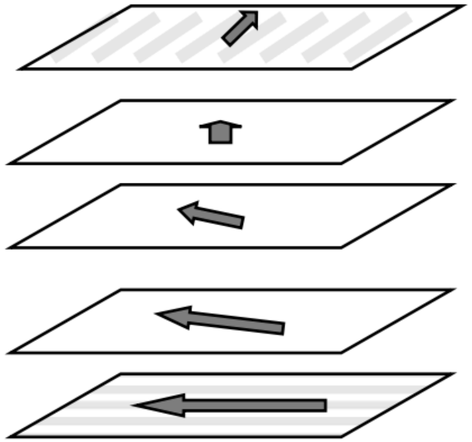
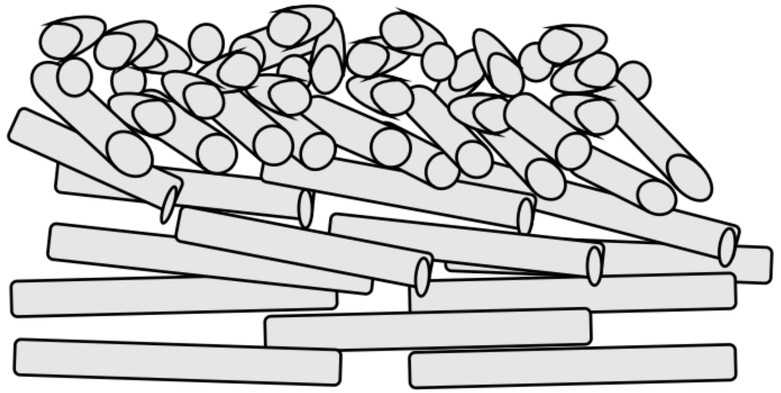
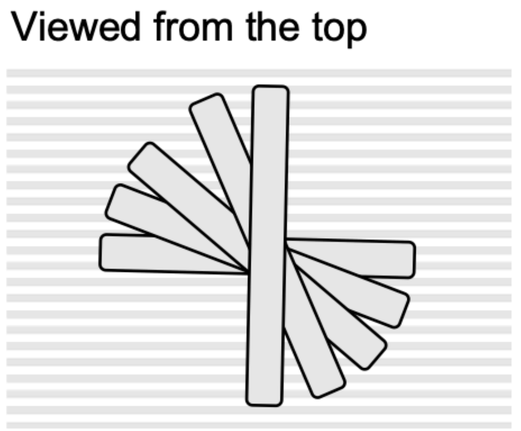


Liquid crystal displays

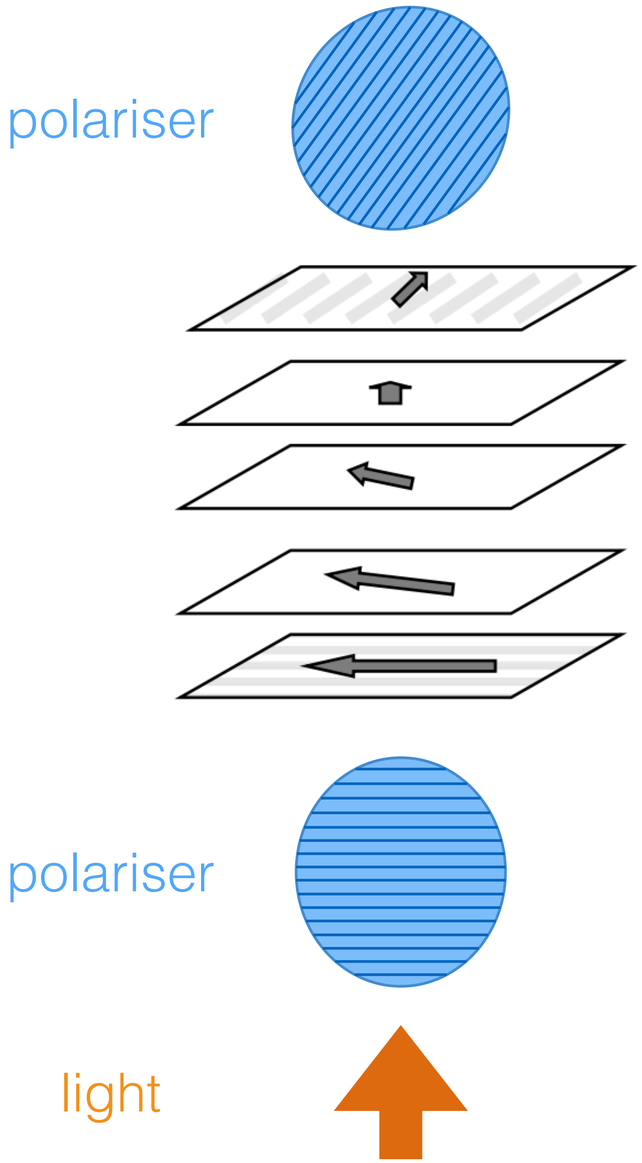






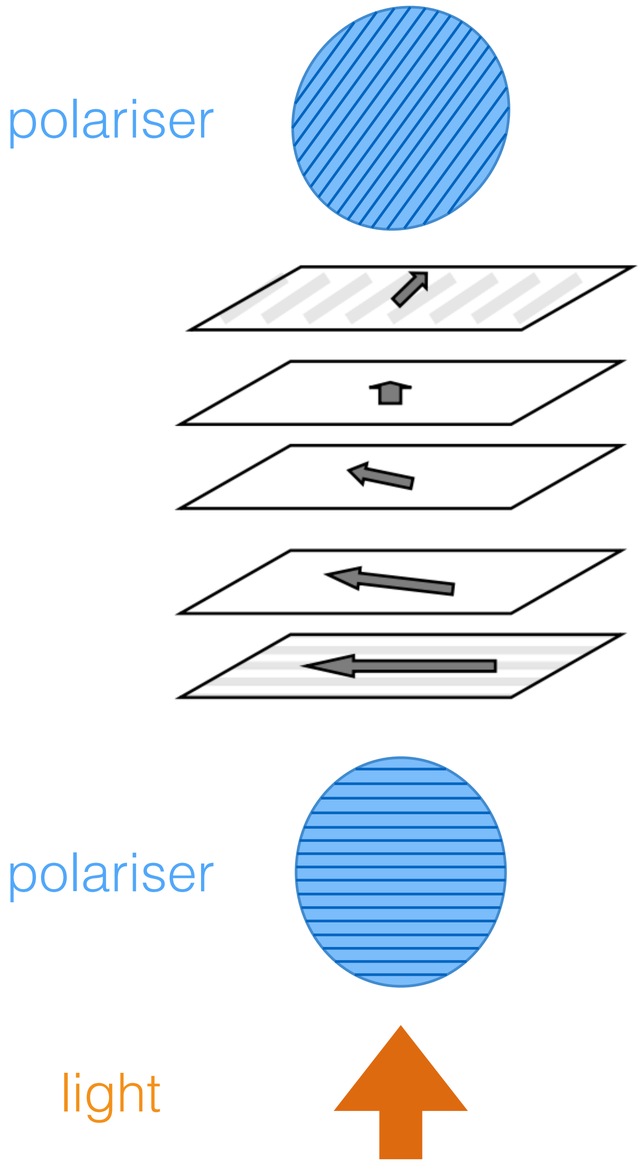
- Director $\boldsymbol{D}$ of a nematic liquid crystal can be forced to lie along a particular direction by creating grooves on a surface in contact with it
- If the nematic liquid crystal is sandwiched between two plates with perpendicular grooves, the director twists across the sandwich
- We end up with a *twisted nematic structure*

Liquid crystal displays



- Polarisers oriented along grooves at bottom and top
- First polariser: light polarised along bottom director
- Twisted nematic: light polarisation is rotated by 90˚
- Second polariser: light polarisation aligned with polariser, so it is fully transmitted

Liquid crystal displays



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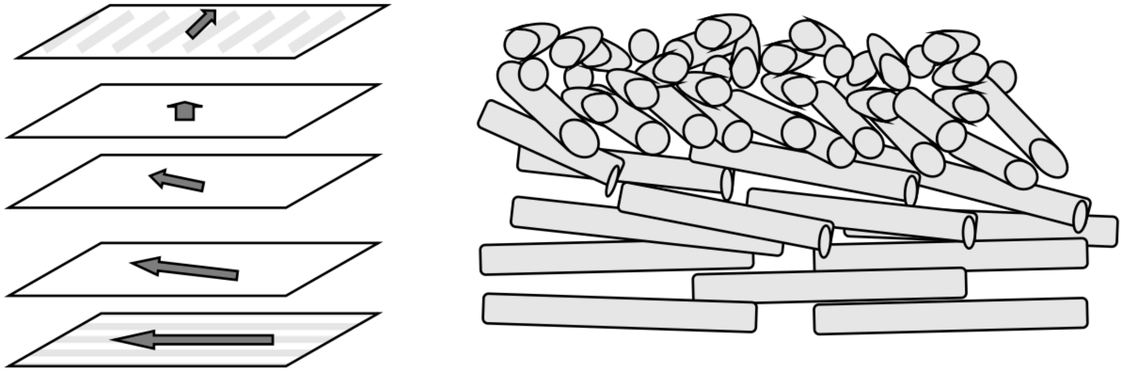
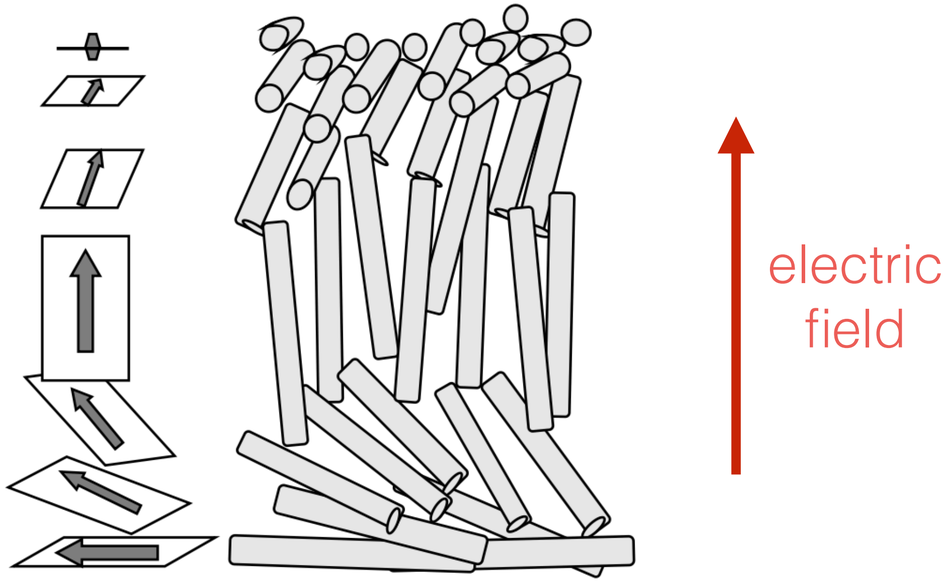
ON state

Liquid crystal displays

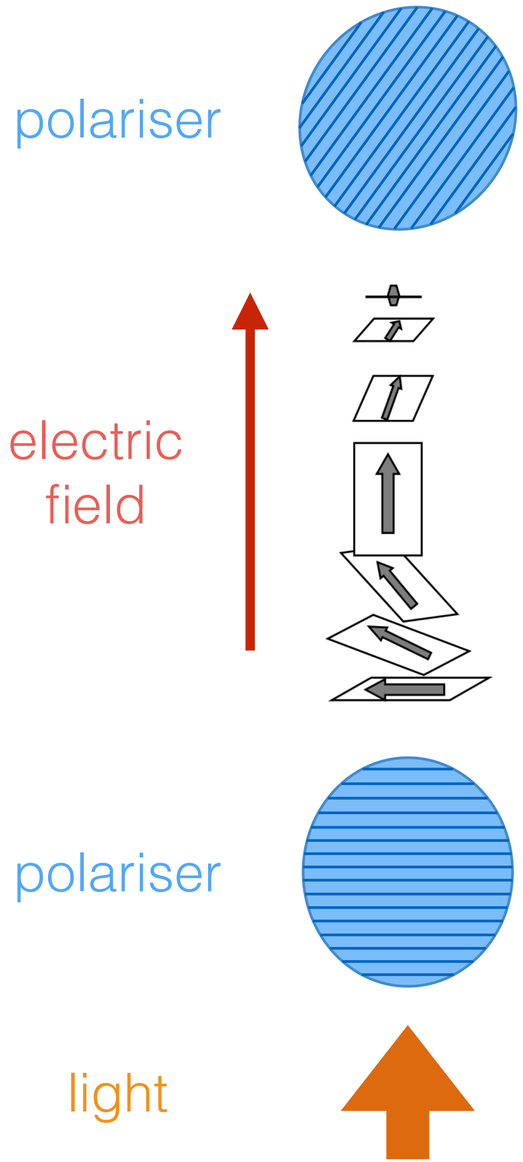


original configuration



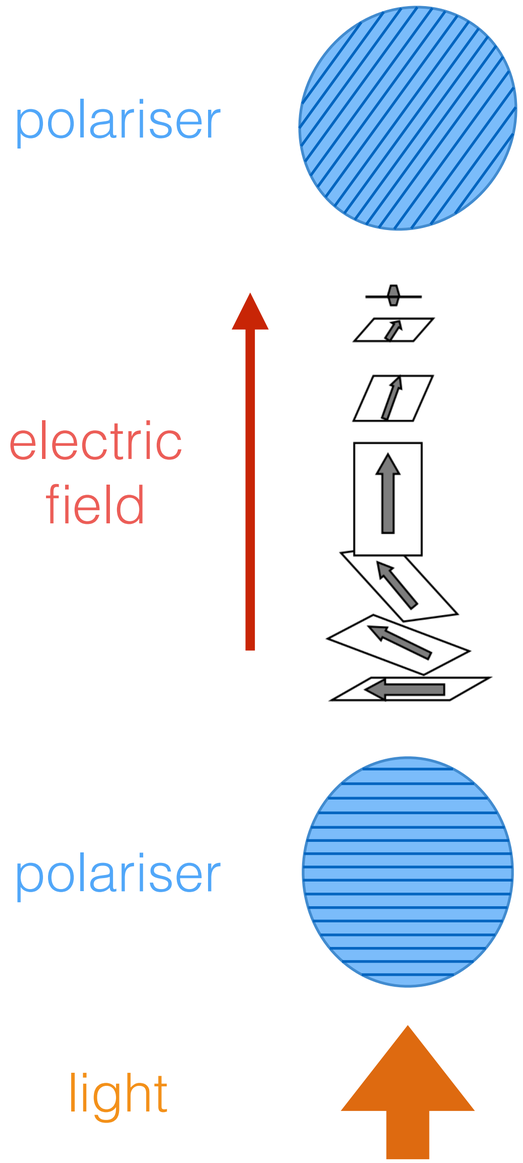
Fréedericksz transition

Liquid crystal displays



- Polarisers oriented along grooves at bottom and top
- First polariser: light polarised along bottom director
- Twisted nematic: light polarisation is no longer rotated by 90°
- Second polariser: no light is transmitted

Liquid crystal displays



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OFF state

Liquid crystal displays

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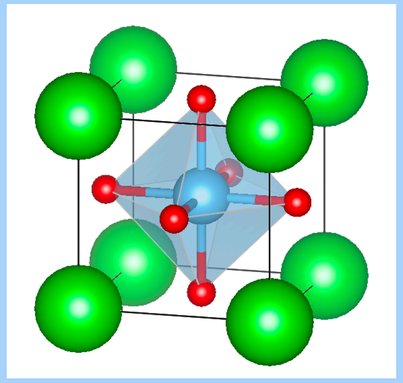
Course B: Materials for Devices

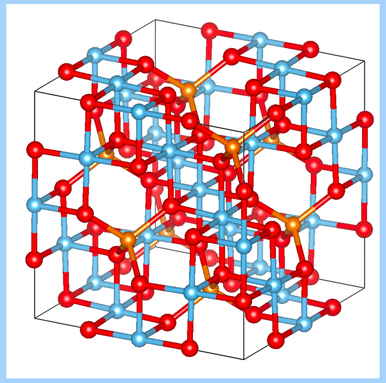
order

disorder

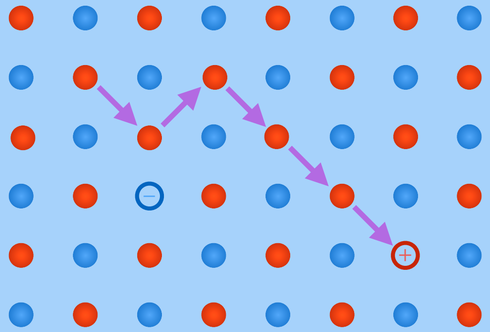
electric polarisation in materials



magnetism in materials



ionic conductors



liquid crystals