LIQUID CRYSTALS

Properties  Synthesis  Applications

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What are liquid crystals?

A thermodynamically stable phase characterized by anisotropy of properties without the existence of a three-dimensional crystal lattice, generally lying in the temperature range between the solid and isotropic liquid phase.

- Positional order
- Orientational order
- Bond orientational order
1849: W. Heintz found that upon heating (at 52°C), stearin, softened and became cloudy, and at 62.5° it became clear. Duffy described this phenomenon as the existence of two melting points.

1850: Mettenheimier found myelin to be birefringent, a property previously known to be possessed by crystals only.

1888: Reinitzer observed the two-melting-points phenomenon, birefringence and the occurrence of iridescent colors between the two melting points in a material that we now know was cholesteryl benzoate.

1889: Lehmann carried out detailed investigation and reasoned that the birefringent portions of the liquid must be crystals. He first referred to this material as liquid crystals.
Historical background

- **1890**: Gattermann synthesized the first liquid crystals of azoxybenzene, with fully known structures.
- **1908**: D. Vorlaender, the first to synthesize a thermotropic smectic compound, related liquid crystallinity to chemical structures, detected polymorphism of liquid crystal state.
- **1922**: Freidel identified and named the various microscopic textures (nematic, smectic, and cholesteric), observed the effects of electric and magnetic fields.
- **1930**: Freedericksz studied the transition from a homogeneous to a deformed structure at some critical value of applied field strength.
- **1965**: The International Liquid Crystal Society by late Glenn Brown at Kent State University.

Lehmann and Reinitzer are known as the grandfathers of liquid crystal science.
Characteristic features

- **Mesogens** point along a common axis, the *director*
- **Orientational order** is between the traditional solid and liquid phases
- **Anisotropic** i.e. the properties differ depending on what direction they are measured relative to the director
- **Birefringent**, resulting in the two components of electric or magnetic field traveling through it at different speeds hence out of phase when they exit
- **Stiffness** necessary for liquid crystallinity results from restrictions on rotation caused by *steric hindrance* and *resonance*
- **Axial ratio** ($x = L/d$) must be at least three to display the characteristics of liquid crystals
**Phases of liquid crystals**

- **Nematic phase**: molecules have no positional order but tend to point in the same direction along the director.

- **Cholesteric phase**: composed of chiral nematic mesogens; intermolecular forces favor alignment between molecules at a slight angle to one another; directors form a continuous helical pattern.
**Phases of liquid crystals**

- **Columnar phase:** disc shaped, stacked columns of molecules, columns are packed together to form a two-dimensional crystalline array.

- **Smectic phase:** molecules show a degree of translational order, tend to align themselves in layers or planes. Separate planes flow past each other.

  - **Smectic A:** director is perpendicular to the smectic plane, and there is no particular positional order in the layer.

  - **Smectic C:** director is at a constant tilt angle measured normally to the smectic plane.
Classification of liquid crystals

1. **Thermotropic liquid crystal**
   - Thermally induced transition to the liquid crystalline state
   - Thermotropic mesophases occur because of **anisotropic dispersion forces** between the molecules and **packing interactions**

   - **Enantiotropic** (lowering the temperature of a liquid as well as raising that of a solid)
   - **Monotropic** (either an increase in the temperature of a solid or a decrease in the temperature of a liquid)
   - **Discotics** flat disc-like molecules with a core of adjacent aromatic rings forming two dimensional columnar ordering
   - **Rod-shaped molecules** molecules with an elongated, anisotropic geometry aligned along one spatial direction
Classification of liquid crystals

2. **Lyotropic liquid crystals**

- Solvent-induced aggregation of the constituent amphiphilic mesogens into micellar structures
- Lyophobic ends stay together and the lyophilic ends extend outward toward the solution
- Size of the micelles increase with increase in concentration and lowering of temperature.
- They coalesce separating the liquid crystalline state
Chemical structure

All the known molecules that form liquid crystalline phases are asymmetric in their shape.

Monomers can be attached:
- in a long single chain forming main chain polymer
- to polymer back bone forming side chain polymer

Monomers commonly used
- cholesterol ester
- phenyl benzoates
- surfactants
- paraffines
- glyco lipids
- cellulose derivatives
Polymer Liquid Crystals

- Mesophases formed by polymeric molecules combine the unique properties of polymer (high strength fiber, ultra thin films) and anisotropic properties of liquid crystals

- Factors influencing the mesomorphic behavior of polymers
  - presence of long flexible spacers
  - low molecular weight
  - regular alternation of rigid and flexible units along the main chain

- Polymer-Dispersed Liquid Crystals
- Polymer-Stabilized Liquid Crystals
Main chain polymer liquid crystals

- Monomers made up of several aromatic rings
- Monomers are stiff, rod-like
- Restricted rotations due to resonance and steric hindrance
- Less prevalent due to very high stiffness

- Mesogenic units are made up of two or more aromatic rings
- Mesogen is directly incorporated in the chain
- Flexible spacer and the stiff mesogen
- 3 times long as they are wide
Temperature Range Problems

Methods of lowering the polymer melting temperatures:

- minimizesd interactions with reduced symmetry

1. Introduction of defects to disrupt the ability for neighboring polymers to line up

2. Molecules are put together in random orientation (head-to-tail, head-to-head)

3. Random copolymerization resulting in irregularity of polymer substituents
Side chain polymer liquid crystals

**The backbone**

- More rigid the backbones higher is the glass transition temperature
- Rigid core of two or more aromatic rings joined together by a functional group forms the mesogen

**The spacer**

- The spacer consists of two to four methylene (CH2) groups. Longer spacers gives lower glass transition temperature

**The mesogen**

- Rigid core of two or more aromatic rings joined together by a functional group forms the mesogen
**Applications**

- The liquid crystal displays (LCDs)
- Liquid Crystal Thermometers. Cholesteric liquid crystals reflect light with a wavelength equal to the pitch which is dependent upon temperature
- High strength fibres. Polymer liquid crystals are used in applications calling for strong, light weight materials e.g kevlar
- Optical imaging. Generation of electric field as light falls on photoconductor plates
- Drug delivery. Lyotropic liquid crystals can coat a drug to keep it from being destroyed in the digestive tract
- Biological membranes. Lyotropic liquid crystals act as biological membranes due to their amphiphilic nature
Liquid Crystal Display

- Consists of an array of tiny segments (called pixels) that can be manipulated to present information.
- LCD consists primarily of two glass plates with some liquid crystal material between them.
- Plates are usually manufactured with transparent electrodes (ITO), that make it possible to apply an electric field across small areas of the film of liquid crystal.
- LCDs consume much less power than their cathode-ray tube (CRT) counterparts.
- Most commonly used are the Twisted Nematic (TN) Displays.
Liquid crystals- an interdisciplinary research area

- **Chemistry.** Creating new materials and using the supramolecular systems for synthesis, analysis and purifications of other materials.

- **Biology.** Study of the cell membrane as a liquid crystal with respect to intercellular transport (drug delivery) and communications.

- **Physics.** Measurement of unique properties of liquid crystals (ferroelectricity, piezoelectricity, phase transitions) and developing new ways of electrooptics.

- **Engineering.** Creating electrooptical displays (LCD, STN, TFT), optical information storage, switchable gearboxes and lubricants etc.

- **Information technology.** Creating object oriented knowledge tools, using the color effects of liquid crystals for special effects.
The Challenger disaster

- As demonstrated by Richard Feynman, a member of the presidential commission appointed to investigate the accident, the elastic O-ring (a gasket) did not respond as expected because of the cold temperature (30°F/-1°C) at launch time and thus could not flex adequately to form a proper seal around one of the two solid rocket boosters.
THANK YOU
• liquid crystal cell is placed between two layers of photoconductor
• light is applied to the photoconductor, which increases the material's conductivity
• electric field corresponding to the intensity of the light develops
• the electric pattern transmitted by an electrode, enabling the image to be recorded
  • Positional order: The extent to which the position of an average molecule or group of molecules shows translational symmetry.
  • Orientational order: Measure of the tendency of the molecules to align along the director on a long-range basis
  • Bond orientational order: Describes a line joining the centers of nearest-neighbor molecules without requiring a regular spacing along that line. Thus, a relatively long-range order with respect to the line of centers but only short range positional order along that line