3.012 Fund of Mat Sci: Structure – Lecture 24

LIQUID CRYSTALS

Source: Wikipedia.

LAST LECTURE !

Last Homework

- Study: Chapter 4 of Allen-Thomas, up to 4.4.3 included

FRI DEC 16 3-5pm 13-5066

MON DEC 19 4-6pm 13-5066

COVERAGE 17-24

Last time:

1. Glass transition, and common glasses
2. Size of linear polymers: random walk model (identical to diffusion in a liquid) $\sqrt{N}\,\ell$
3. Packing fraction
4. Solvent – self-avoiding random walk
5. Rouse and reptation diffusion
6. Network glasses: oxides and chalcogenides

Fliessende Krystalle !

A2
Zeitschrift für Physikalische Chemie **4**, 462–72 (1889)

Über fliessende Krystalle.

Von
O. Lehmann.

(Mit Tafel III und 3 Holzschnitten.)

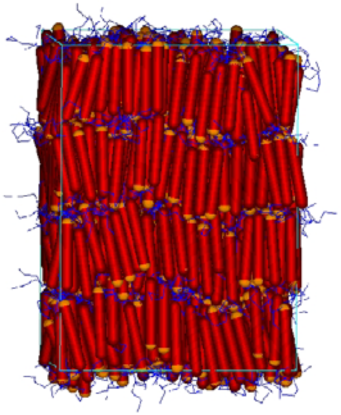
Fliessende Krystalle! Ist dies nicht ein Widerspruch in sich selbst — wird der Leser der Überschrift fragen —, wie könnte denn ein starres, wohlgeordnetes System von Molekülen, als welches wir uns einen Krystall vorstellen, in ähnliche äussere und innere Bewegungszustände geraten, wie wir sie bei Flüssigkeiten als „Fliessen" bezeichnen und durch mannigfache Verschiebungen und Drehungen der ohnehin schon des Wärmezustandes halber äusserst lebhaft durcheinander wimmelnden Moleküle zu erkären pflegen?

Flowing crystals! Is that not a contradiction in terms? Our image of a crystal is of a rigid well-ordered system of molecules. The reader of the title of this article might well pose the following question: 'How does such a system reach a state of motion, which, were it in a fluid, we would recognise as flow?' For flow involves external and internal states of motion, and indeed the very explanation of flow is usually in terms of repeated translations and rotations of swarms of molecules which are both thermally disordered and in rapid motion.

Liquid crystals

- Flow easily: “liquid-like” fluidity, as in isotropic liquids
- Anisotropic material properties, as in crystals

Images of liquid crystal structures removed for copyright reasons.



Movie

Image removed for copyright reasons. See liquid crystal movies at http://micro.magnet.fsu.edu/movies/crystals/index.html.

Mesogens

- Molecular-shape anisotropy is key structural requirement for LCs
- Molecules that induce liquid-crystallinity are called *mesogens*
- Typical mesogens are needle-like (large length-to-diameter ratio) or disk-like

Mesogens

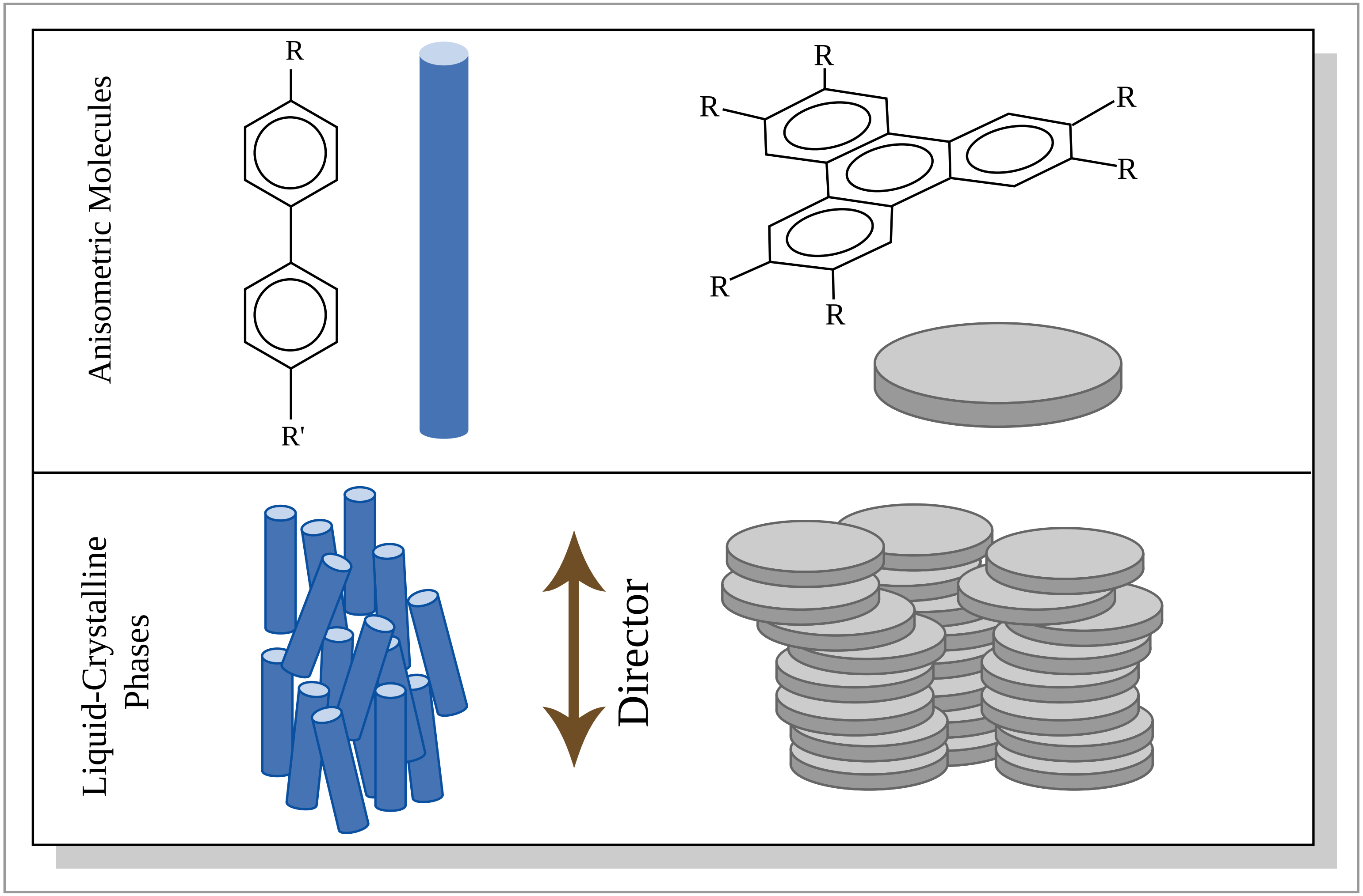
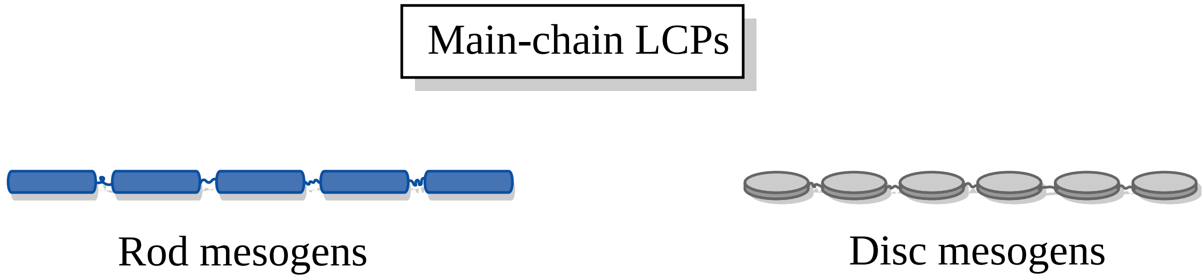


Figure by MIT OCW.

Liquid Crystalline Polymers

- A string of mesogens
  - Connect into backbone



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  - Connect as side chain

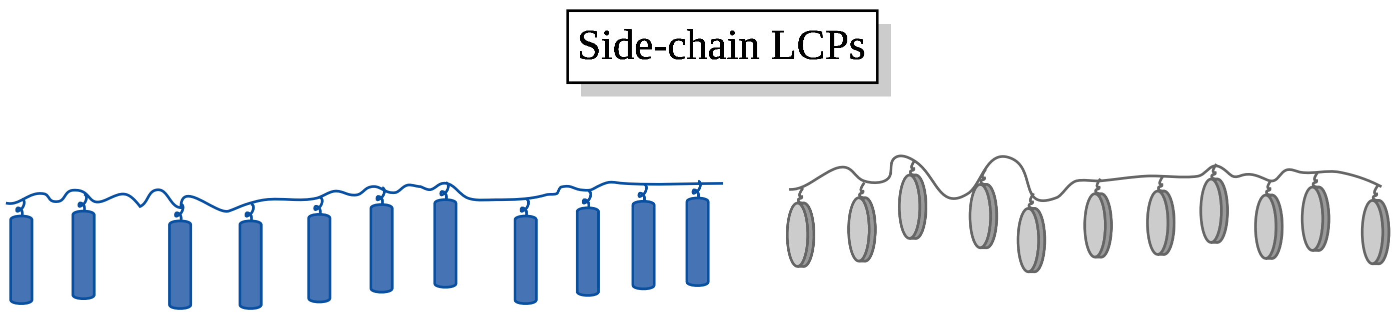


Figure by MIT OCW.

Friedel classification (1922)

- Nematic
- Cholesteric (i.e. twisted nematic)
- Smectic
- Columnar *(discovered later)*

Nematic phases

- Long-range orientational order (uniaxial)
- Short-range translational order

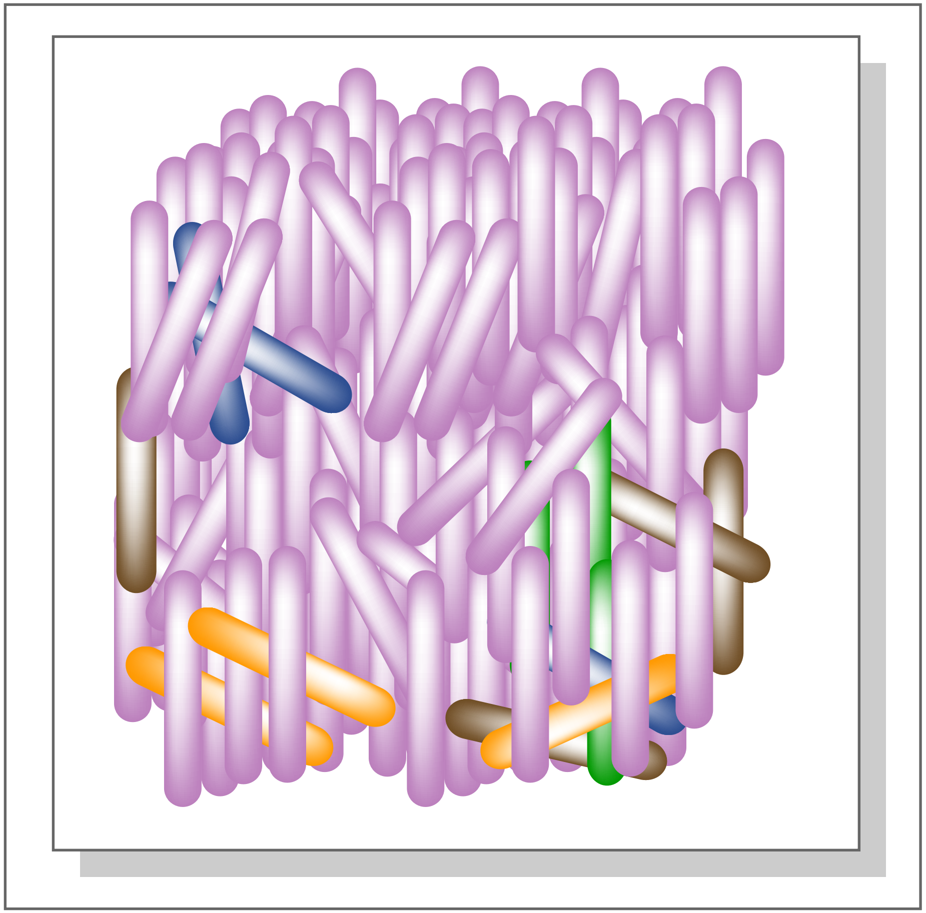


Figure by MIT OCW.

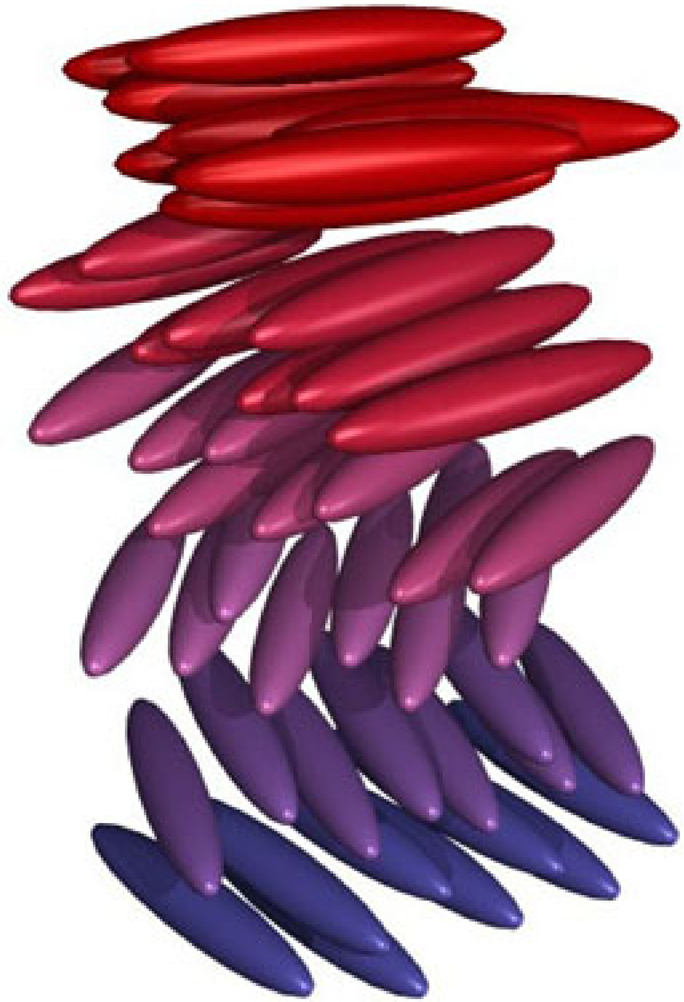
Birefringence

- Different refraction index n=c/v depending on direction
- Schlieren pictures between cross polarizers highlight refraction-index texture

Images removed for copyright reasons.

Twisted nematic (cholesteric)

Nematic alignment with slight preference for a twist



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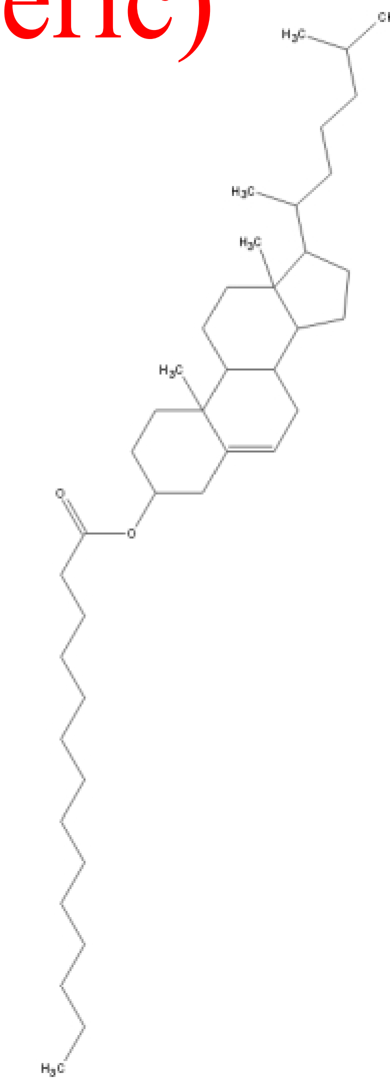
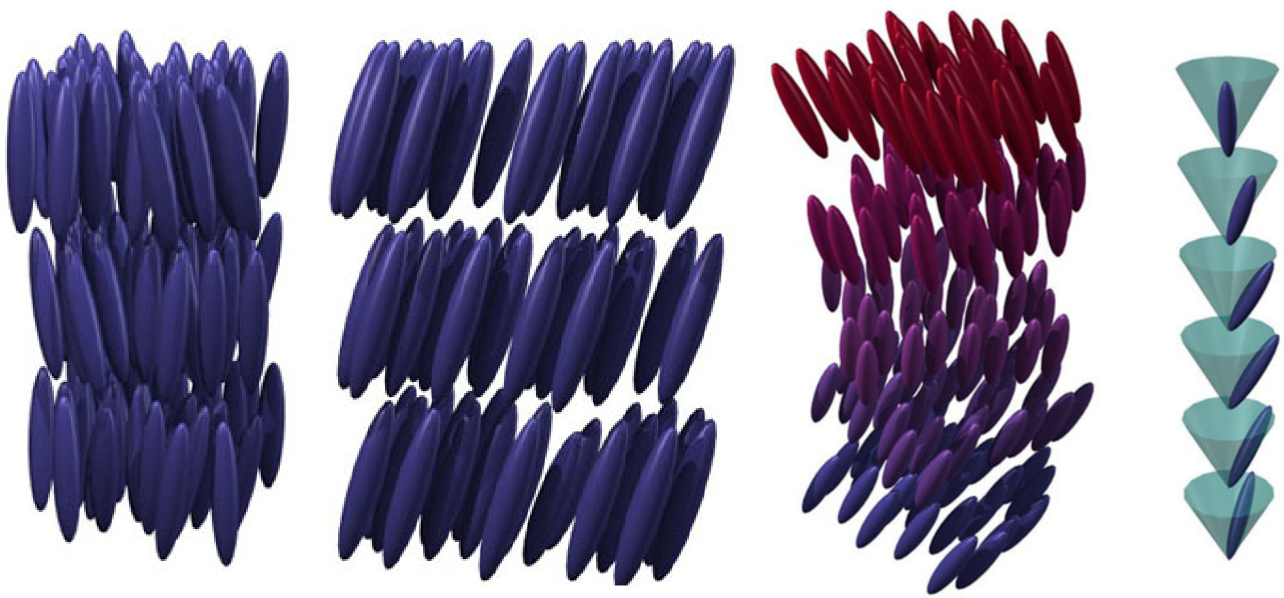


Smectic phases

- Long-range one-dimensional translational order
- Long-range orientational order

Smectic A　　Smectic C　　Smectic C*



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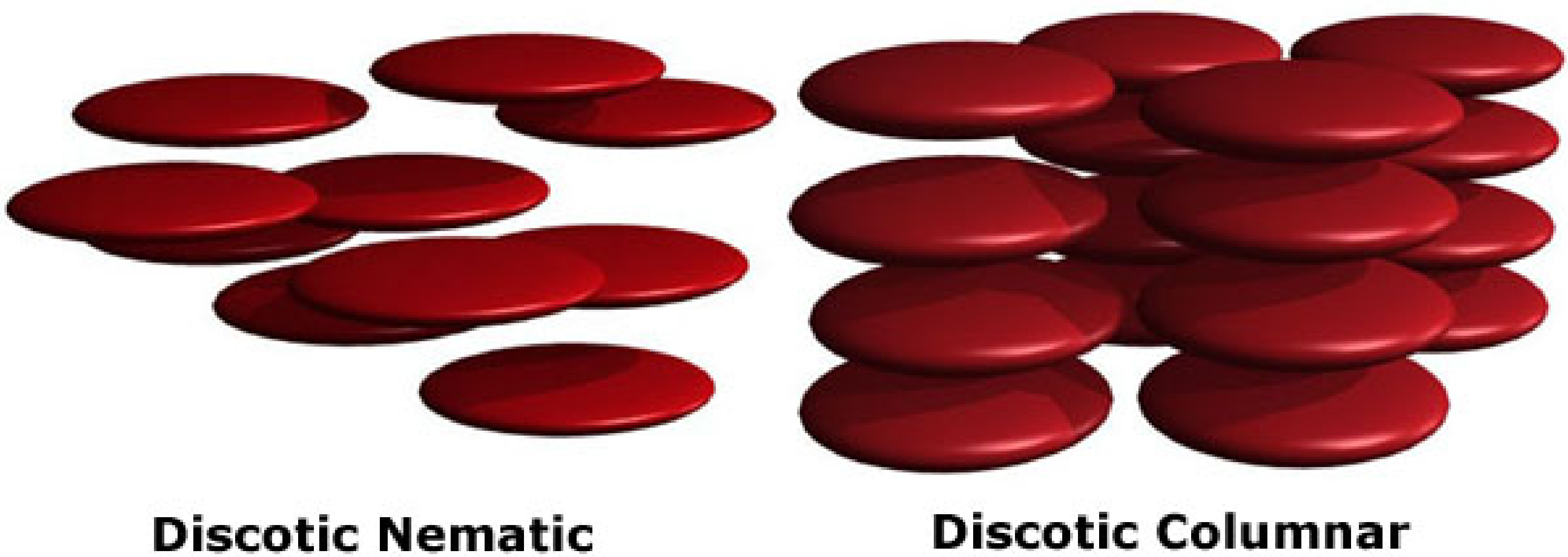
http://www.barrett-group.mcgill.ca/teaching/liquid_crystal/LC01.htm

Columnar phases

- Typically generated by discotic mesogens



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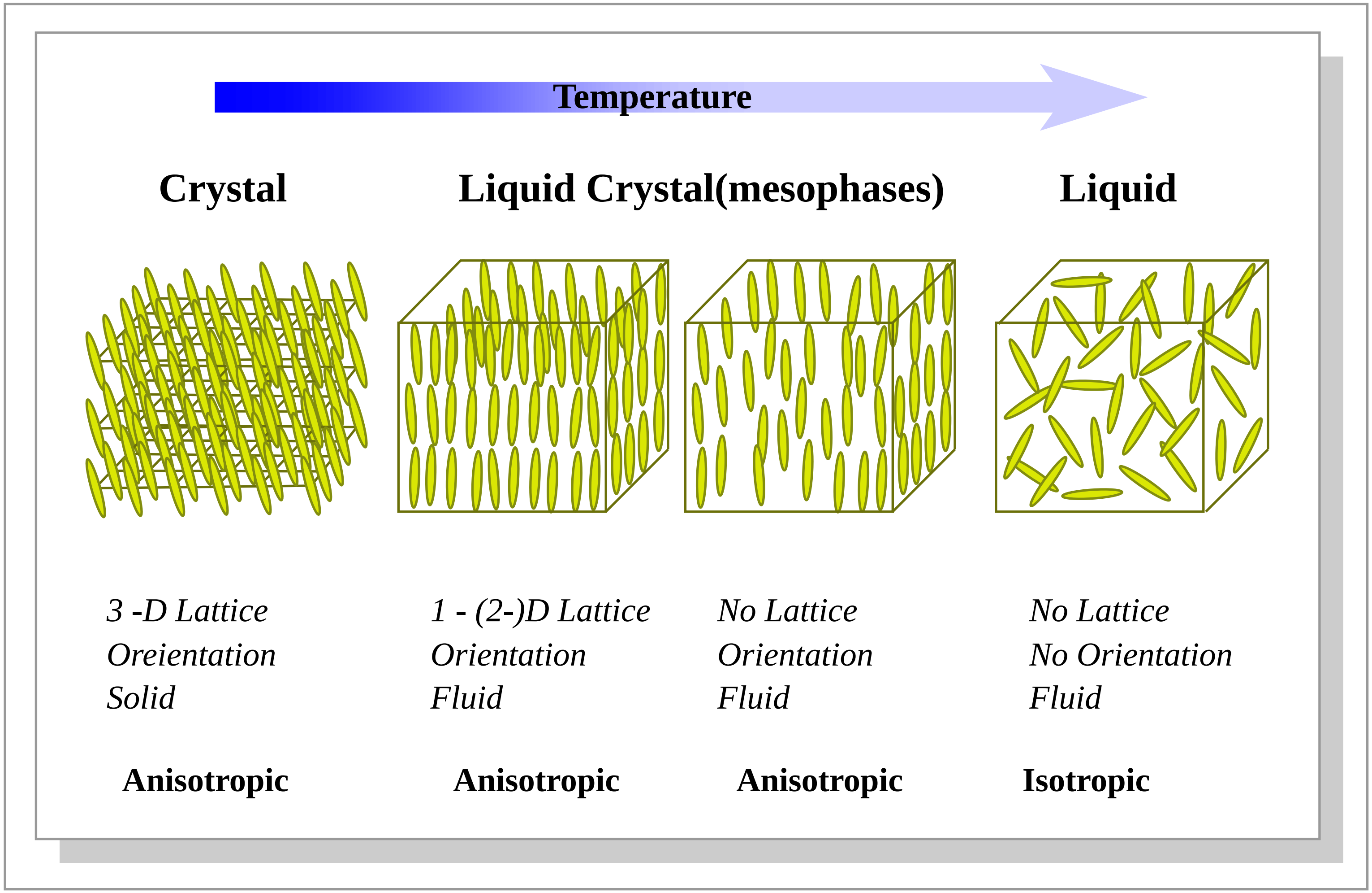
Thermotropic liquid crystal

- Hierarchy of temperature-driven phase transitions



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Lyotropic liquid crystals

- Phase transitions are mostly driven by changes in concentration

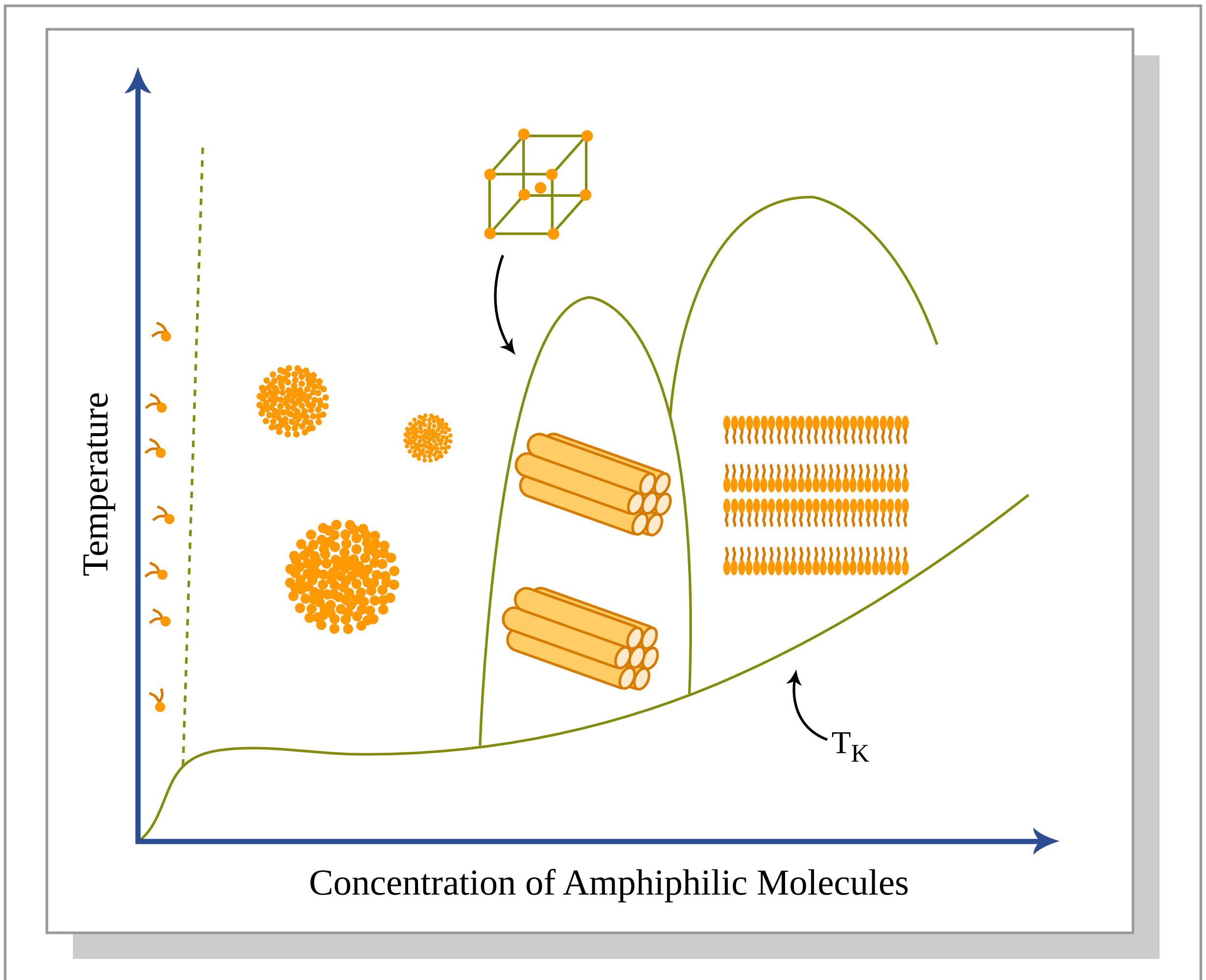
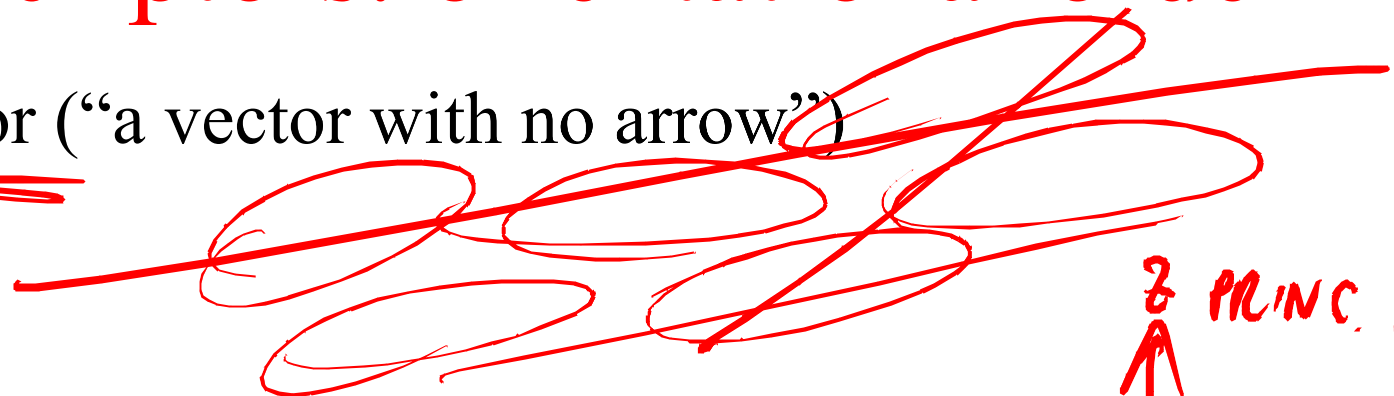


Figure by MIT OCW.

Descriptors: orientational order

- Director ("a vector with no arrow")



- Director field: P(θ,φ)

- Scalar orientational order parameter:

ENSEMBLE AVERAGES

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

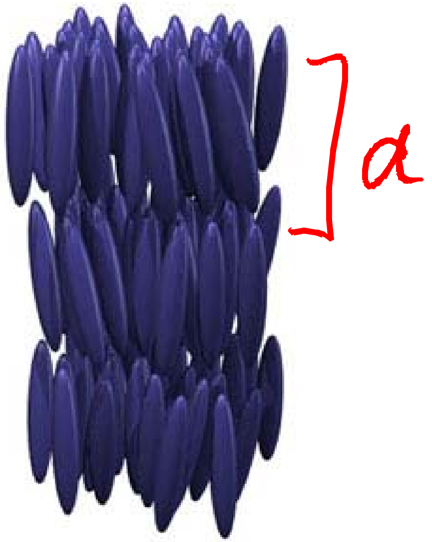
= 1 PERFECT ORDER

= 0

$$\frac{\int_0^{\pi} d\vartheta \int_0^{2\pi} d\varphi \cos^2\vartheta \sin\vartheta}{\int d\vartheta \int d\varphi \sin\vartheta}$$

Descriptors: translational order

$$\Sigma_{SM} = \left\langle \cos\frac{2\pi z}{a} \right\rangle = \frac{\int_{-a/2}^{a/2} \cos\frac{2\pi z}{a} P(z)\,dz}{\int_{-a/2}^{a/2} \cos\frac{2\pi z}{a}\,dz}$$



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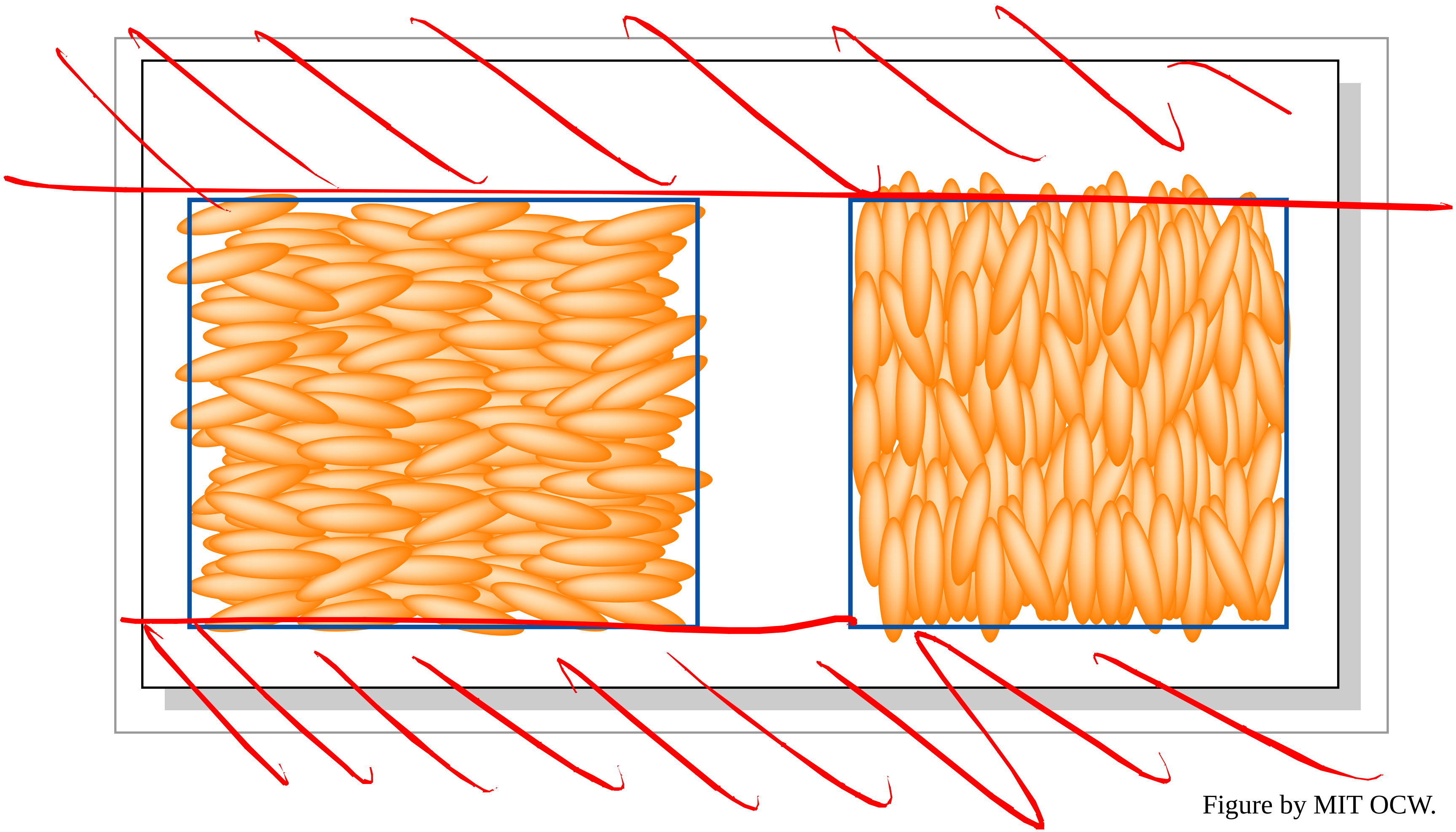
Graph removed for copyright reasons. See: p. 231, Figure 4.15 in Allen, S. M., and E.L. Thomas. *The Structure of Materials*. New York, NY: J. Wiley & Sons, 1999.

Homogeneous vs homeotropic

- Surface boundary conditions



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Homogeneous vs homeotropic

- Surface boundary conditions

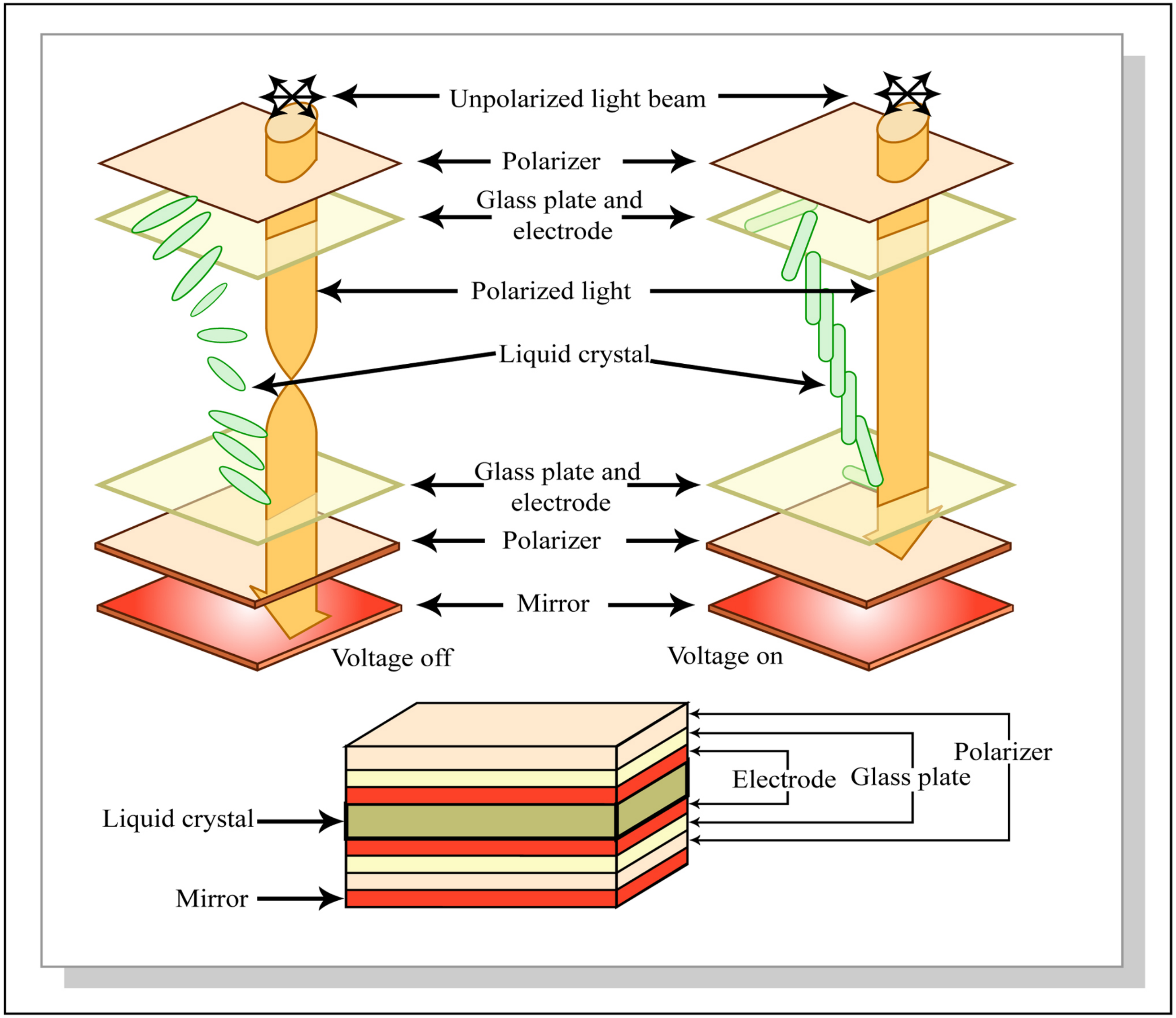
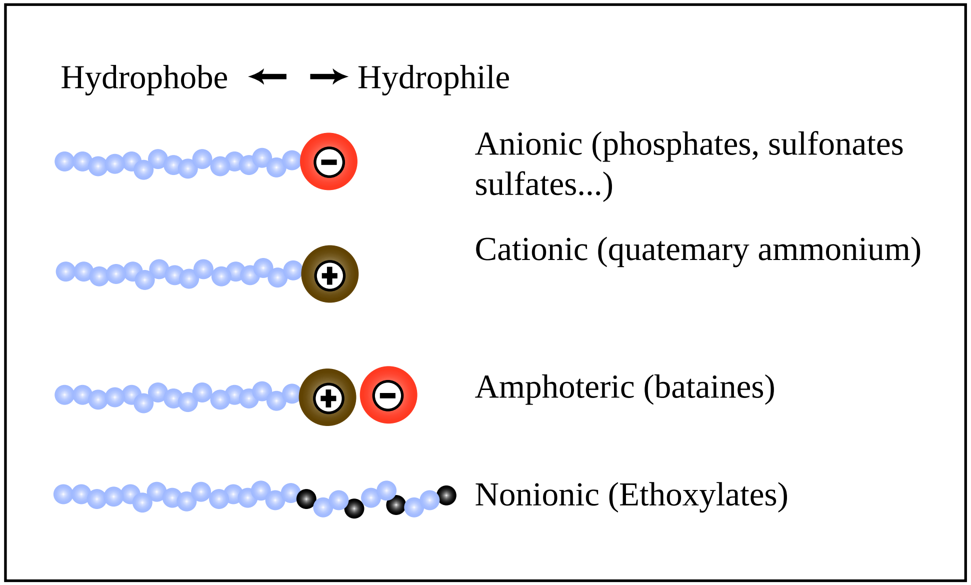


Photo of an LCD removed for copyright reasons.

Figure by MIT OCW.

Amphiphilic mesogens

- Last (5th) class of mesogens: amphiphilic molecules (they self-assemble in micelles, columns, layers, and higher-order structures that then form mesophases).



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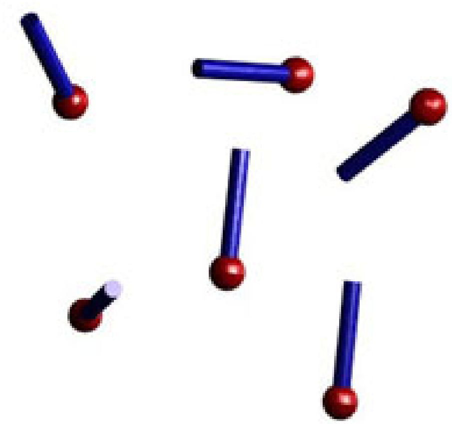

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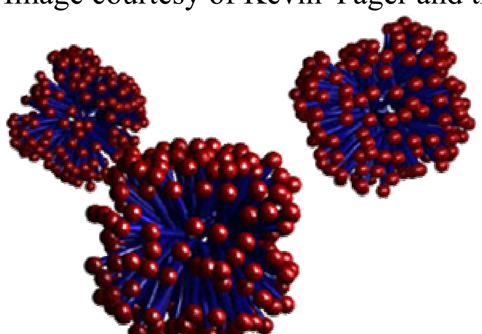
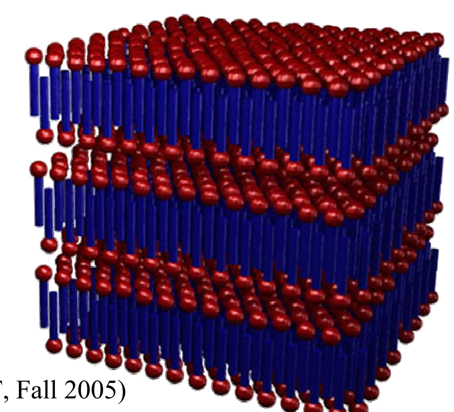
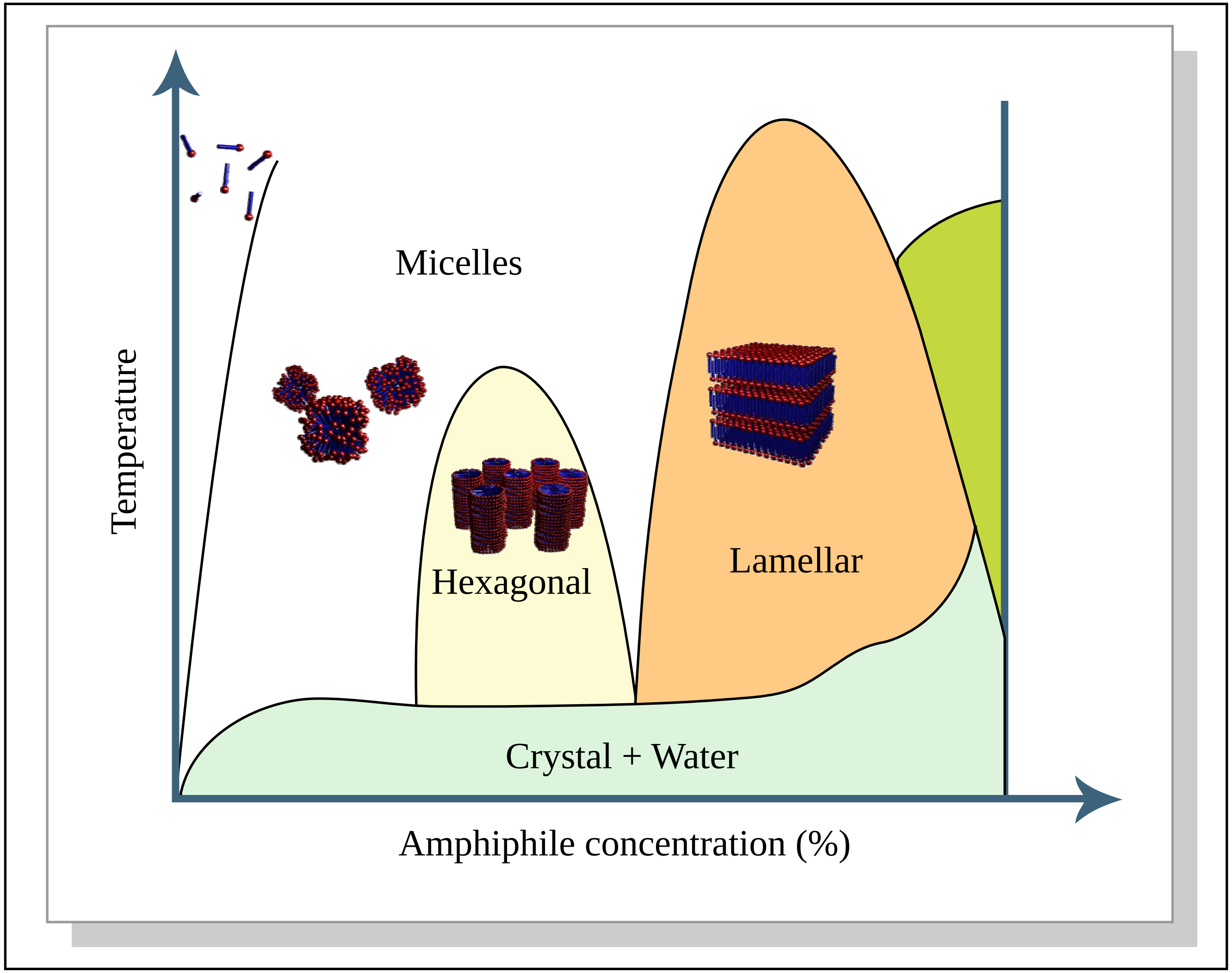




Lyotropic phase diagram



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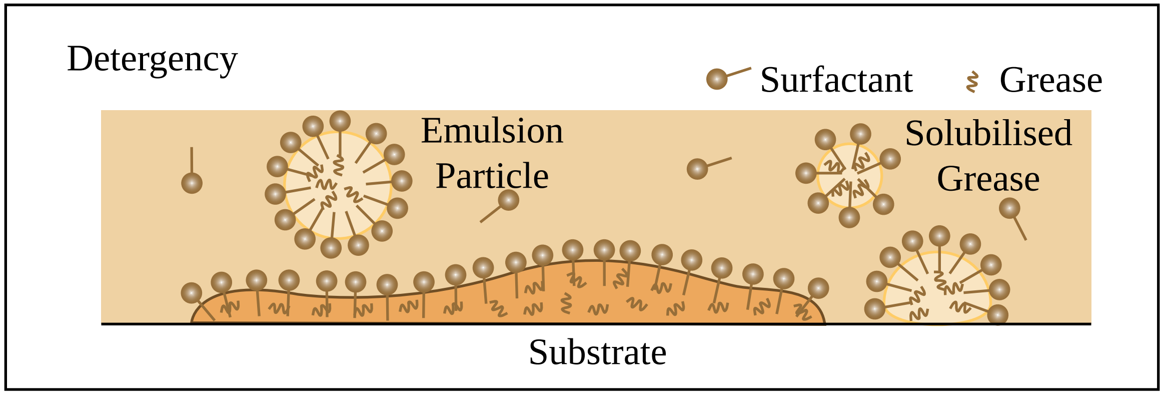
Surfactants and phospholipids



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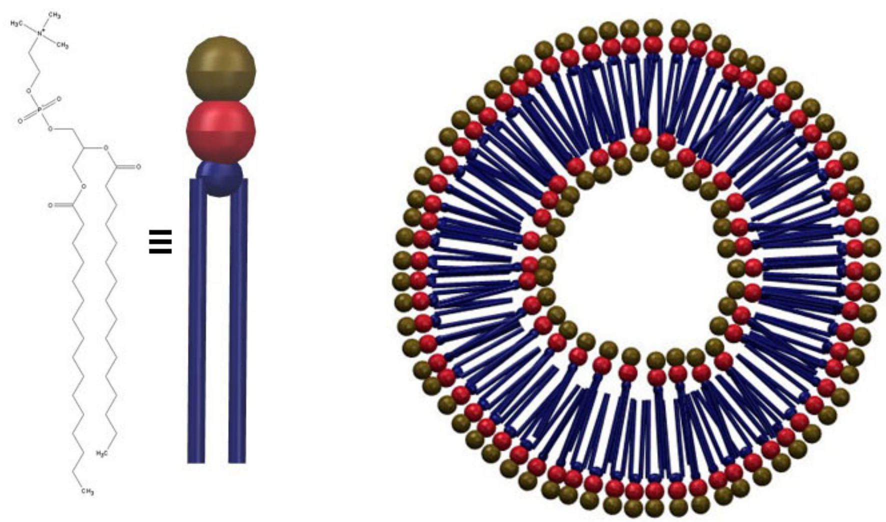

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