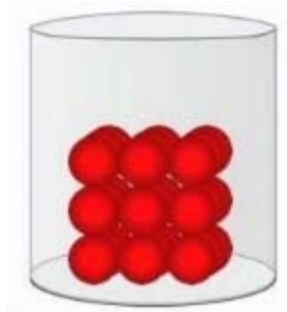
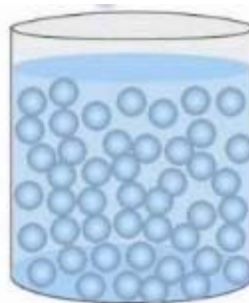


Gases, liquids, liquid crystals and solids

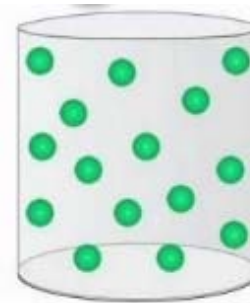
Erika Balog



Solid (crystals)



Liquid



Gas

long-range order

rigid

fixed shape

fixed volume

short-range order

not rigid

no fixed shape

fixed volume

no order

not rigid

no fixed shape

no fixed volume

Gases (rep.)

The ideal gas

- Particles are **point-like**, their volume is negligible.
- There is **no interaction** between the particles.
- State equation:

$$pV = Nk_B T$$

The real gas

- Particles are **not point-like**, their volume (b) is not negligible.

$$V - Nb$$

- **Interactions** (a) arise between the particles.

$$p = \frac{Nk_B T}{V - Nb} - a \frac{N^2}{V^2}$$

- Van der Waals state equation:

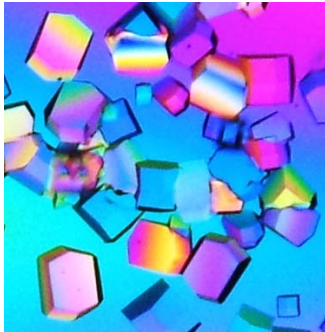
$$\left(p + a \frac{N^2}{V^2} \right) (V - Nb) = Nk_B T$$

P = pressure (Pa)
 V = volume (m^3)
 T = absolute temperature (K)
 N = number of particles
 k_B = Boltzmann's constant

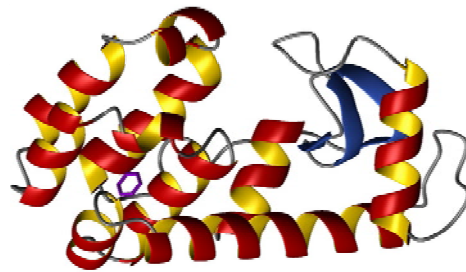
Solids

A. Crystalline materials

- Periodic long-range order
- Lattice - elementary cell (in nature 14 different, “Bravais-lattices”)
- According to the nature of interactions (bonds) of the structural elements:
 - covalent bond: atomic lattice (Si)
 - ionic bond: ionic lattice (NaCl)
 - metallic bond: metal lattice (positive ions)
 - secondary bonds: molecular lattice (molecules eg. lysozyme)



Lysozyme protein crystals in polarized light (anisotropy)

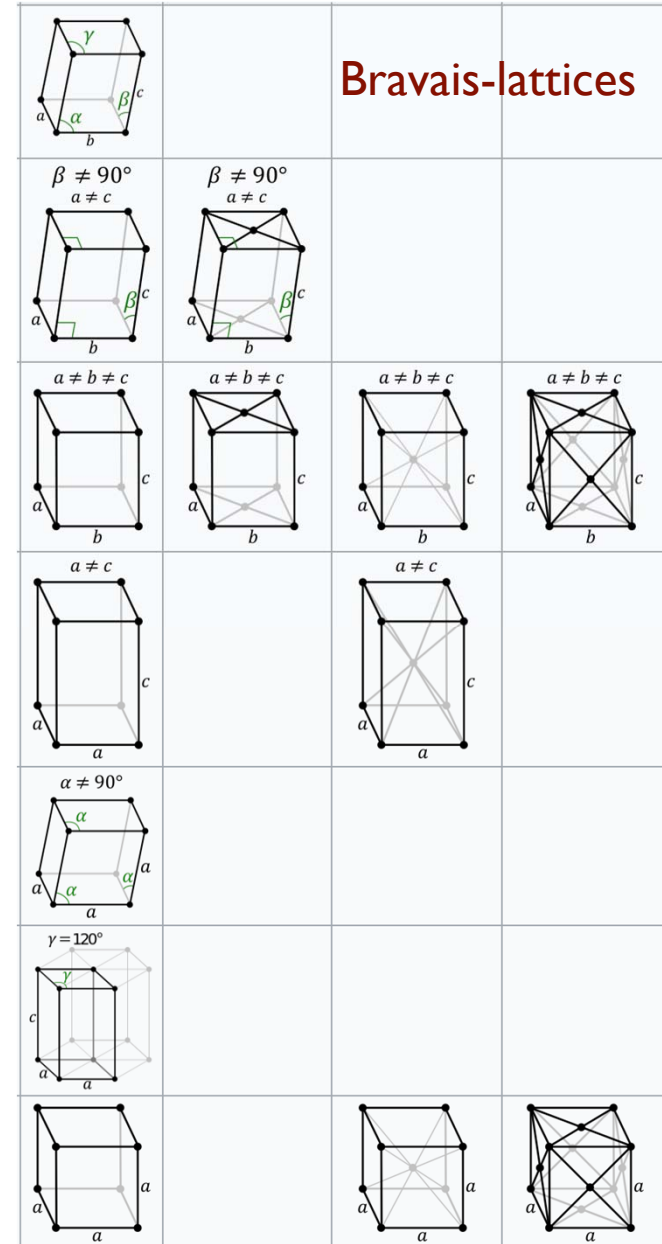


Lysozyme protein molecule

B. Amorphous materials

glass-like, viscous “fluids”

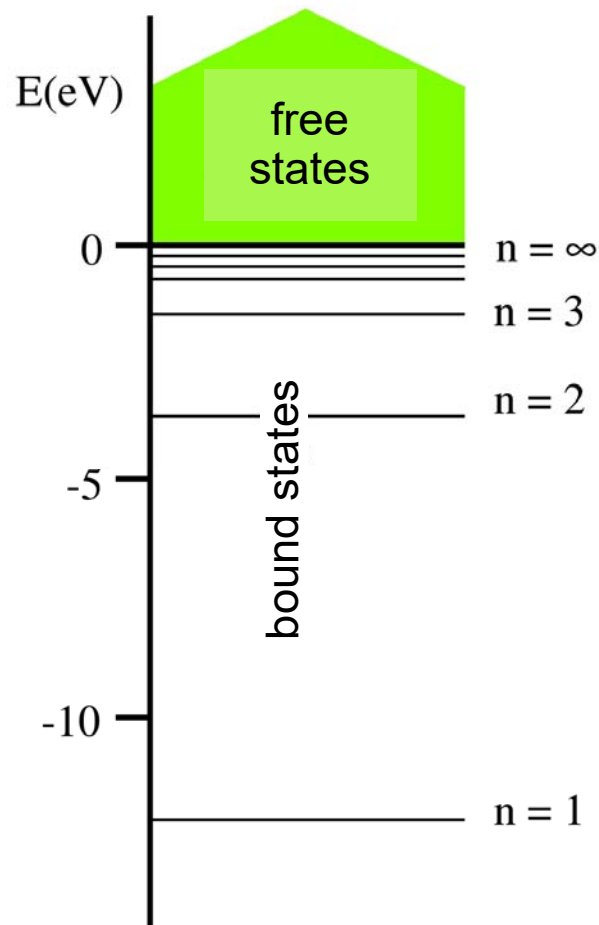
Bravais-lattices



Energy levels in crystals

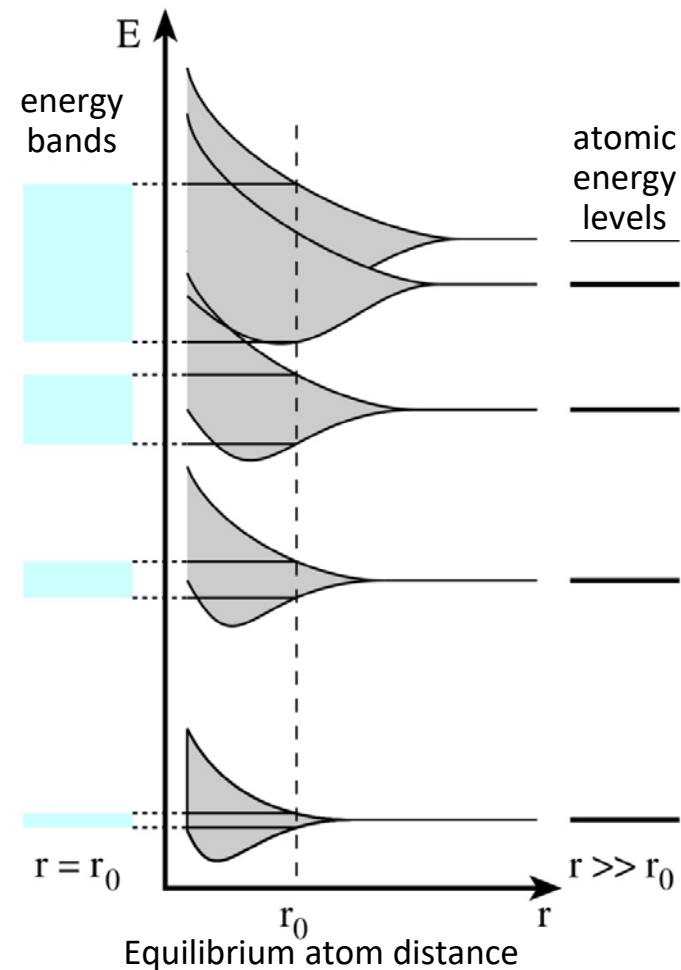
Isolated hydrogen atom

- No interaction with other atoms
- Discrete (quantized) energy levels
- Pauli's principle: there can not be two electrons bound to the same atom with all 4 quantum numbers being identical

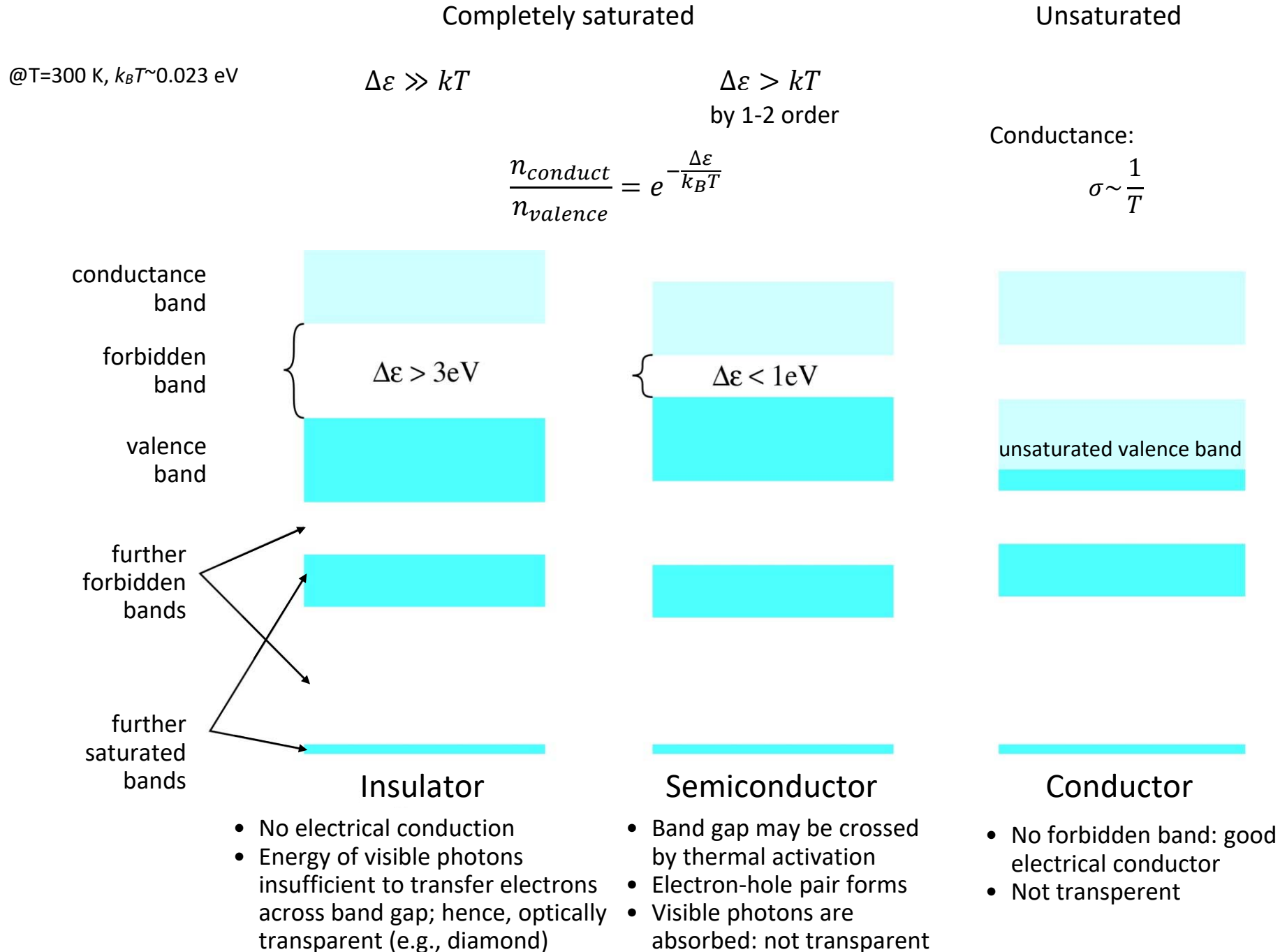


Crystal

- Atoms interact
- consequence of Pauli's principle: in order to avoid identical quantum states, the discrete atomic energy levels of interacting atoms split, forming: **energy bands**
- Nearby levels merge into **energy bands**



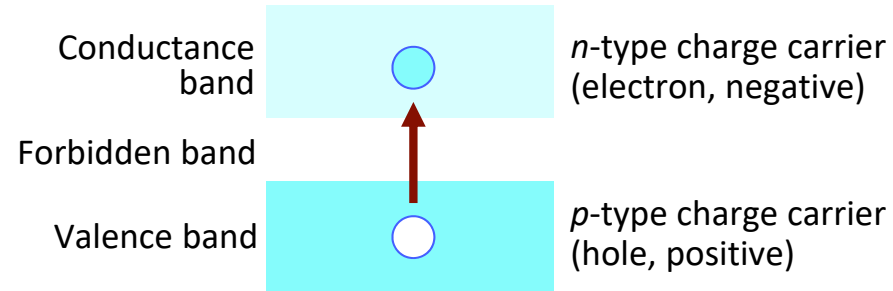
Solids with different band structure



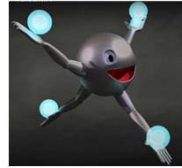
Semiconductors

A. Pure semiconductors

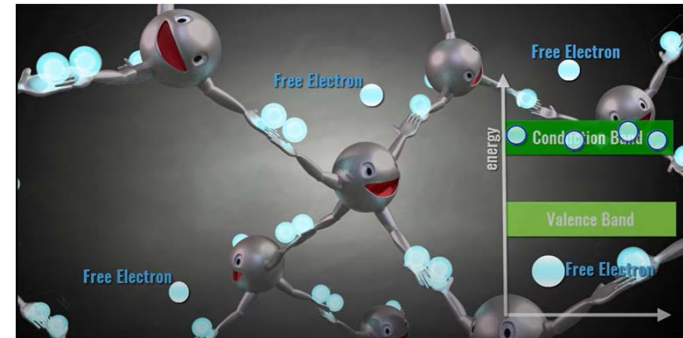
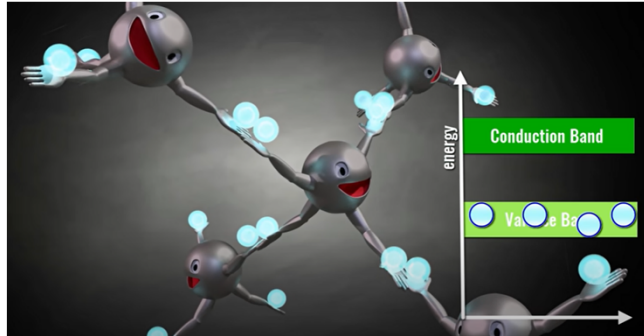
- Two types of charge carriers (n , p):



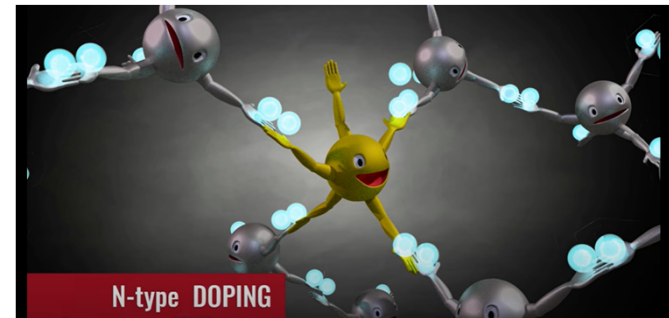
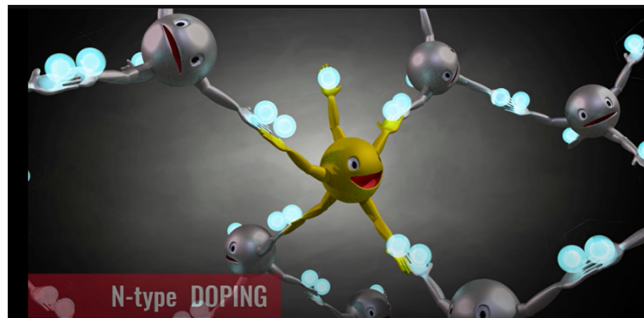
- Electrical conductance is temperature-dependent: $\sigma = konst \cdot e^{-\frac{\Delta\varepsilon}{2k_B T}}$
- Width of forbidden band ($\Delta\varepsilon$) < 1 eV
- Crossing of forbidden band may be evoked by the absorption of visible light (1.5-3 eV):
- Forbidden band may be crossed by thermal activation $hf_{vis} > \Delta\varepsilon$
- Optically not transparent



Si



Si



Si - P

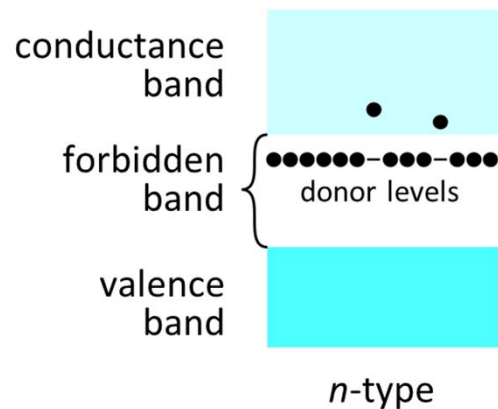
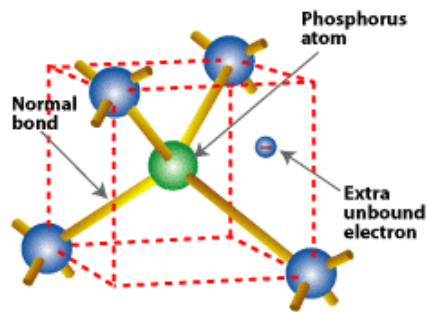
Semiconductors

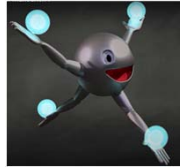
B. Doped semiconductors

Dopant: - small number of foreign atoms in between the host atoms of the lattice:
- provides a new electron state that narrows the forbidden band

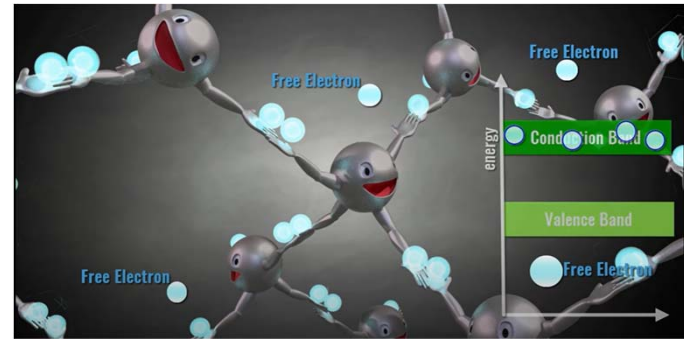
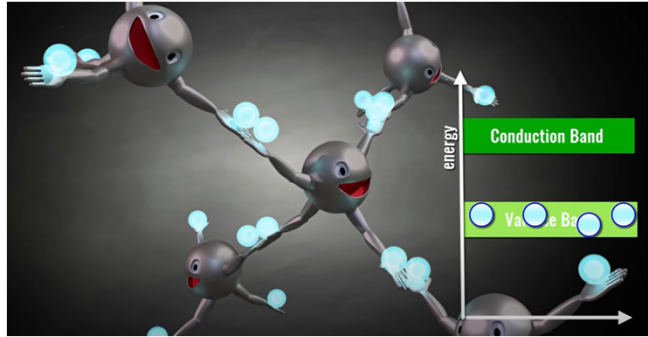
$$\frac{N_{host}}{N_{dopant}} \approx 10^6$$

n-type semiconductor (e-donor): 5-valence dopant (P, As, Bi) in a 4-valence host (Si, Ge)

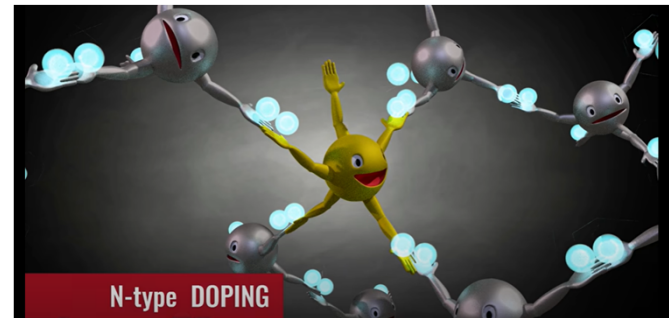
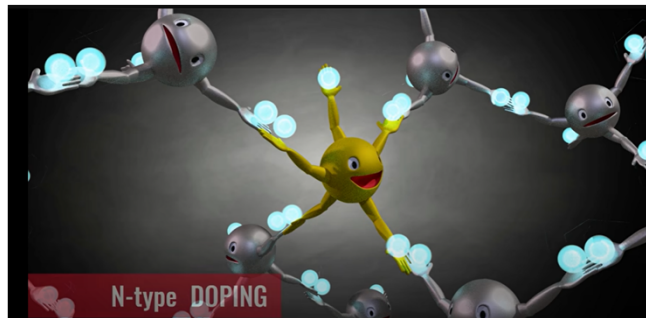




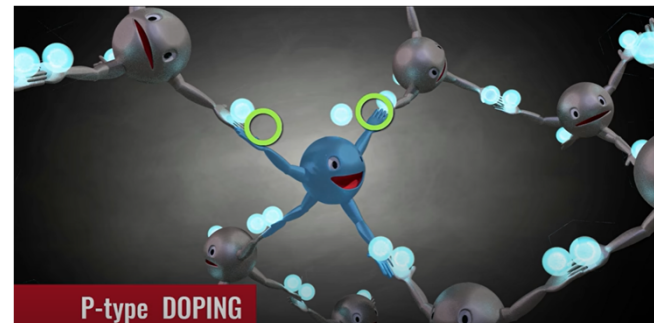
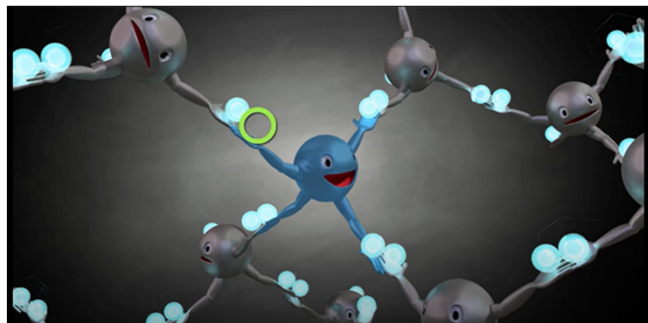
Si



Si



Si - P



Si - B

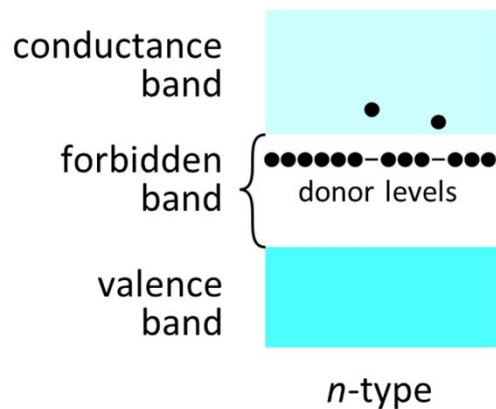
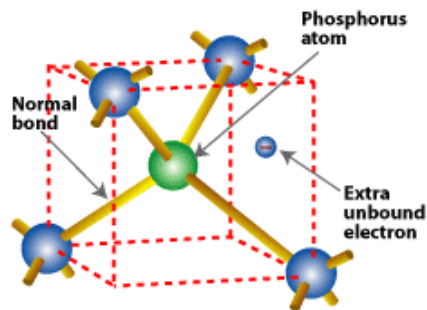
Semiconductors

B. Doped semiconductors

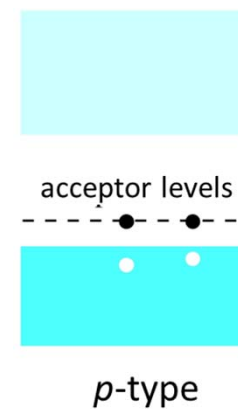
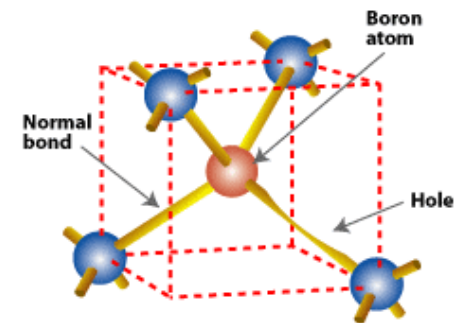
Dopant: - small number of foreign atoms in between the host atoms of the lattice:
 - provides a new e^- state that narrows the forbidden band

$$\frac{N_{host}}{N_{dopant}} \approx 10^6$$

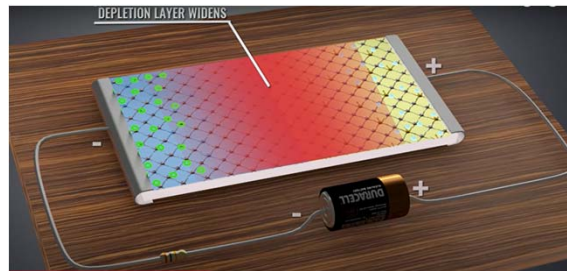
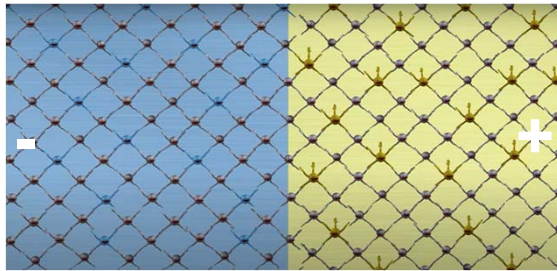
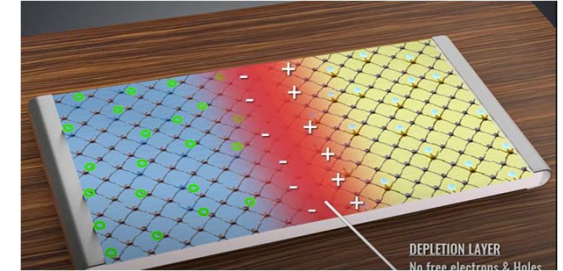
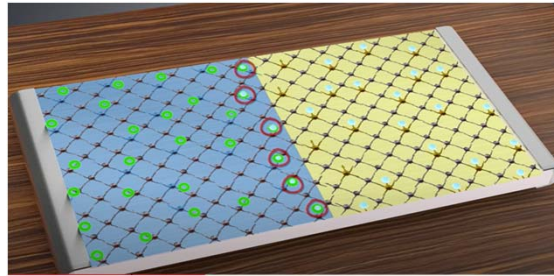
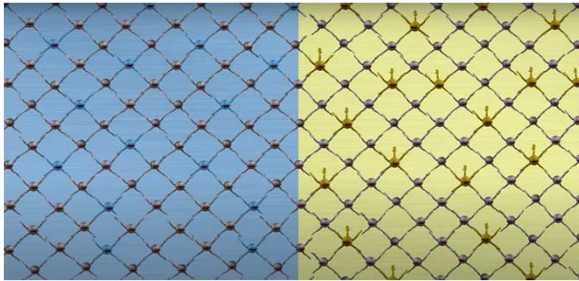
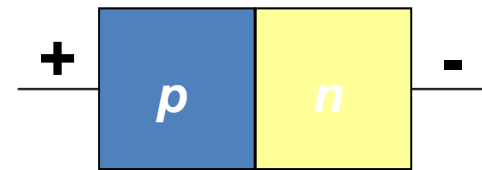
n-type semiconductor (e-donor): 5-valence dopant (P, As, Bi) in a 4-valence host (Si, Ge)



p-type semiconductor (e-acceptor): 3-valence dopant (Al, Ga, In, B) in a 4-valence host (Si, Ge)

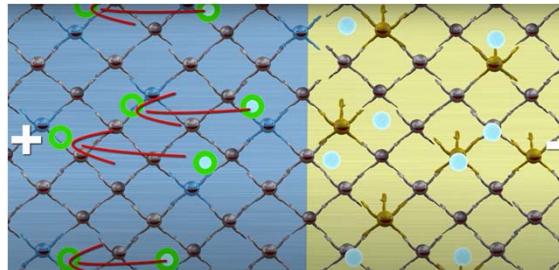
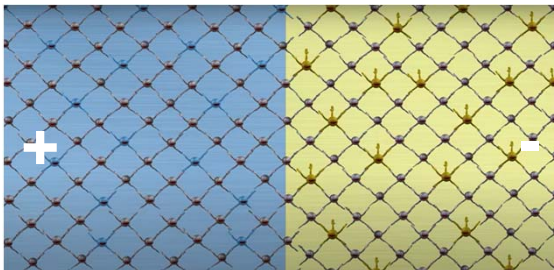


Diode - microelectronic devices constructed by adjoining doped, p - and n -type semiconductors



- reverse biasing

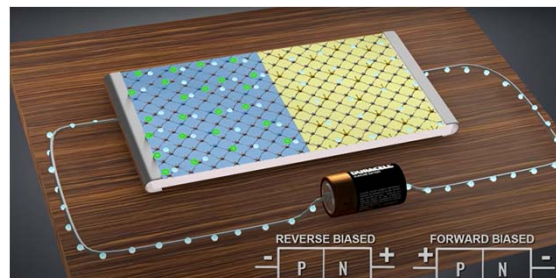
- asymmetric conductance



- forward biasing

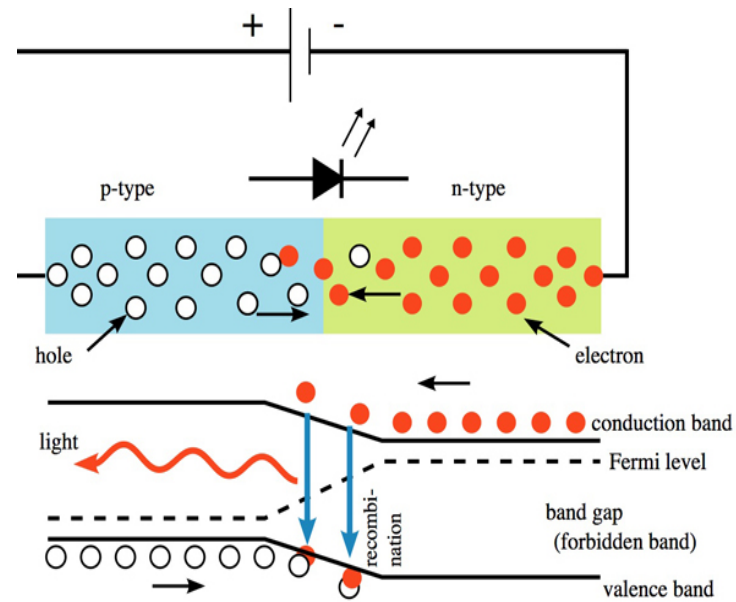
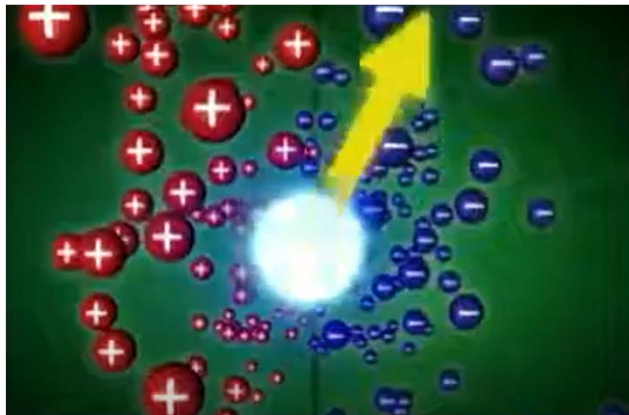
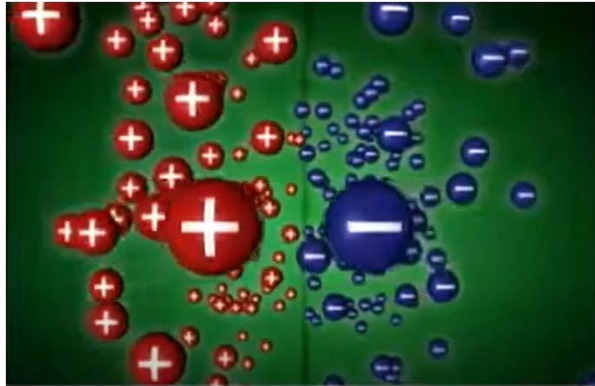
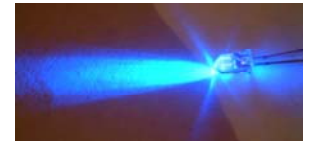
Usage:

- electrical voltage \rightarrow light emission, LED
- illumination \rightarrow voltage \rightarrow CCD pixel



<https://www.youtube.com/watch?v=7ukDKVHnac4>

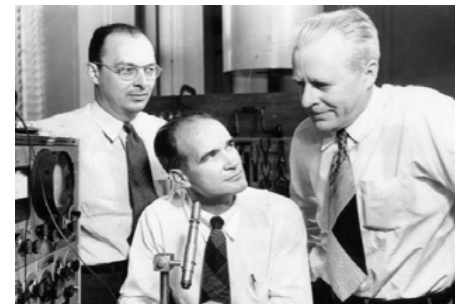
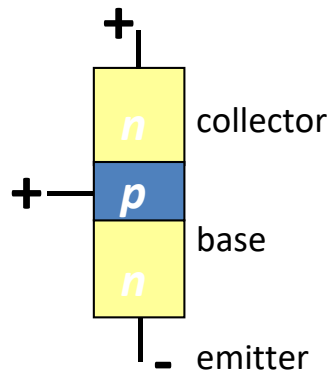
Light Emitting Diode (LED)



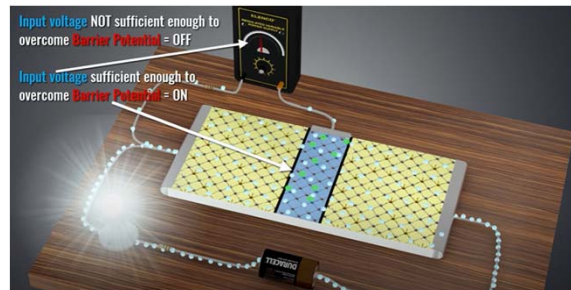
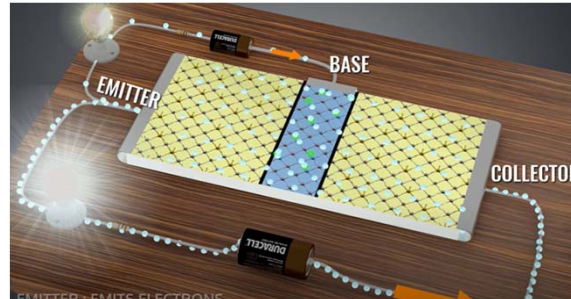
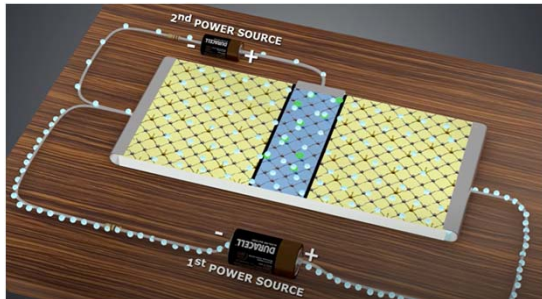
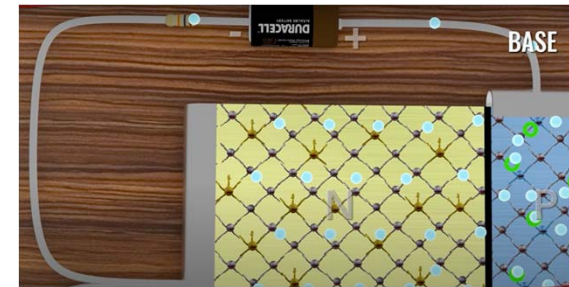
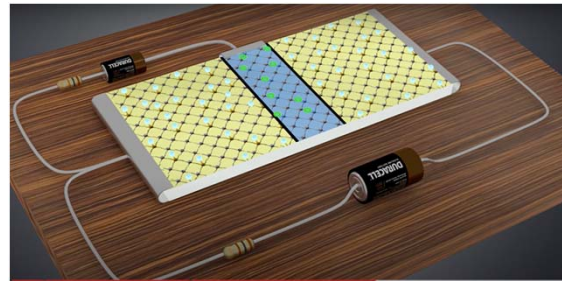
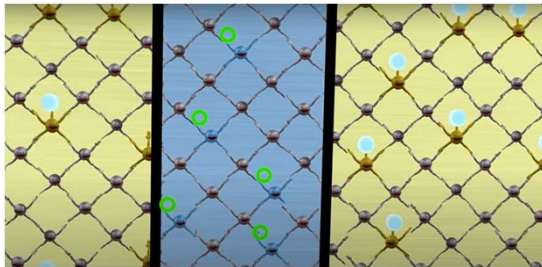
Isamu Akasaki, Shuji Nakamura, Hiroshi Amano, Nobel-prize 2014

Transistor

Smart phone processor:



John Bardeen, William Shockley, Walter Brattain,
Nobel-prize 1956



Usage

- amplifier
- elements of digital memory
- counters, multivibrators

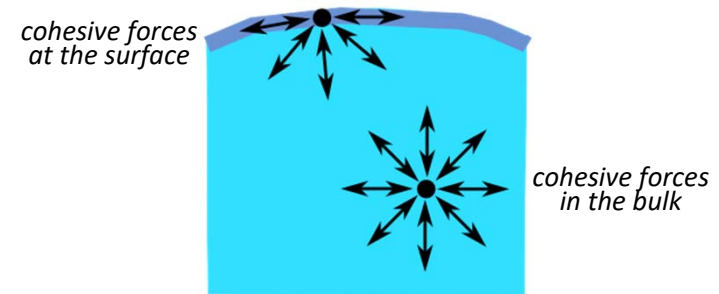
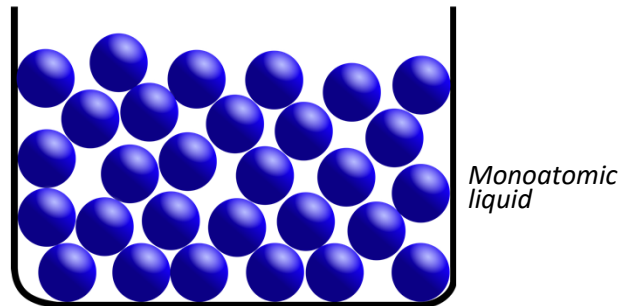
<https://www.youtube.com/watch?v=7ukDKVHnac4>

Liquids

- Incompressible: retains nearly constant volume independent of pressure.
- Density similar to that of the solid (“consensed matter”).
- Flows: displays fluid behavior (as gases and plasma); conforms to the shape of the container; internal friction (“viscosity”, η) decreases with temperature:

$$\eta \sim e^{-\frac{E}{k_B T}}$$

Viscosity decreases with increase in the relative concentration of vacancies.



- Microscopically: composed of particles (atoms, molecules) held together by short-range cohesive forces (no long-range order)
- Imbalance of cohesive forces (between bulk *versus* surface) results in surface tension (tendency to contract into spherical shape)

Liquid crystals

Review

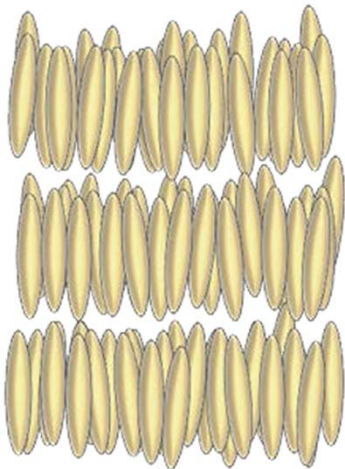
Physics of liquid crystals in cell biology

Amin Doostmohammadi^{1,*} and Benoit Ladoux^{2,*}

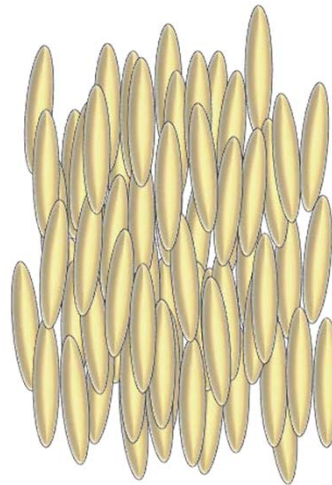
The past decade has witnessed a rapid growth in understanding of the pivotal roles of mechanical stresses and physical forces in cell biology. As a result, an integrated view of cell biology is evolving, where genetic and molecular features are scrutinised hand in hand with physical and mechanical characteristics of cells. Physics of liquid crystals has emerged as a burgeoning new frontier in cell biology over the past few years, fuelled by an increasing identification of

Highlights
Various forms of liquid crystalline order, including nematic, smectic, and chiral features, have been established in cytoskeletal constructs *in vitro* and in subcellular filaments *in vivo*.

- Display both liquidlike and solidlike behavior: flow (weak intermolecular interactions), long-range order.
- Molecules are not spherically symmetric: calamitic (rod-like), discotic (disc-like)
- Order type: translational, rotational



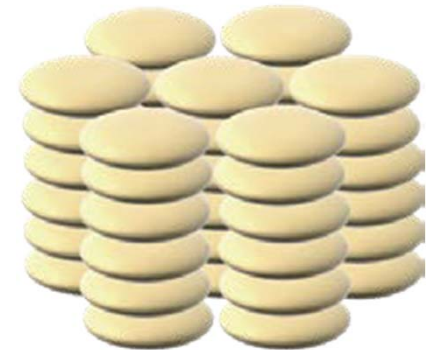
Smectic phase (orientational and translational order)



Nematic phase (only orientational order, but no translational order)



Cholesteric phase (nematic order in different planes; special case: twisted nematic phase - pitch affects color)



Discotic phase (disc-shaped molecules, translational order)

Liquid crystals

Thermotropic

(order depends on temperature)

- Color changes with temperature (thermo-optical properties) – cholesteric liq. cryst; application: contact thermography
- If molecules are electrical dipoles, polarization, transmittance changes with electrical field (electro-optical properties) – nematic liq. cryst; application: LCD displays, etc.



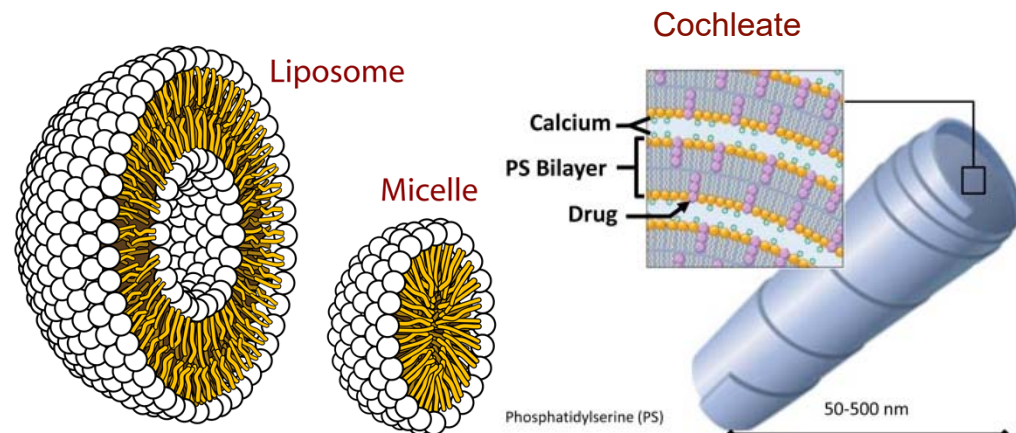
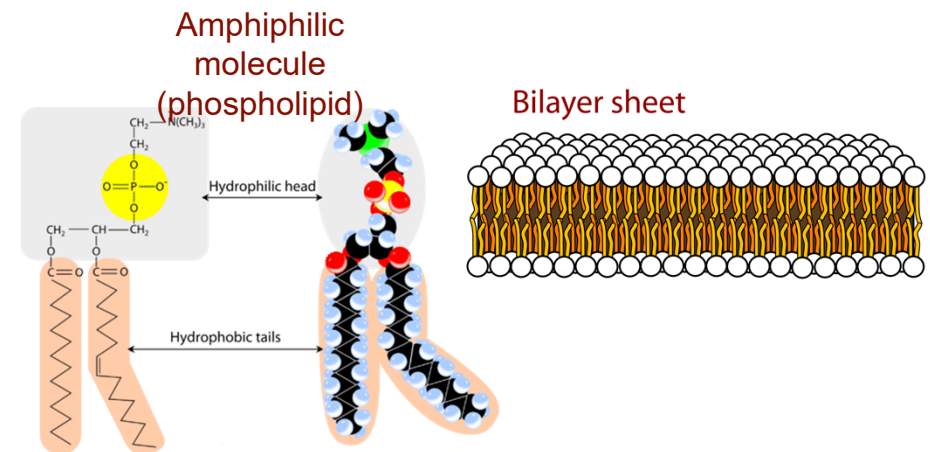
Contact thermography



LCD display

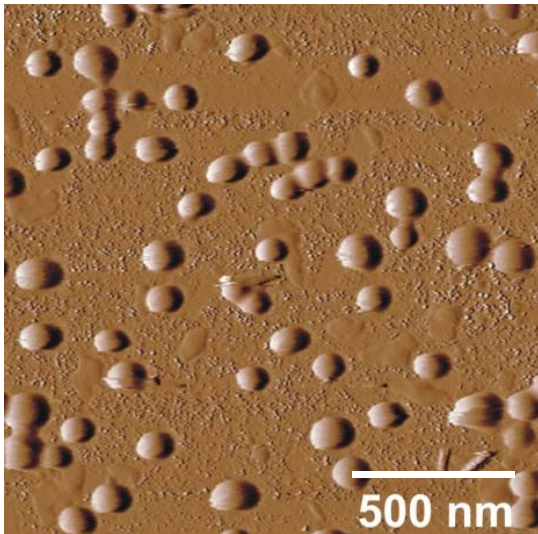
Lyotropic

(order depends on concentration of the components)

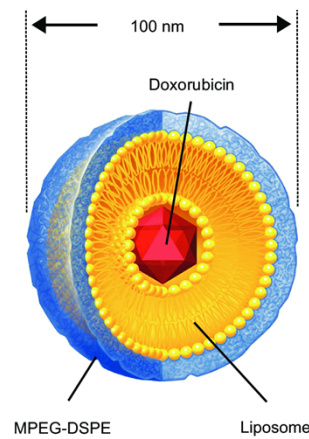


Liposome applications

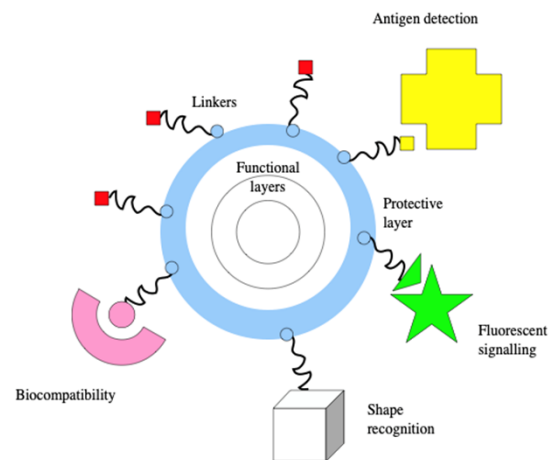
AFM image of liposomes on substrate surface



Liposome as carrier of toxic drug



“Intelligent” liposome



Teranostics
(therapy + diagnostics)

