Crystalline materials

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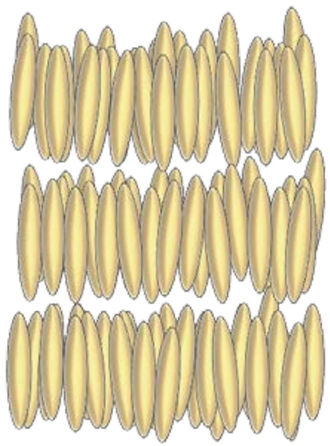
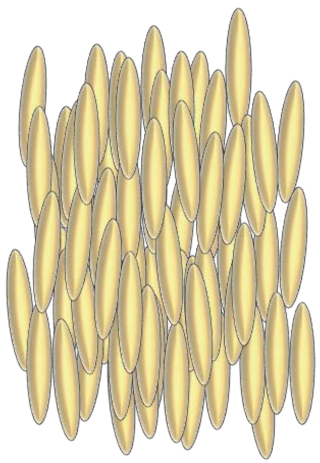
Liquid crystals

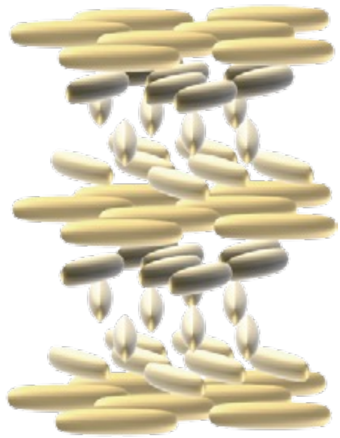
- Display both liquidlike and solidlike behavior:
  they flow (weak intermolecular interactions), and they display long-range order.
- Molecules are not spherically symmetric: calamitic (rod-like), discotic (disc-like)
- Order type: translational, rotational (orientational)



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

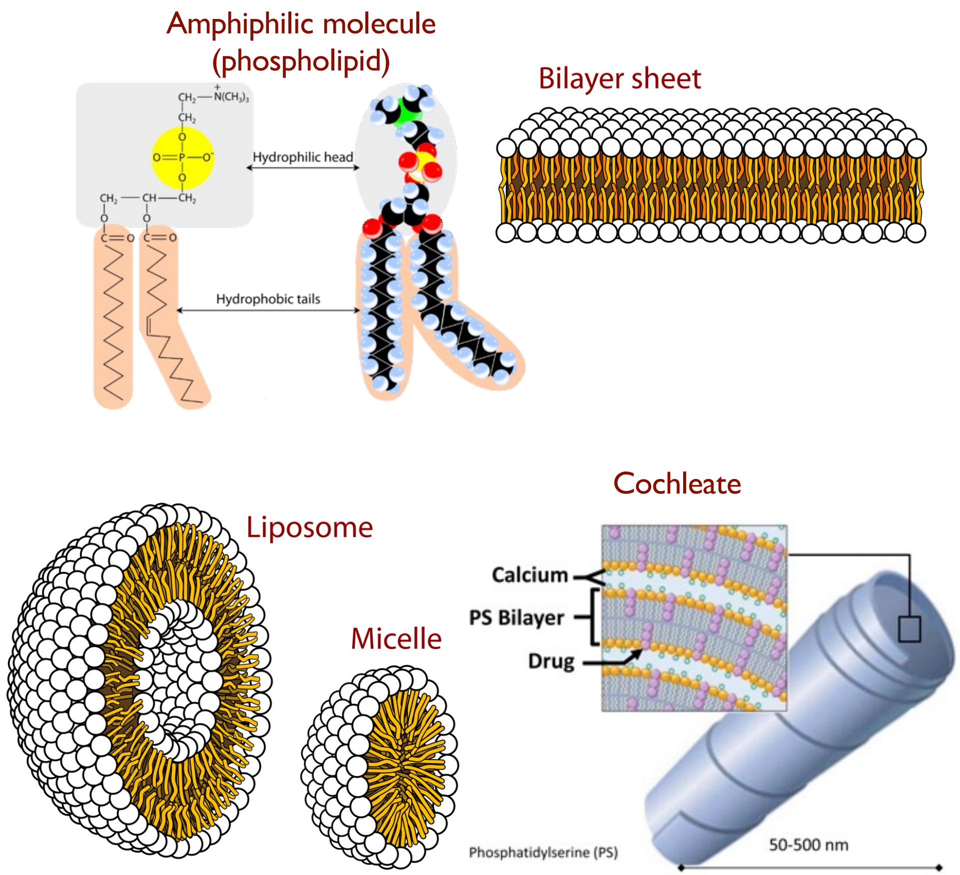
Thermotropic

(order depends on temperature)

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

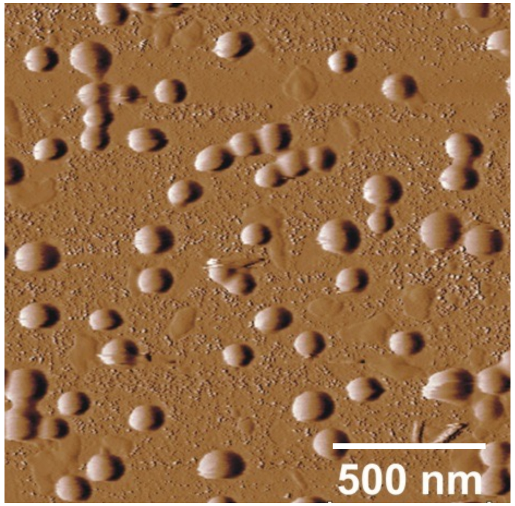
Lyotropic

(order depends on concentration)

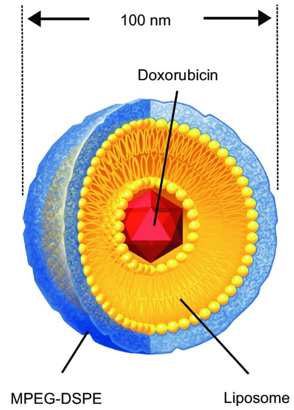


Liposome applications

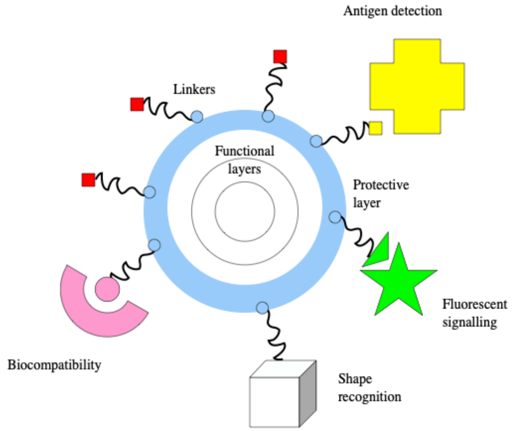
AFM image of liposomes on substrate surface



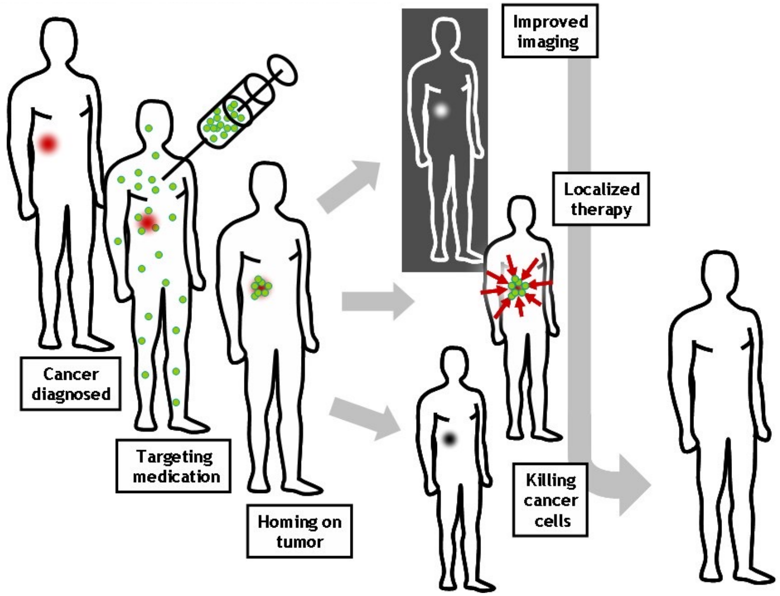
Liposome as carrier of toxic drug



"Intelligent" liposome

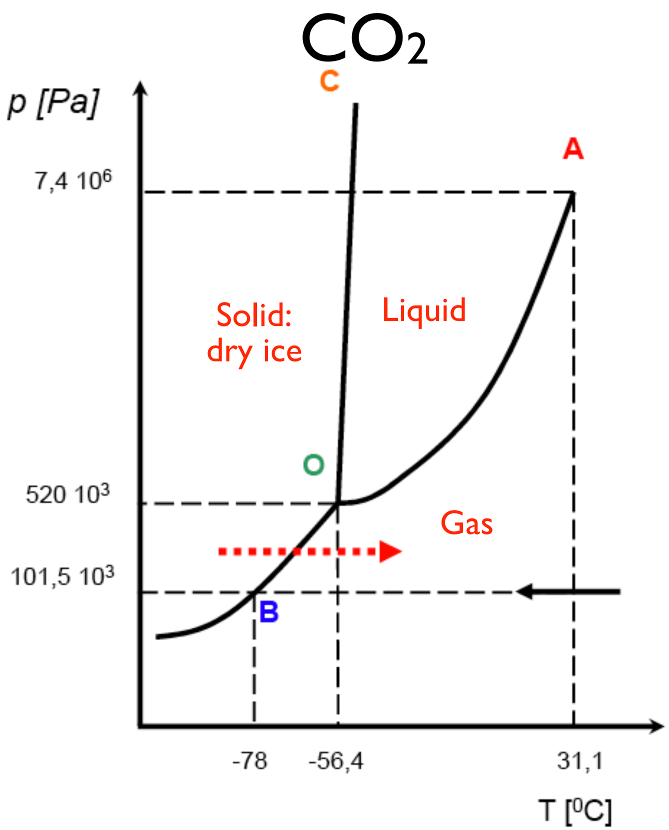


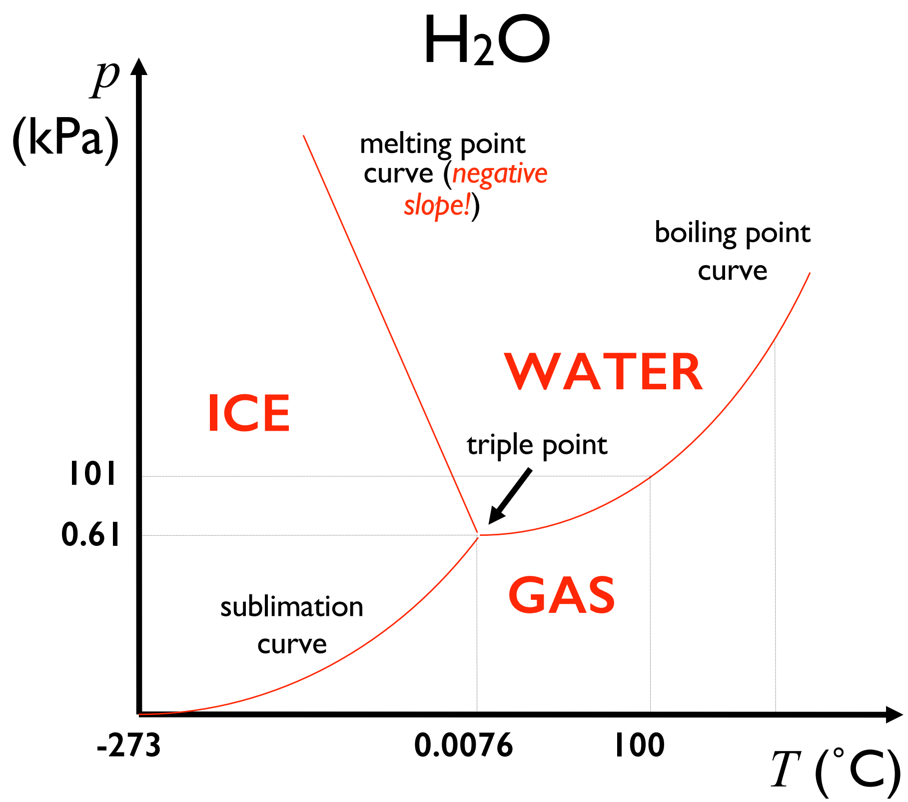
Teranostics
(therapy + diagnostics)



Phase, phase transition

- Phases: regions of the material with identical chemical, but different physical properties
- Phase diagram: plot displaying the nature of phases as a function of thermodynamic variables (pressure, temperature)
- Phase curve: two phases are in equilibrium
- Area between phase curves: a single phase is present
- Intersection of phase curves: triple point

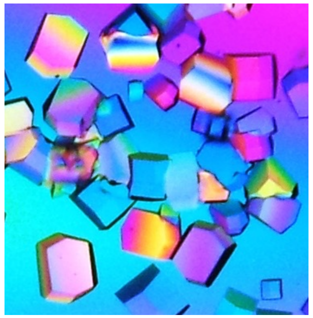




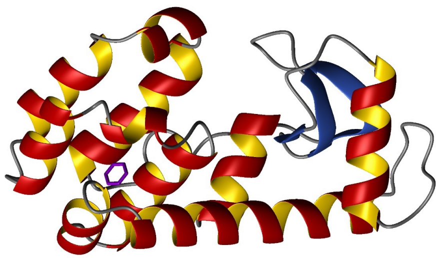
Solids

A. Crystalline materials

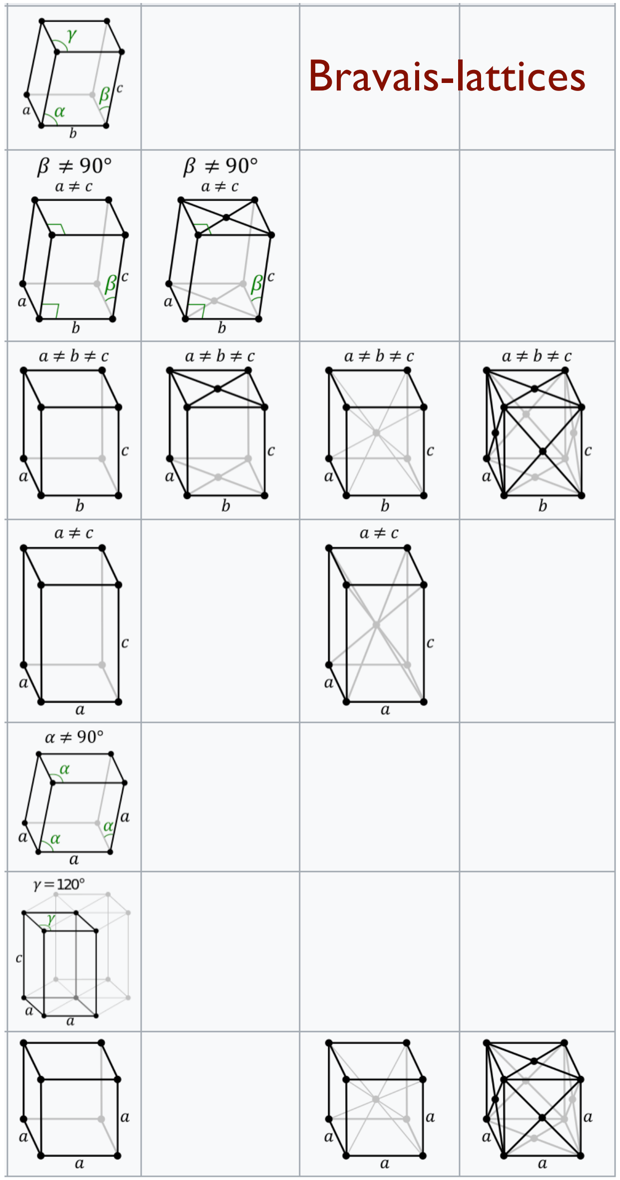
- Periodic long-range order
- Lattice - elementary cell (in nature 14 different, “Bravais-lattices”)
- According to the nature of interactions (bonds)
  -covalent bond: atomic lattice
  -ionic bond: ionic lattice
  -metallic bond: metal lattice
  -secondary bonds: molecular lattice



Lysozyme protein crystals in polarized light (anisotropy)



Lysozyme protein molecule



B. Amorphous materials

glass-like, viscous “fluids”

Amorphous materials

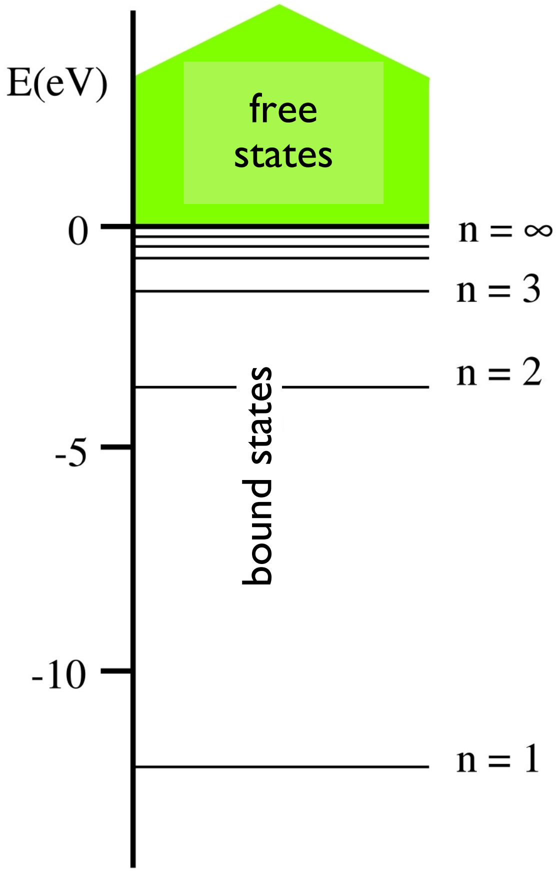
University of Queensland pitch drop experiment: 9 drops since 1927

http://www.thetenthwatch.com/feed/

Energy levels in crystals

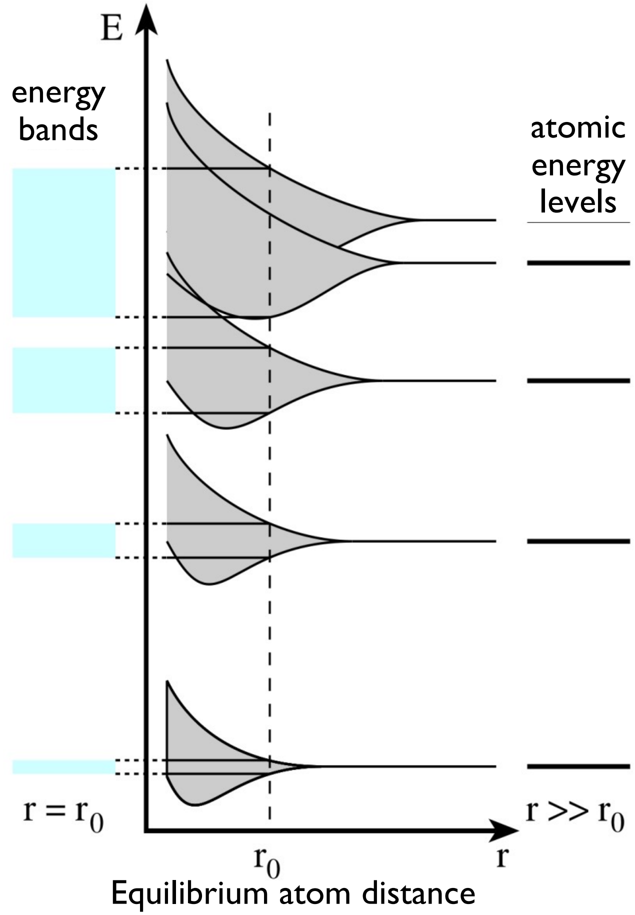
Isolated hydrogen atom

- No interaction with other atoms
- Discrete (quantized) energy levels
- Pauli's principle



Crystal

- Atoms interact
- Pauli's principle: electron energy levels of interacting atoms split
- Nearby levels merge into energy bands

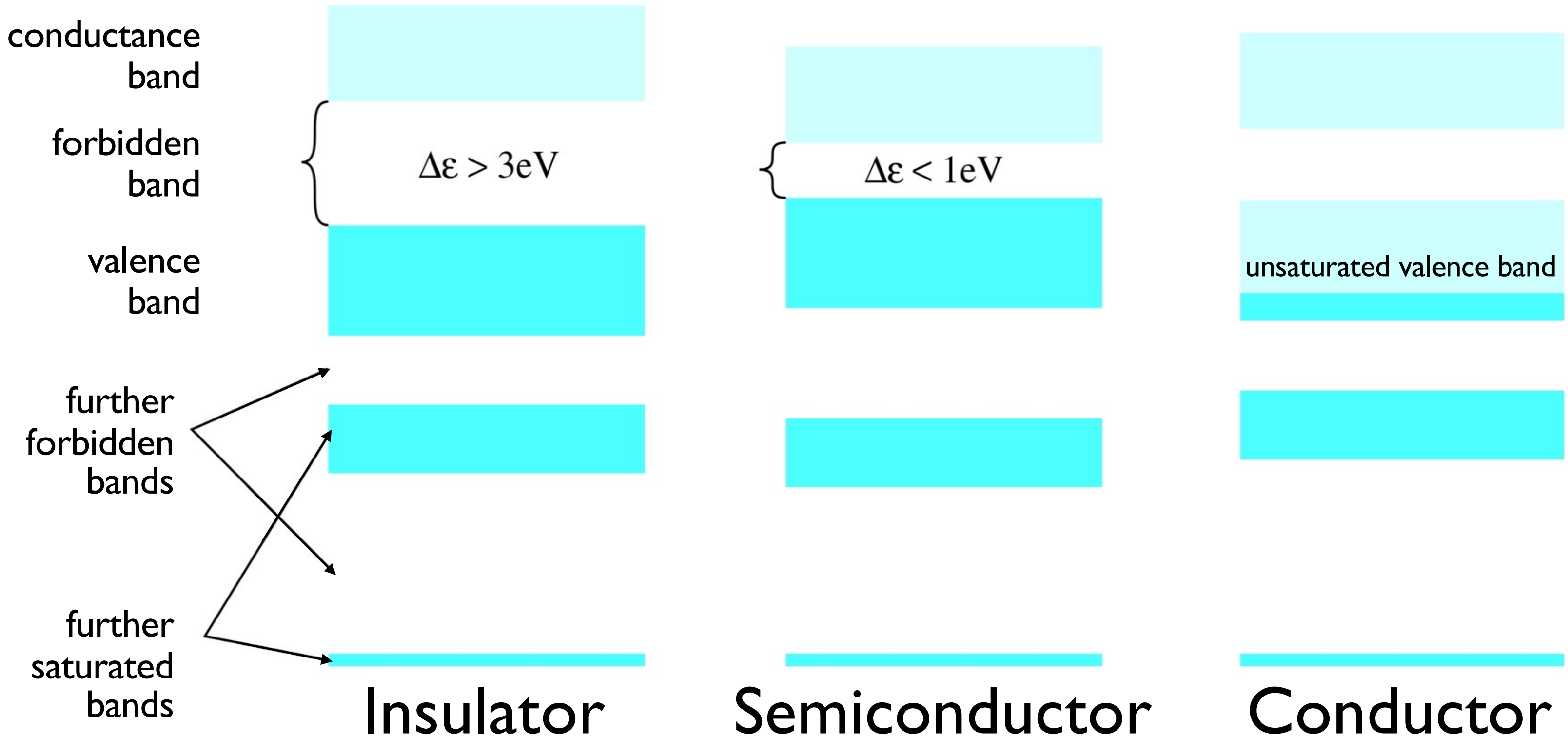


Solids with different band structure

The probability of electrons entering the conductance band from the valence band is determined by the width of the forbidden band (“band gap”, $\Delta\varepsilon$) relative to thermal energy ($k_B T$), based on the Boltzmann distribution:

$$\frac{n_{conduct}}{n_{valence}} = e^{-\frac{\Delta\varepsilon}{k_B T}}$$

@T=300 K, $k_B T$~0.023 eV



Insulator

- No electrical conduction
- Energy of visible photons insufficient to transfer electrons across band gap; hence, optically transparent (e.g., diamond)

Semiconductor

- Band gap may be crossed by thermal activation
- Electron-hole pair forms
- Visible photons are absorbed: not transparent

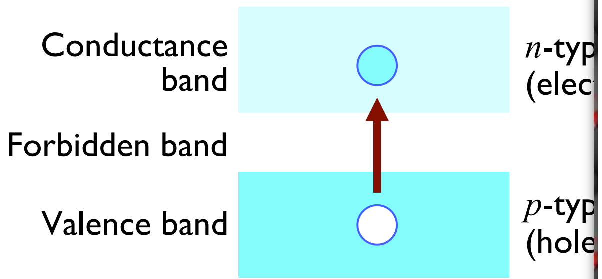
Conductor

- No forbidden band: good electrical conductor
- Not transparent
- Conductance: $\sigma \approx \frac{1}{T}$

Semiconductors

A. Pure semiconductors

- Forbidden band ($\Delta\varepsilon$) may be crossed by thermal activation
- Width of forbidden band <
- Two types of charge carrier



- Electrical conductance is te dependent:

$$\sigma = const \cdot e^{-\frac{\Delta}{2k}}$$

- Crossing of forbidden band may be evoked by the absorption of visible light (1.5-3 eV):

$$hf_{vis} > \Delta\varepsilon$$

- Optically not transparent

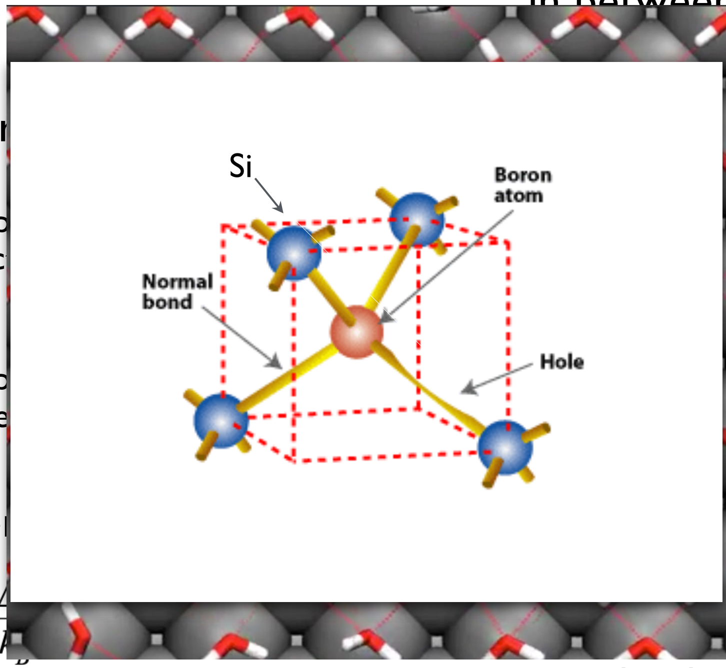
B. Doped semiconductors

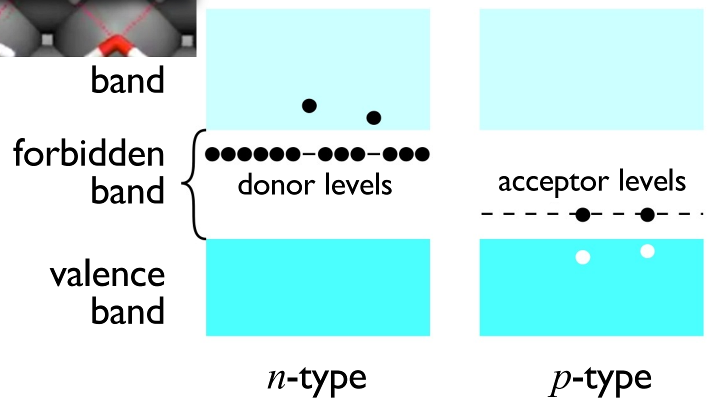
- Dopant: small number of foreign atoms in between the host atoms of the lattice:

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

dopant (P, As, Bi) in a 4-
st (Si, Ge): *e*-donor, *n*-type

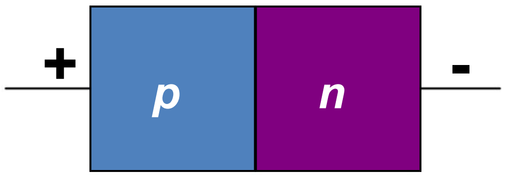
dopant (Al, Ga, In, B) in a 4-
st (Si, Ge): *e*-acceptor, *p*-type





Semiconductor diode and transistor

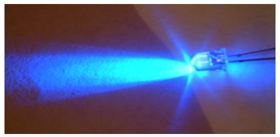
Microelectronic devices constructed by adjoining doped, *p*- and *n*-type semiconductors

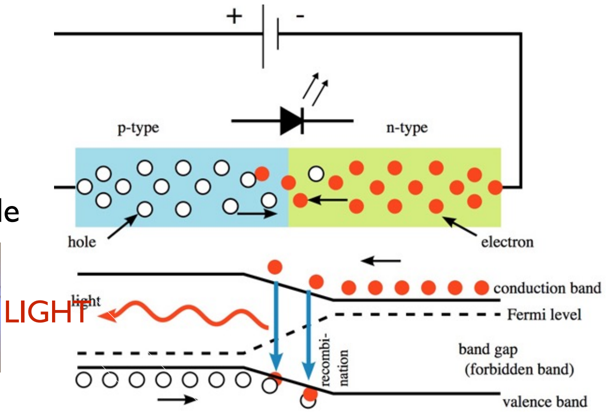


Diode

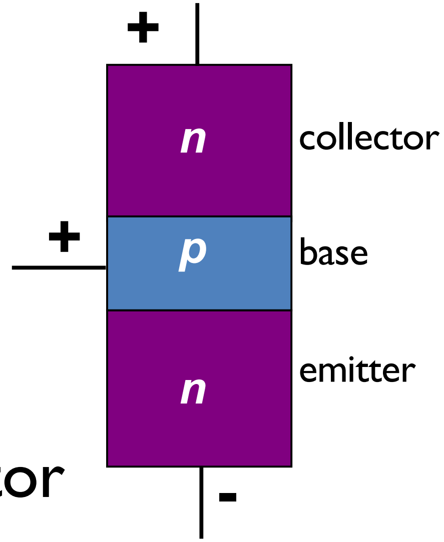
- asymmetric conductance
- electrical voltage → light emission, LED
- illumination → voltage → CCD pixel

LED:
Light Emitting Diode



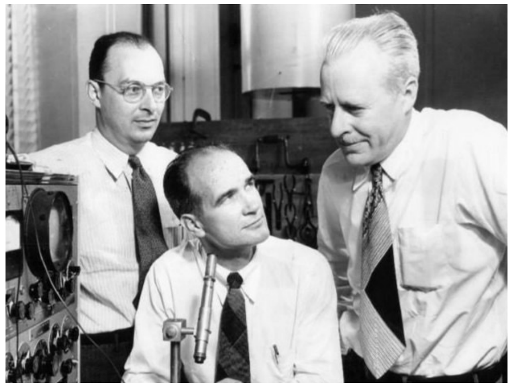


Isamu Akasaki, Shuji Nakamura, Hiroshi Amano, Nobel-prize 2014



Transistor

- amplifier
- elements of digital memory
- counters, multivibrators



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

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https://feedback.semmelweis.hu/feedback/pre-show-qr.php?type=feedback&qr=V9AZJ9BHAYZPFXBG