


Physical Foundations of Dental Materials Science 2.

Structure of matter

Liquids, solids, liquid crystals

Highlights:
- Viscosity
- Water and saliva
- Crystals - apatite
- Polymorphism
- Crystal defects
- Amorphous materials
- Liquid crystals (Material found in Medical Biophysics!)

E-book Chapters: 4, 5
Medical Biophysics I/3.4.2.

Problems:
Chapter 1.:
22, 23, 32, 33, 34, 35

States of matter - Phases

T →

	solid	liquid	gas
definite volume	+	+	-
stable shape	+	-	-

Fluids **versus** **Solids**

indefinite shape:

Shape does not recover after deformation, lack of restoring forces.

definite shape:

Shape recovers after deformation, due to restoring forces.

Fluids

INTERACTIONS

REPULSIVE = ATTRACTIVE

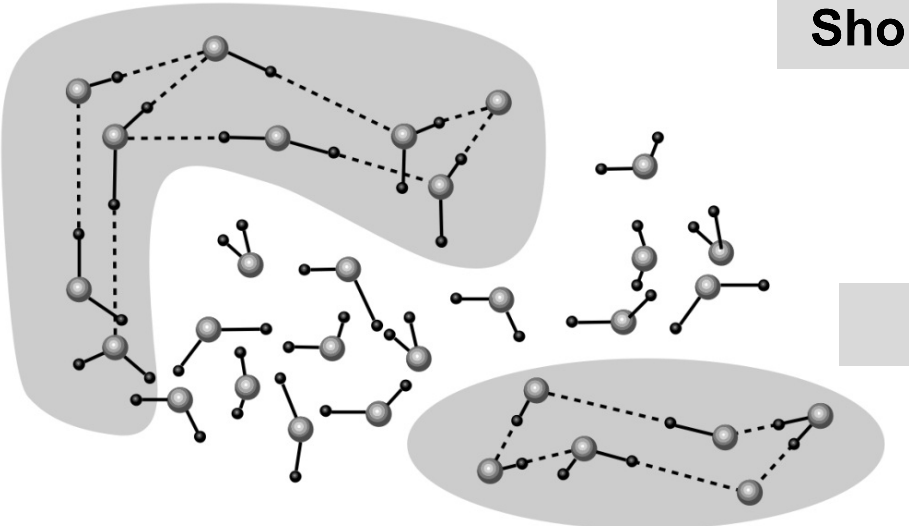
particle movement versus inter-particle bonds

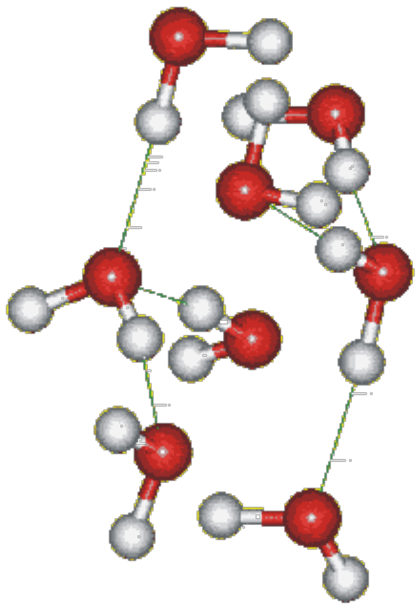
↓

Short range, dynamic order

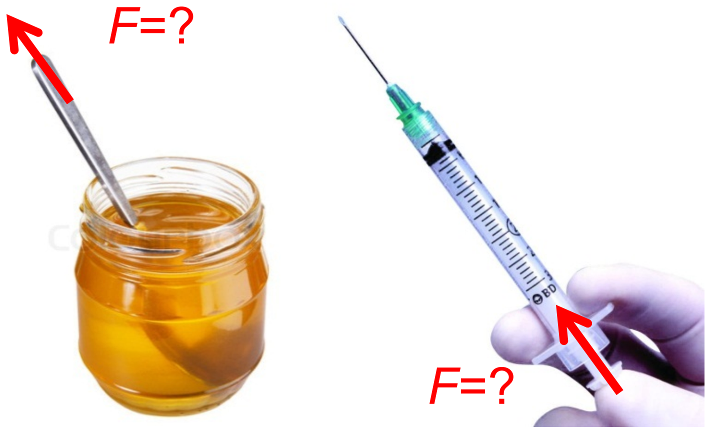
↓

isotropic

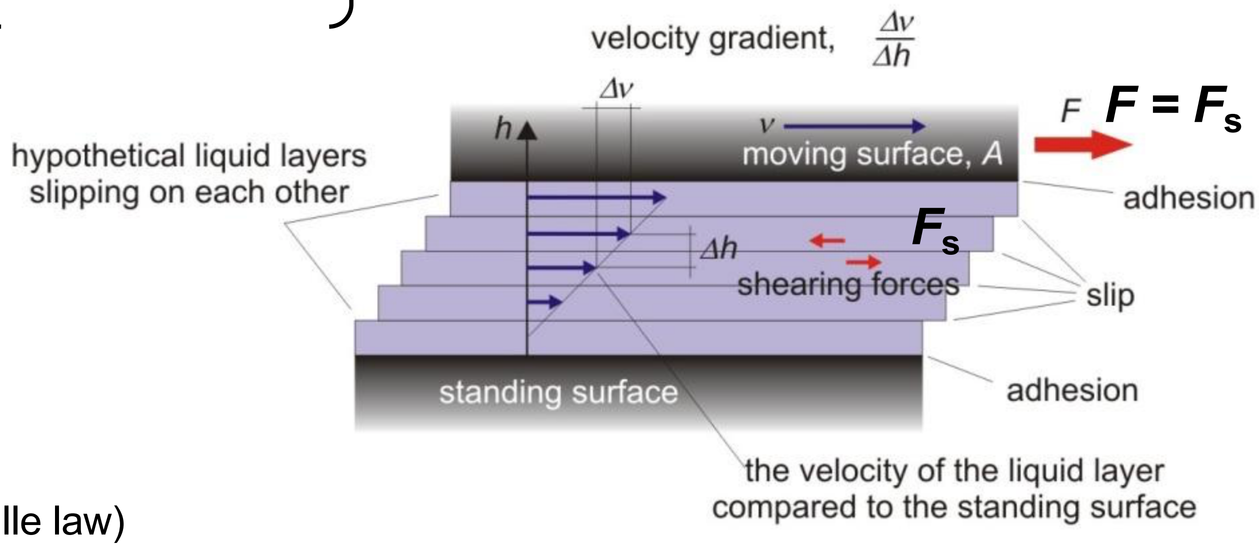




Viscosity (η) ⟺ [Fluidity ($1/\eta$)]



(later: Hagen-Poiseuille law)



Newton's law of viscosity:

$$F_s = \eta \cdot A \cdot \frac{\Delta v}{\Delta h}$$

viscosity (coefficient of internal friction)

$$[\eta] = \mathrm{Pa \cdot s}$$

Another form of Newton's law:

$$\sigma_{shear} = \frac{F_s}{A} = \eta \cdot \frac{\Delta v}{\Delta h} \quad g_v$$

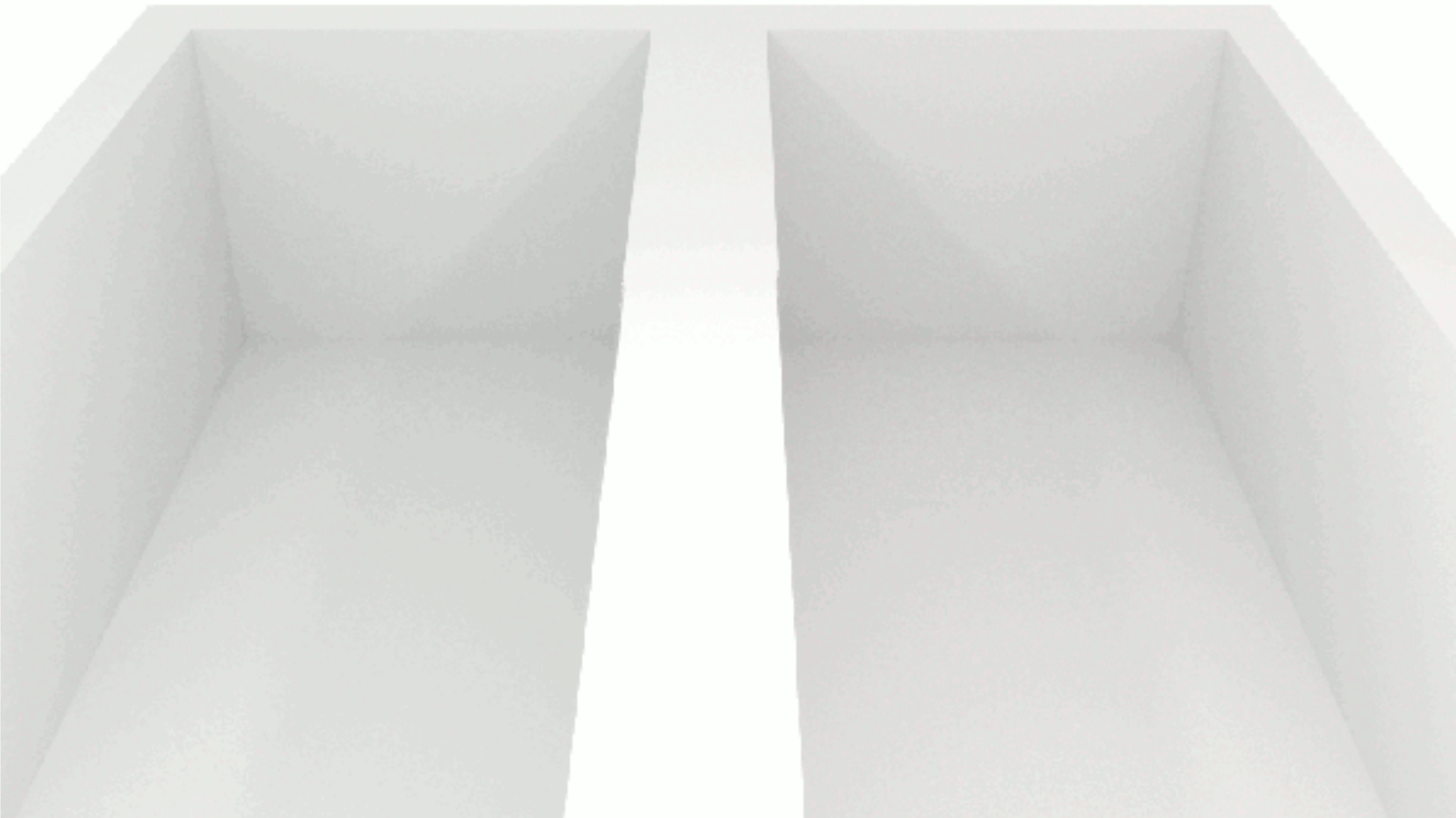
shear stress

velocity gradient

$$\sigma_{shear} = \eta g_v$$

Which one has higher viscosity?

$$\eta \quad < \quad \eta$$



Rotational viscometer:

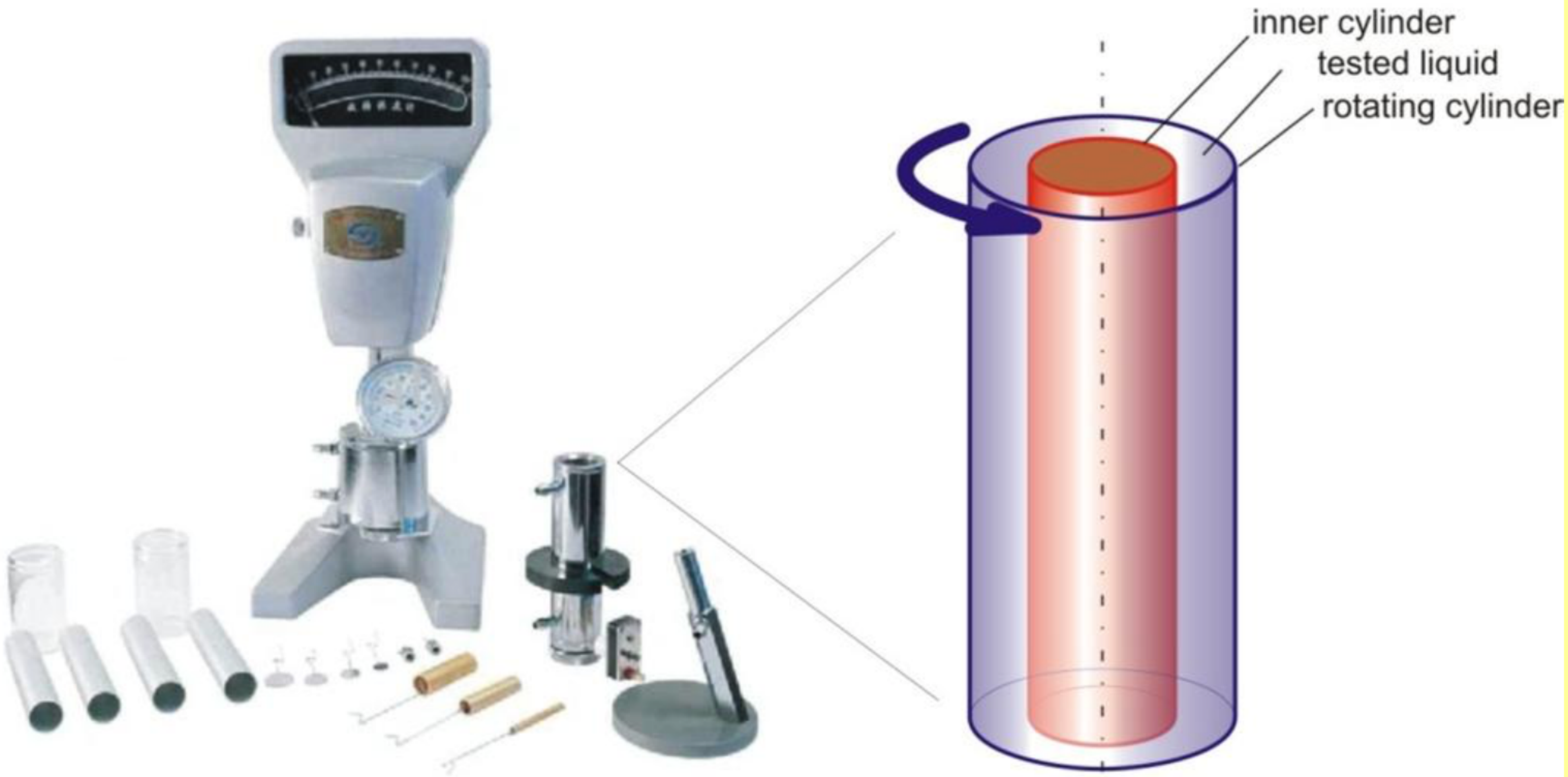
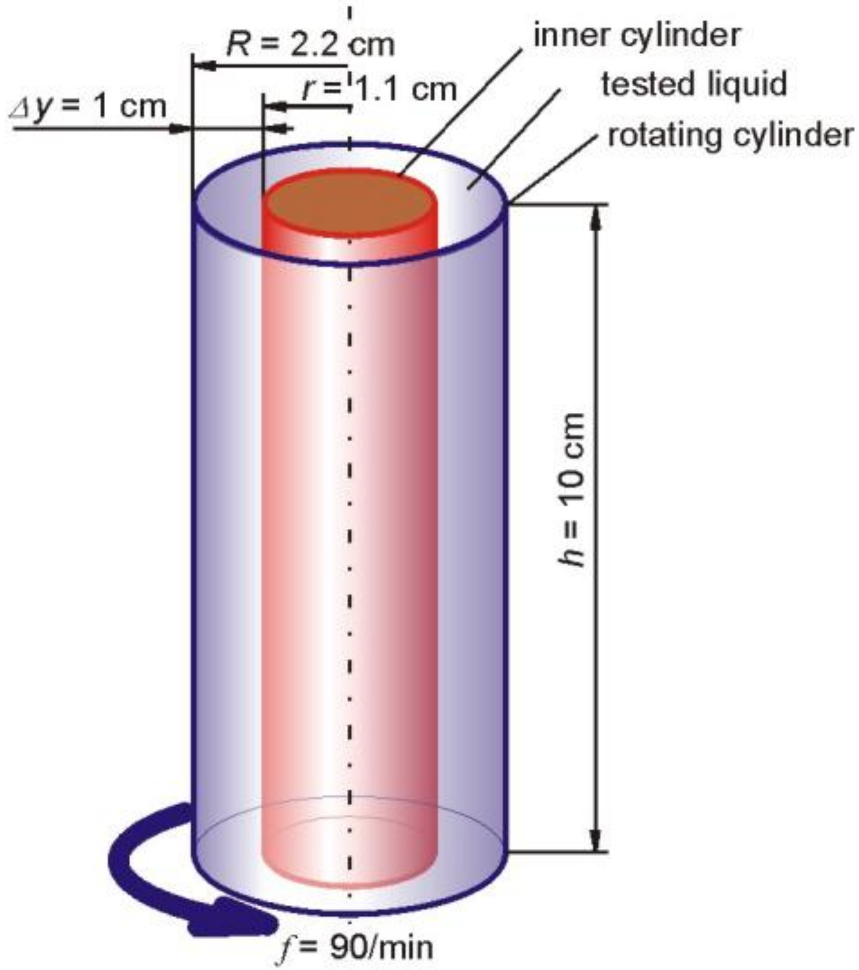
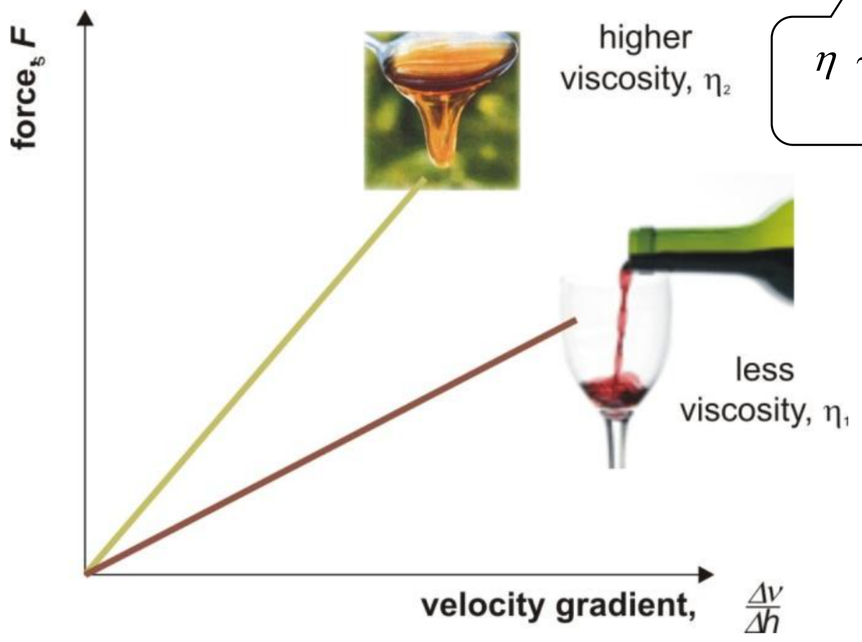


Figure schematically shows the structure of a rotational viscometer. The inner cylinder is still and the outer is rotated. The radius of the outer cylinder R = 2.2 cm, the inner cylinder r = 1.2 cm. The cylinder's height is h = 10 cm. The tested liquid between cylinders is glycerine. Layer thickness is $\Delta y = R - r$ = 1cm. Calculate the force that is necessary for uniform rotation of the cylinder does 90 revolutions per minute? (viscosity of the glycerine η = 1500 mPas. The flow is laminar.)



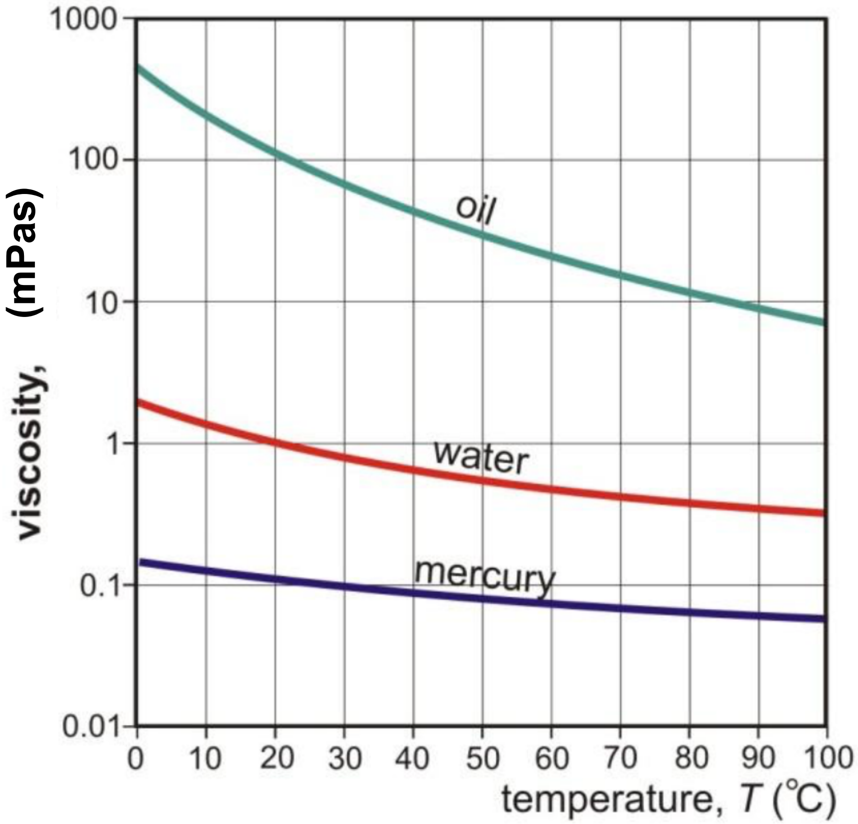
Newton's law of viscosity: $F_s = \eta \cdot A \cdot \dfrac{\Delta v}{\Delta h}$

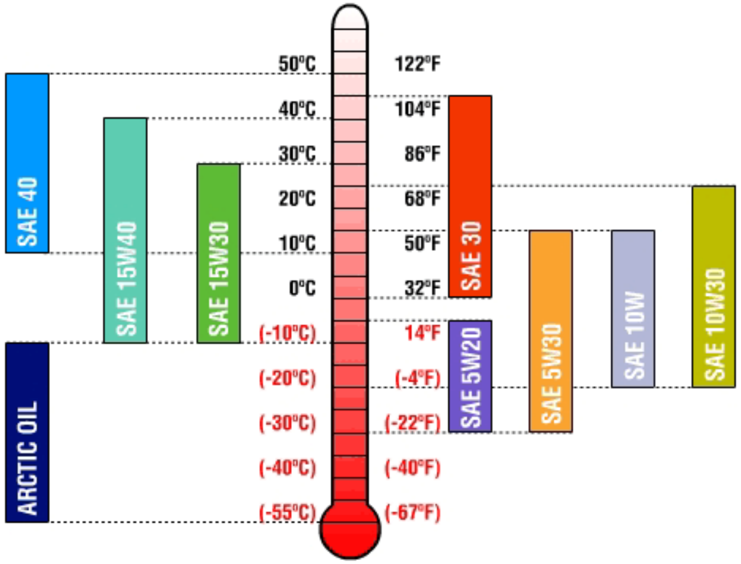
η ~ is the slope (constant)



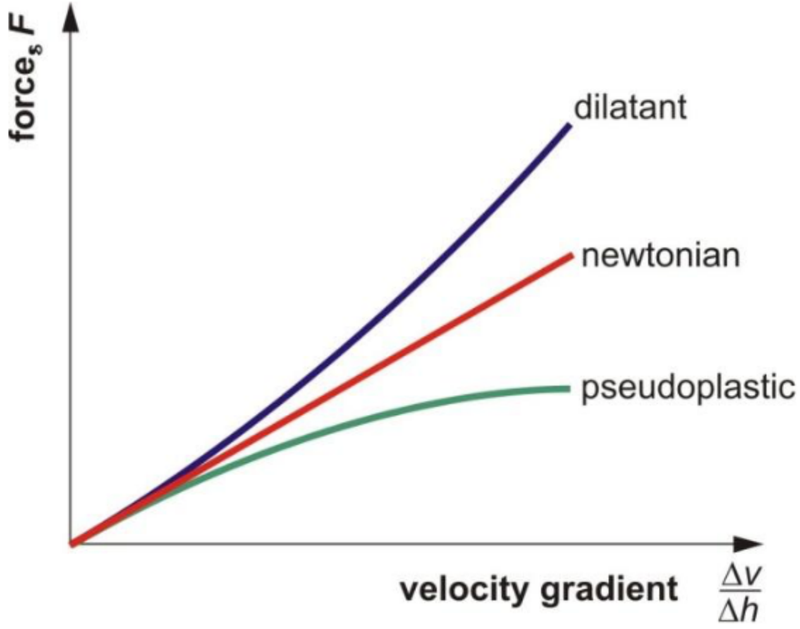
material	η (mPas)
air	0,019 (20° C)
water	1 (20° C)
saliva substitute (USA patent)	2–10
glycerol	1500 (20° C)
ethyl methacrylate monomer	0,5 (25° C)
ethylene glycol dimethacrylate monomer	3,4 (25° C)
zinc phosphate	95 000 (25° C)
zinc oxide -eugenol	100 000 (37° C)
silicone	60 000-1 200 000 (37° C)

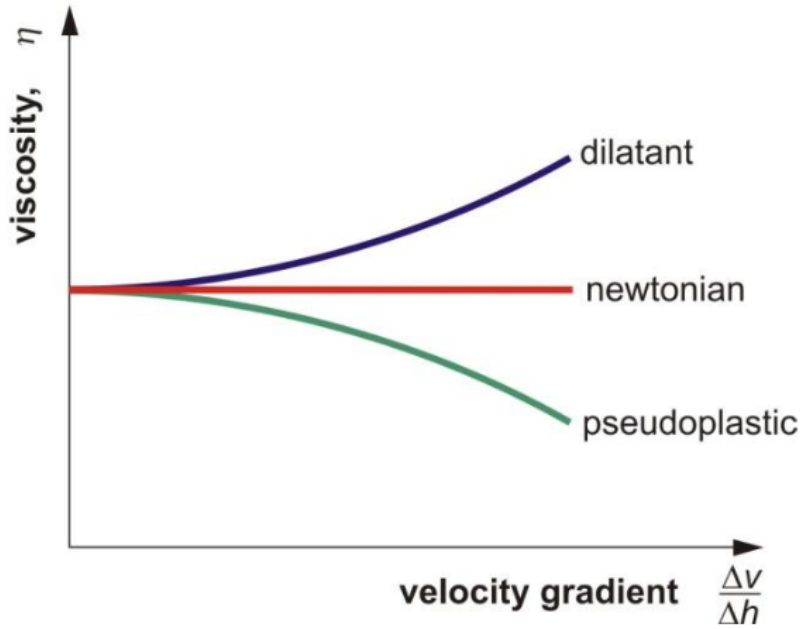
η **depends on:**
- material quality
- temperature





η depends on: **1.** shear forces/velocity gradient





liquids

Newtonian fluids

i.e. water, oil

Non-Newtonian fluids

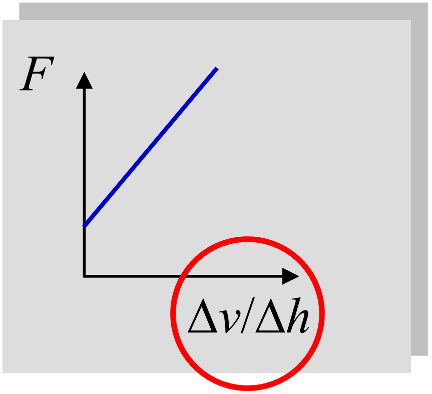
pseudoplastic

i.e. saliva, blood
polycarboxylate cements,
elastomer impression
materials

dilatant

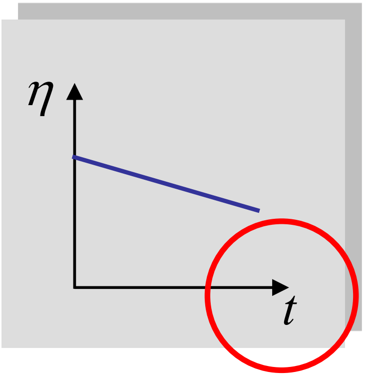
i.e. dental composite resins

Bingham-fluid:

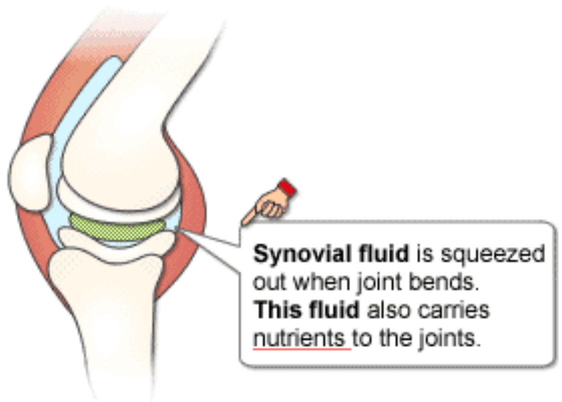


η depends on: 2. time of mechanical stress

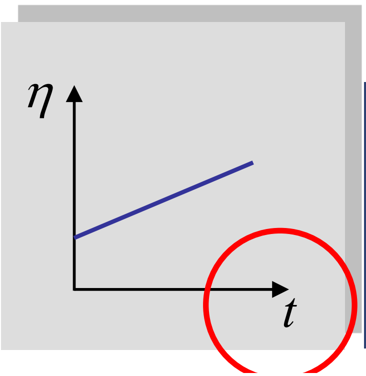
Thixotropic fluid:



some dental impression materials

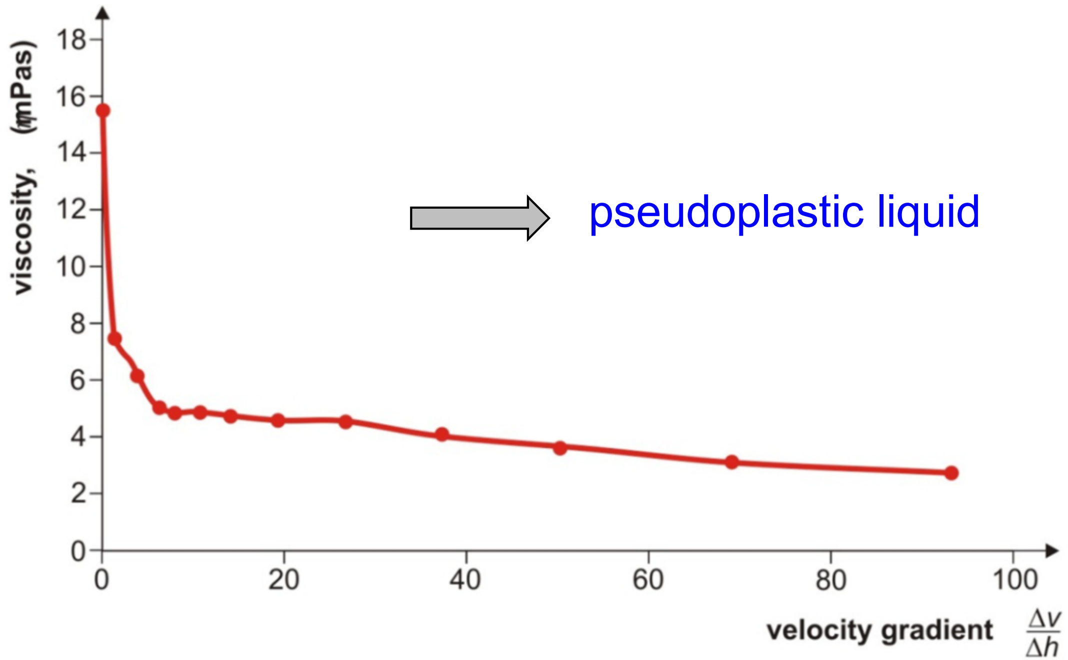


Rheopex fluid:



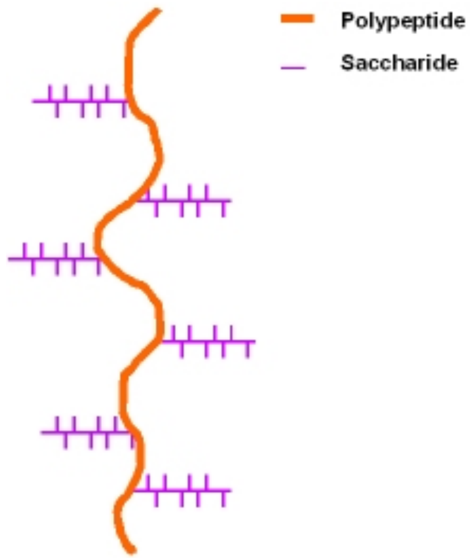
Not to confuse them with dilatant and pseudoplastic fluids!

Saliva

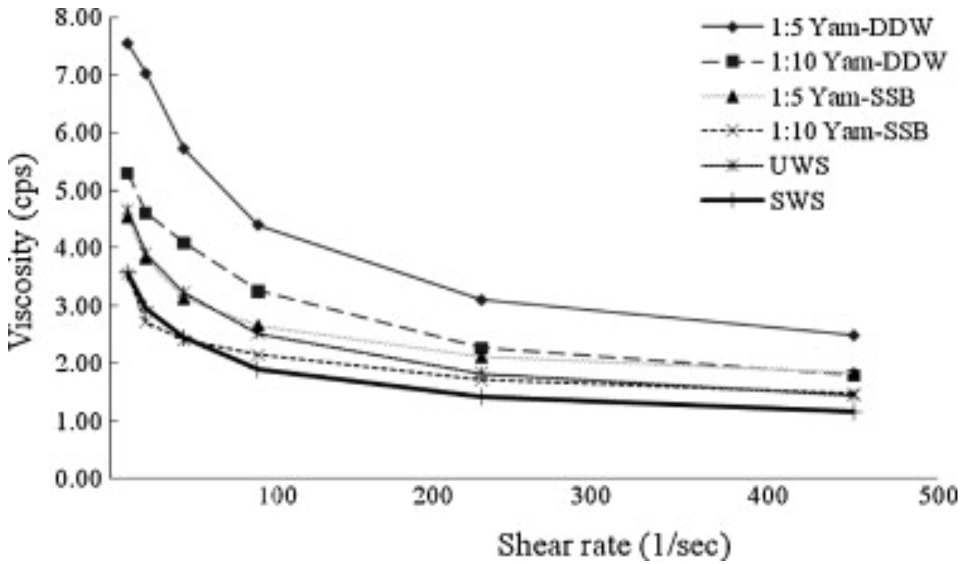


→ pseudoplastic liquid

mucin



saliva substitutes:



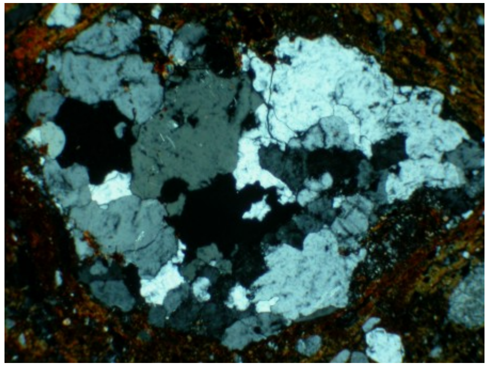
Solid materials

(crystal = solid body)

crystalline

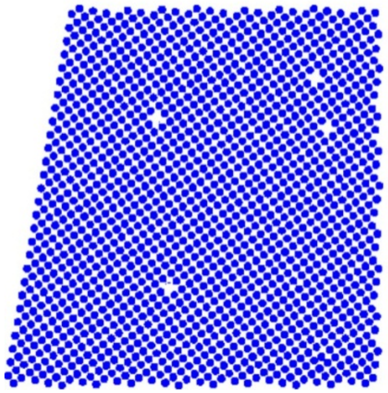
single crystal

policrystalline

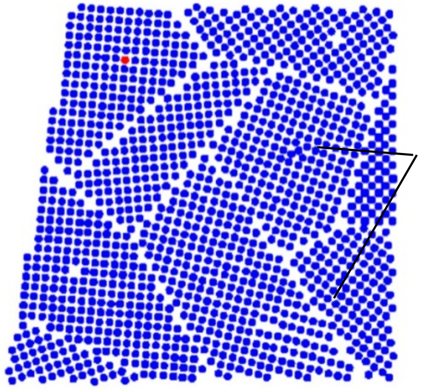


amorphous

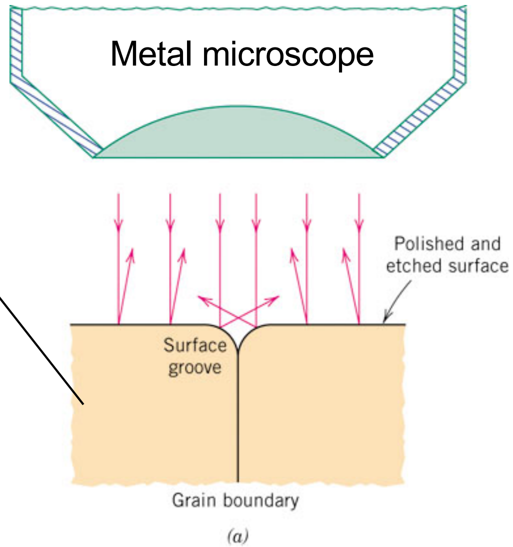
single crystal

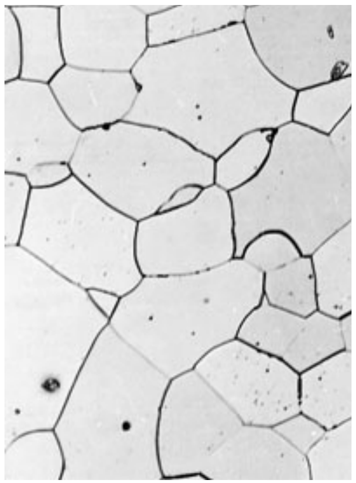


polycrystalline



crystallites or grains





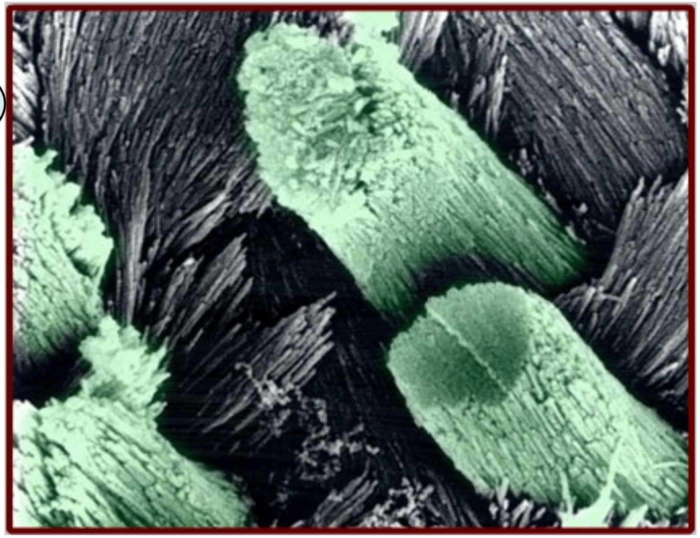
anisotropic ↔ isotropic

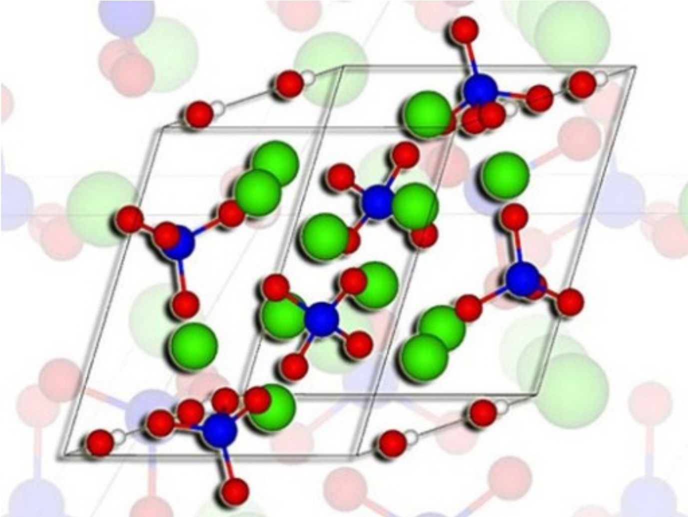
Apatite

OH$^-$: hydroxyapatite
F$^-$: fluorapatite

$Ca_{10}(PO_4)_6(X)_2$ hexagonal ioncrystal

$\left(Ca_5(PO_4)_3X\right)$





Dentin, bone: 20-60 nm x 6 nm crystals

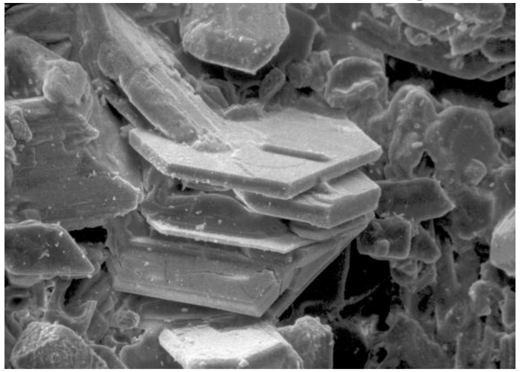
Enamel: 500-1000 nm x 30 nm crystals

Polymorphism

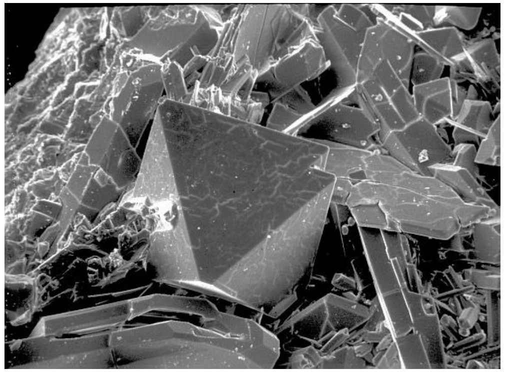
Examples:

SiO_2

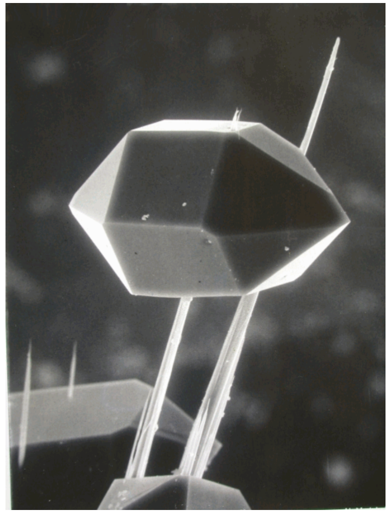
tridymite



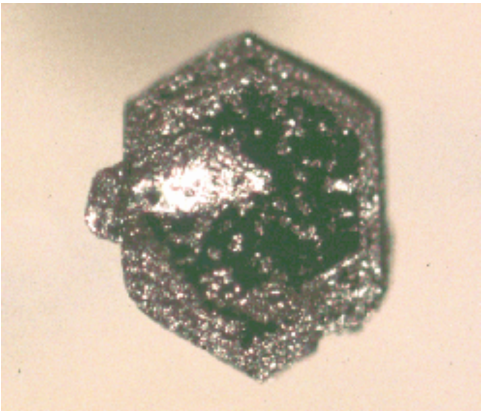
cristobalite

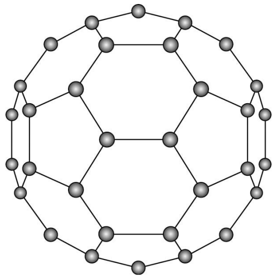


quartz

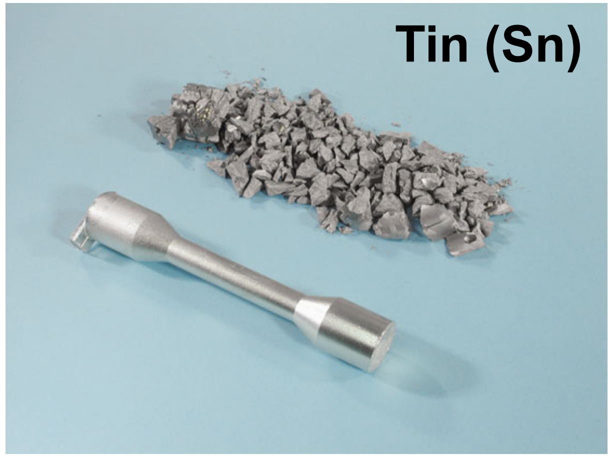


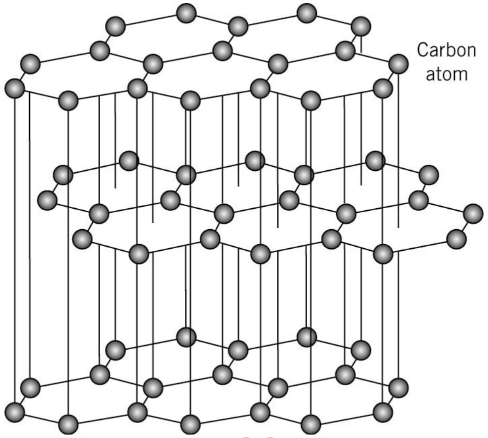
carbon (C)



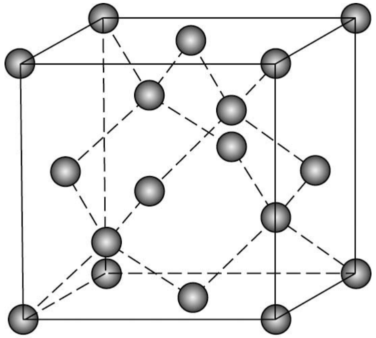


fullerene



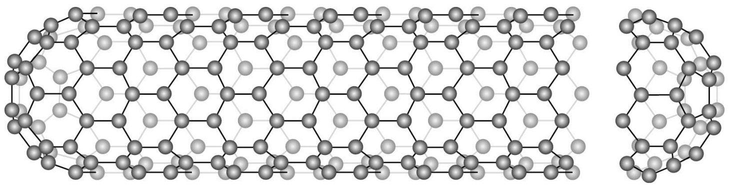


graphite



diamond

C



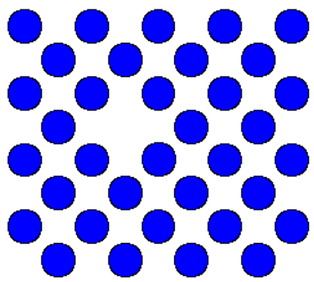
nanotube

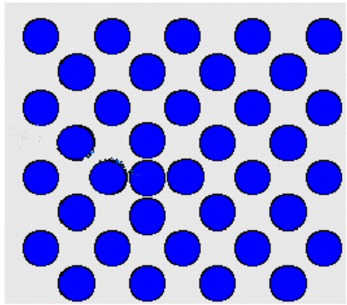
polymorphism of elements = **allotropy**

Crystal defects

- **point defects**
  - **thermal defect**
    - **vacancy (Schottky-defect)**
    - **interstitial defect**
  - **Impurity (dopant)**
    - **substitutional impurity atom**
    - **interstitial impurity atom**

(alloys !!)

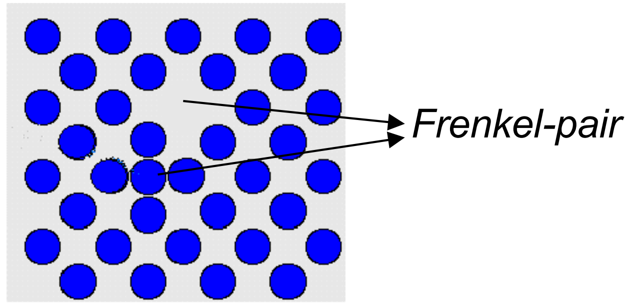


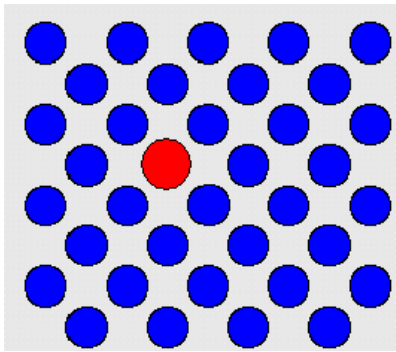


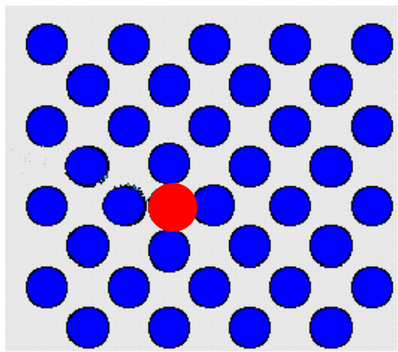
$$n_S = N \cdot e^{-\frac{\varepsilon_S}{kT}}$$

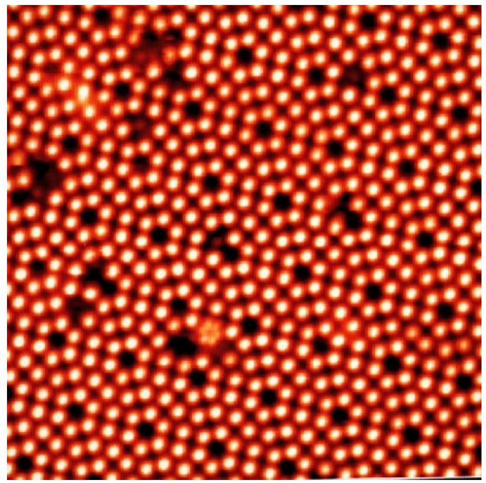
No. of Schottky-defects

Frenkel-defect





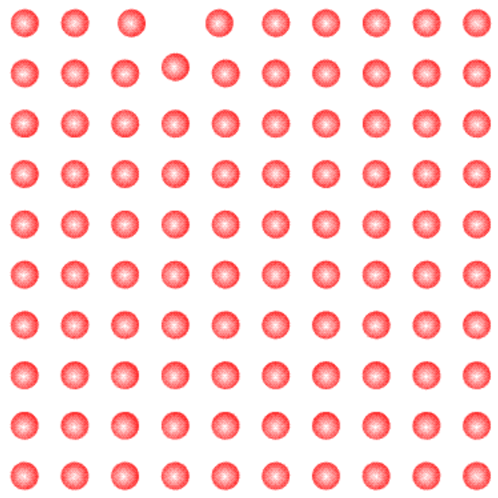


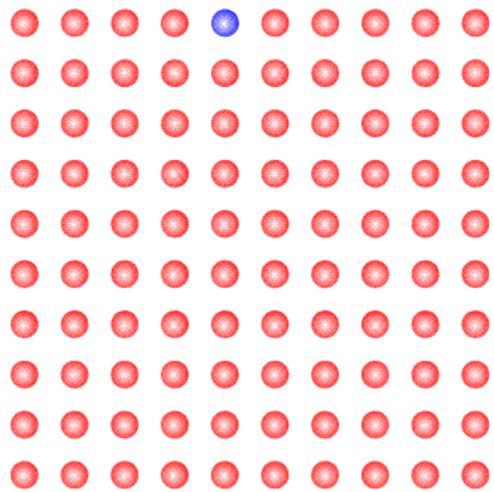


0.9 eV energy is necessary to produce a vacancy in copper.
a) How many percnt is the ratio of vacancies in the crystal at 1000°C?

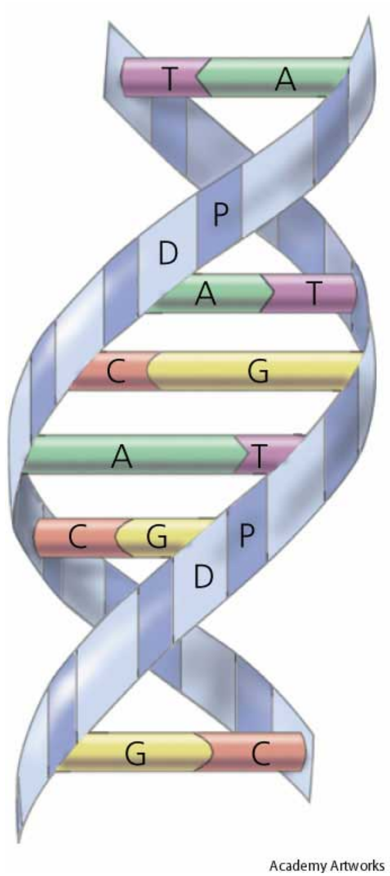
$$n_S = N \cdot e^{-\frac{\varepsilon_S}{kT}}$$

Generation and diffusion of point defects:



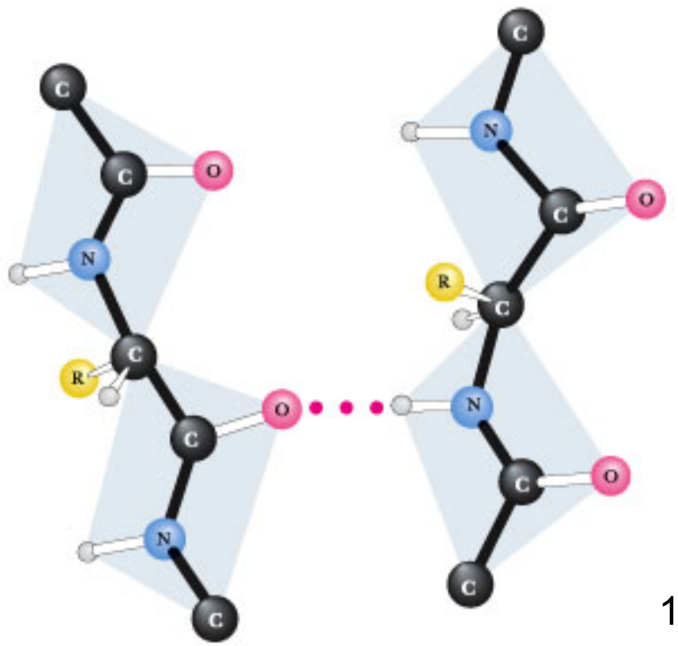


Thermal defects in biomolecules

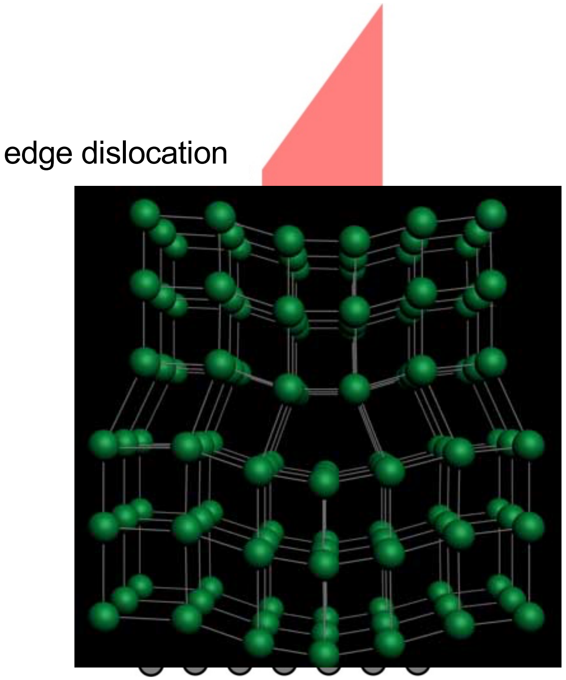


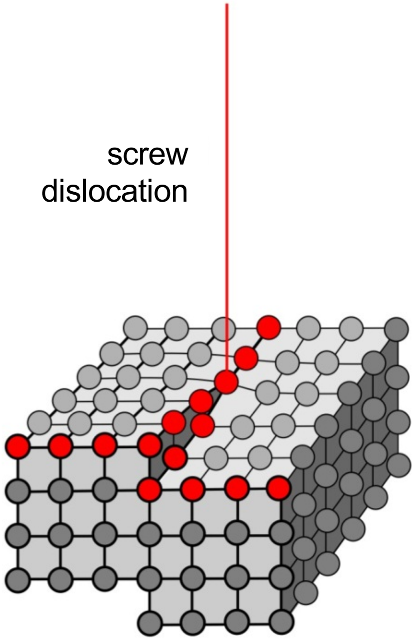
$$n_{S_\circ} = N \cdot e^{-\frac{\varepsilon_S}{kT}}$$

No. of broken H-bonds

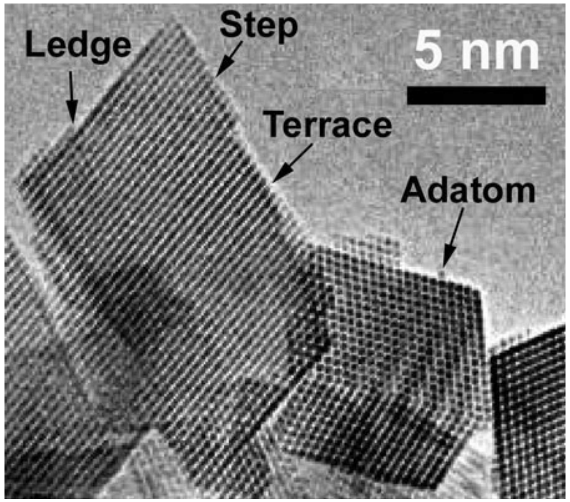


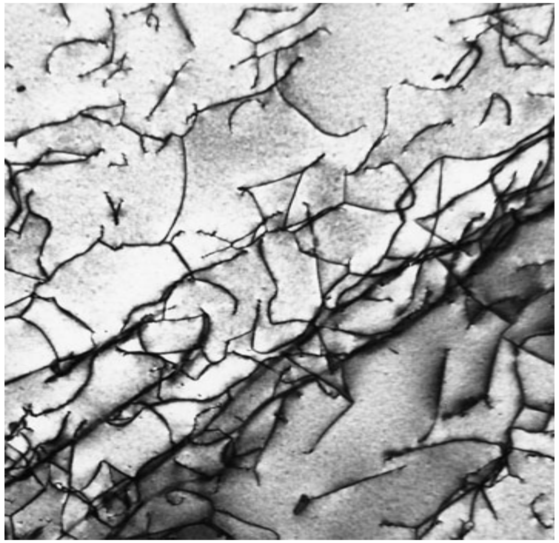
- Line defects
  - edge dislocation
  - screw dislocation





- planar defects



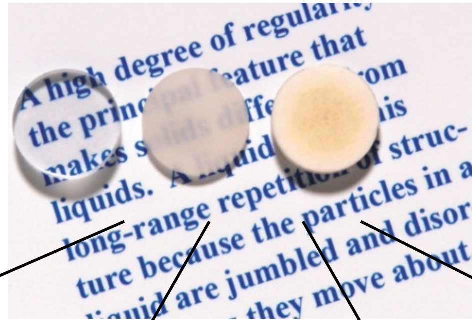


dislocations in titanium alloy

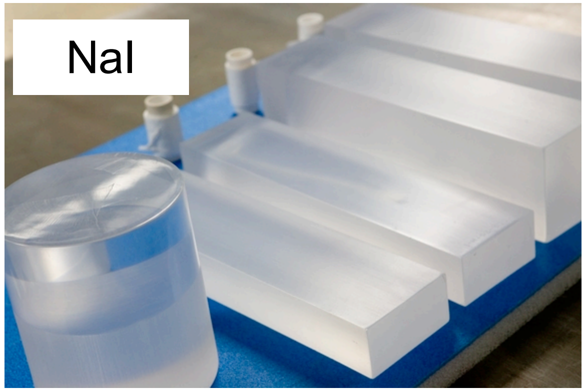
Lattice defects strongly influence the properties!

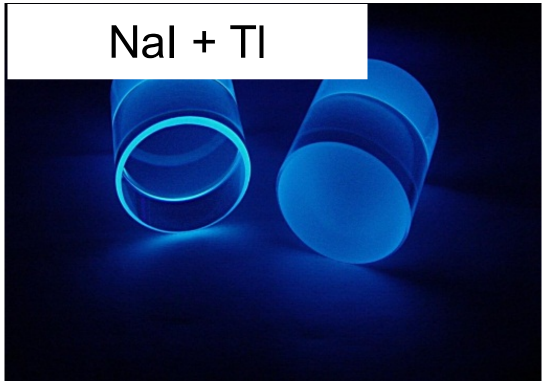
i.e. optical properties

Al_2O_3



+ Cr^{3+} + V^{2+} Fe^{2+} $+Ti^{4+}+Fe^{2+}$





Emits light when irradiated by X-ray!

→ Scintillation crystals for detecting X-ray and gamma rays.

i.e. mechanical properties

i.e. chemicl properties

$Ca_{10}(PO_4)_6(OH)_2$ ⟺ $Ca_{10}(PO_4)_6F_2$

hydroxyapatite

fluorapatite

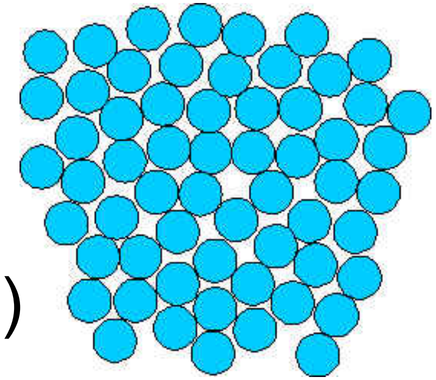
Lower solubility in acids.

i.e. electronic properties

→ doped semiconductors

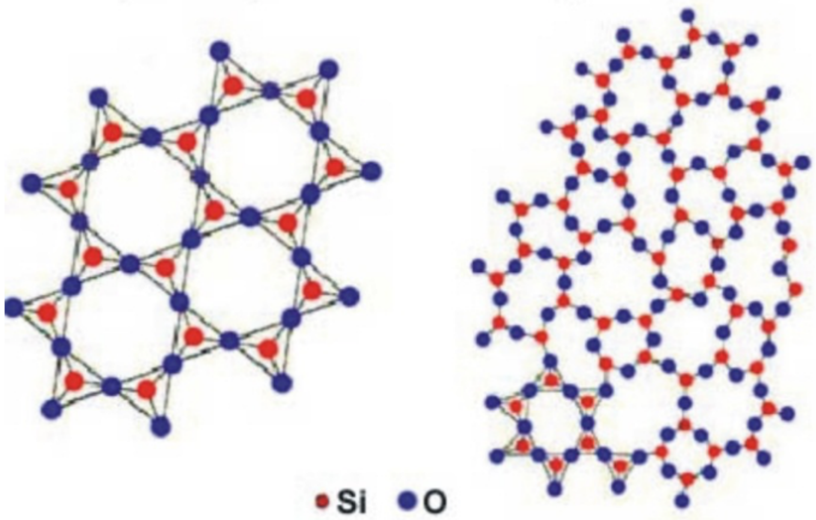
Amorphous materials = glass, glassy materials

- short distance order
- many defects
- no defined shape (flows)
  (extreme high viscosity, thus flow is extremely slow)
- hard materials
- isotropic



i.e. glass, synthetic resins, wax, asphalt, ...

crystalline SiO_2 amorphous SiO_2

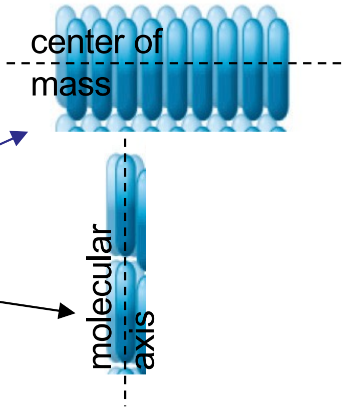


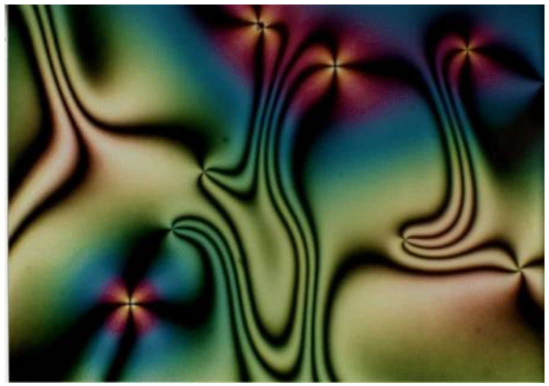
pitch drop experiment

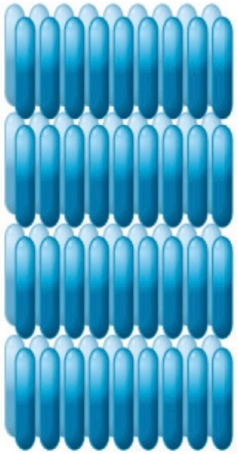
❖ (Medical Biophysics I/3.4.2.)

Liquid crystals

- anisodimensional molecules
- mesophasic
- partially ordered structure
  - Translational order
  - Orientational order
- fluid
- optically anisotropic
- structure can change according to environment
  - temperature can change the order: *thermotropic liquid crystals*
  - concentration: *lyotropic liquid crystals*





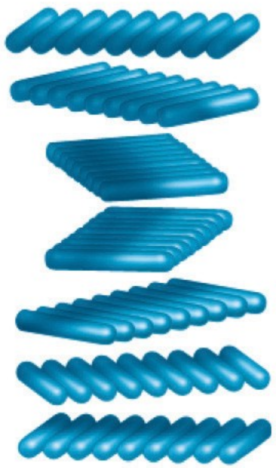


smectic

translational + orientational order

nematic

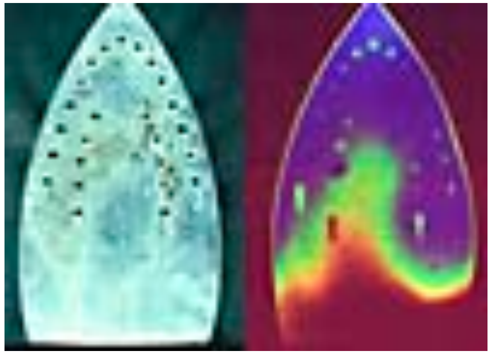
only orientational order

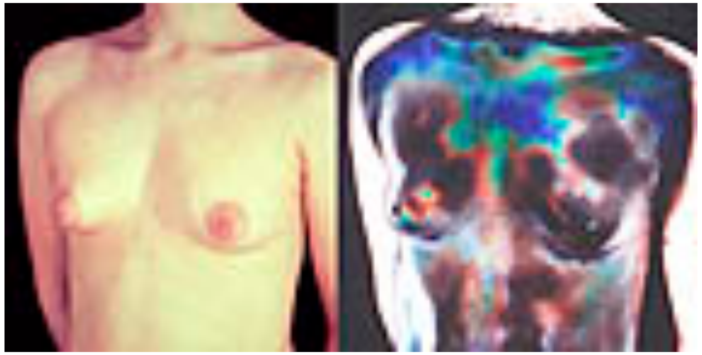


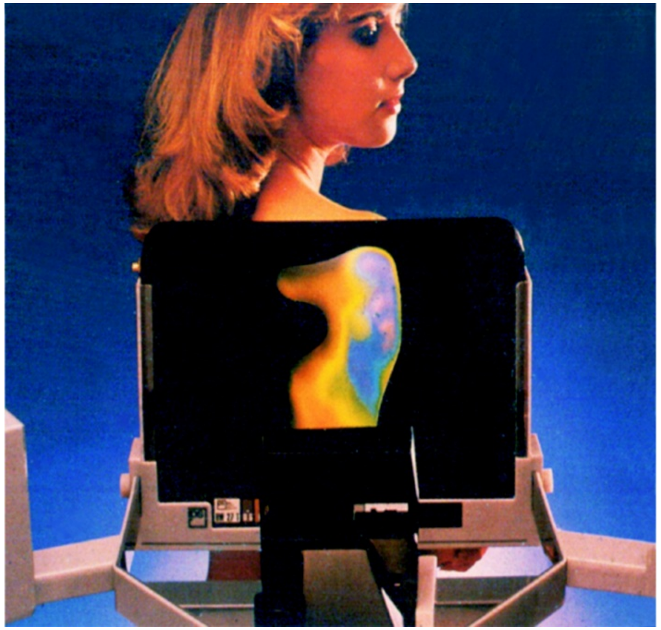
cholesteric

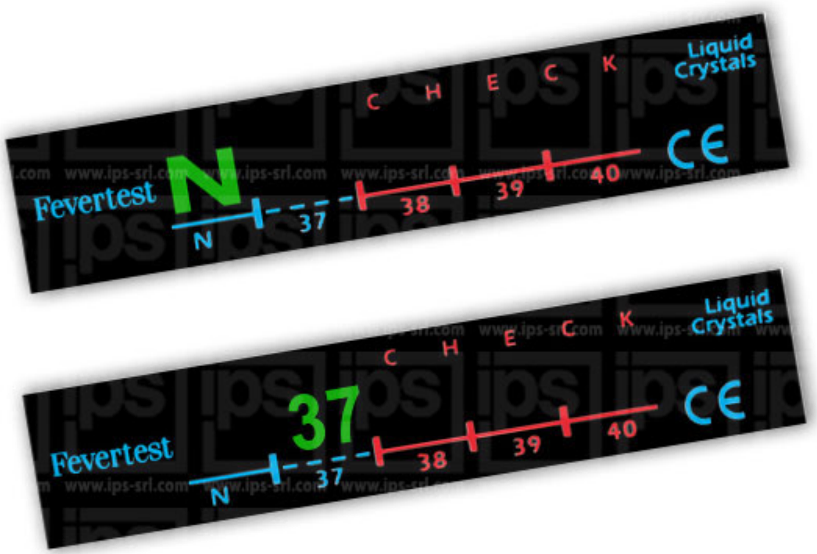
only orientational order (twisted nematic)

Contact thermography
(thermo-optical effect)

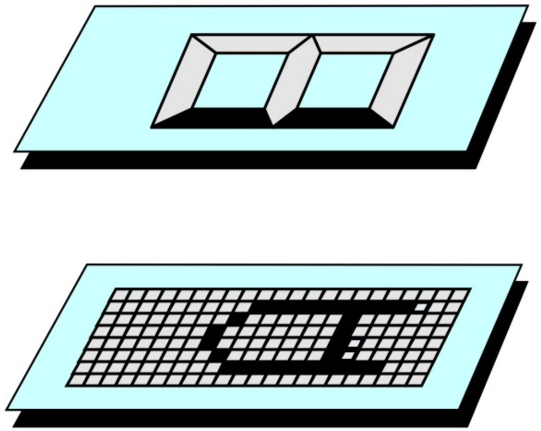


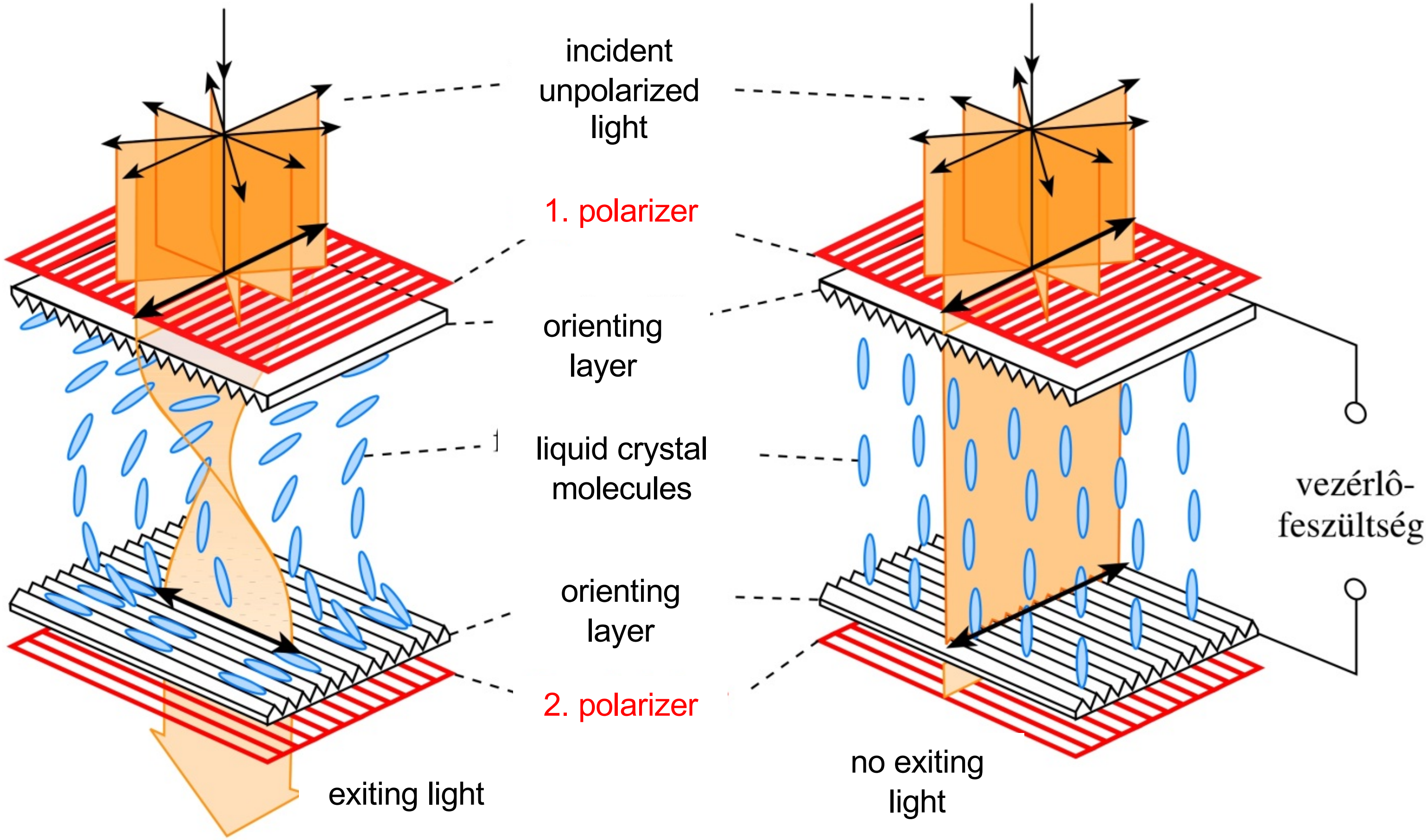




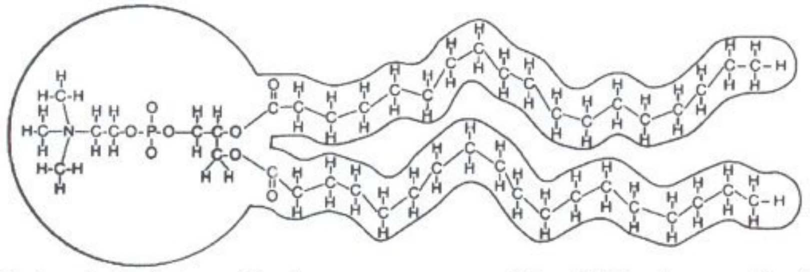


LCD
(electro-optical effect)

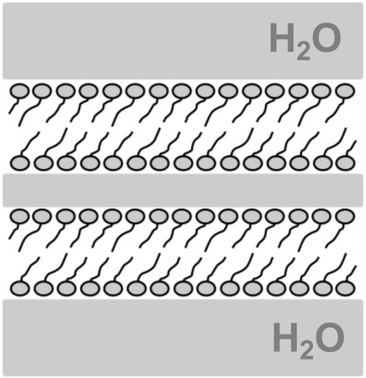




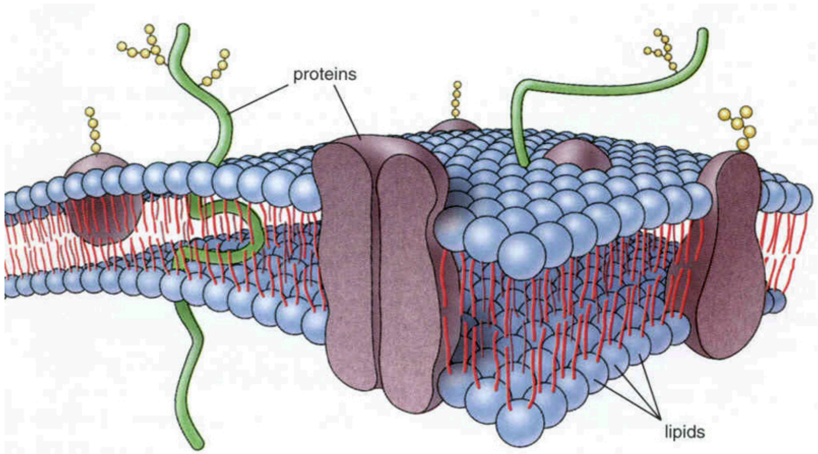
Lyotropic liquid crystals

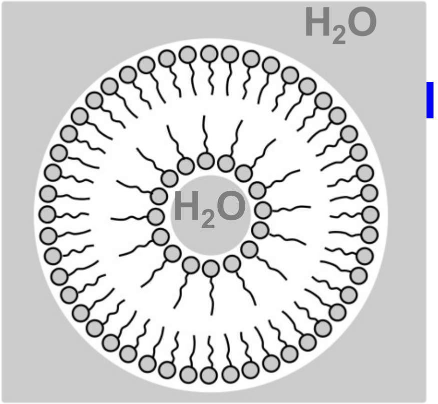


Shape of phospholipid molecule



lamellar





liposome