



Physical Foundations of Dental Materials Science

2. Structure of matter

Liquids, solids, liquid crystals

Highlights:

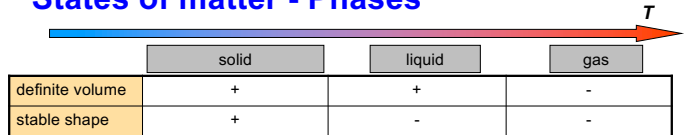
- ❖ Viscosity
- ❖ Water and saliva
- ❖ Crystals - apatite
- ❖ Polymorphism
- ❖ Crystal defects
- ❖ Amorphous materials
- ❖ Liquid crystals (Material found in Medical Biophysics!)

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

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


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States of matter - Phases



	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.

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Fluids

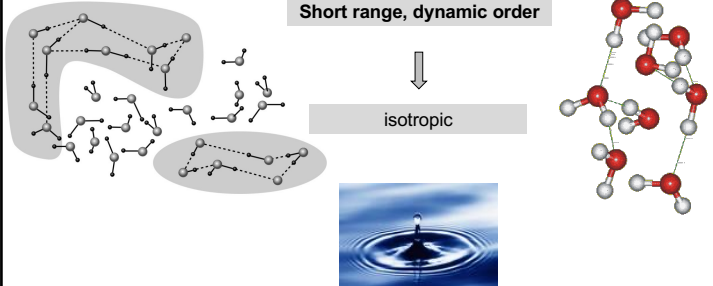
INTERACTIONS

REPULSIVE = ATTRACTIVE

particle movement versus inter-particle bonds

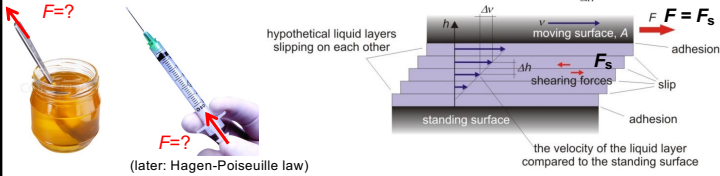
Short range, dynamic order

isotropic



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Viscosity (η) \leftrightarrow Fluidity ($1/\eta$)



$F = ?$

$F_s = ?$

(later: Hagen-Poiseuille law)

velocity gradient, $\frac{\Delta v}{\Delta h}$

hypothetical liquid layers slipping on each other

moving surface, A

standing surface

shearing forces

adhesion

slip

the velocity of the liquid layer compared to the standing surface

$F = F_s$

Newton's law of viscosity:

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

viscosity (coefficient of internal friction)
 $[\eta] = \text{Pa} \cdot \text{s}$

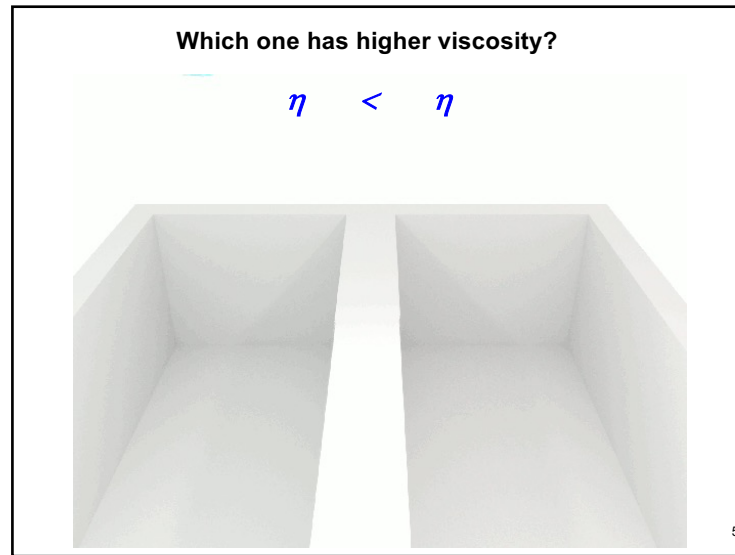
Another form of Newton's law:

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

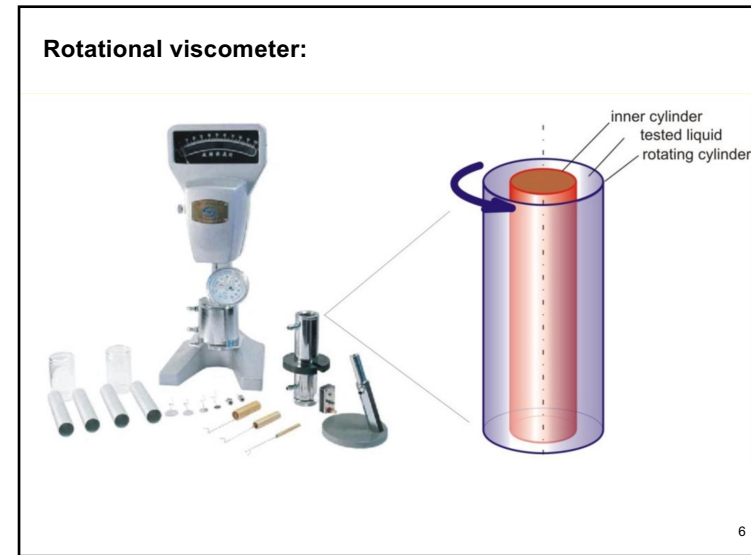
shear stress

velocity gradient

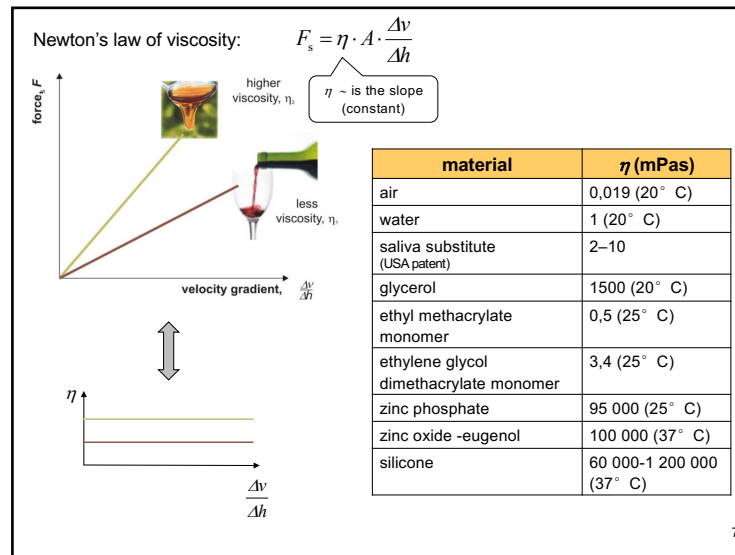
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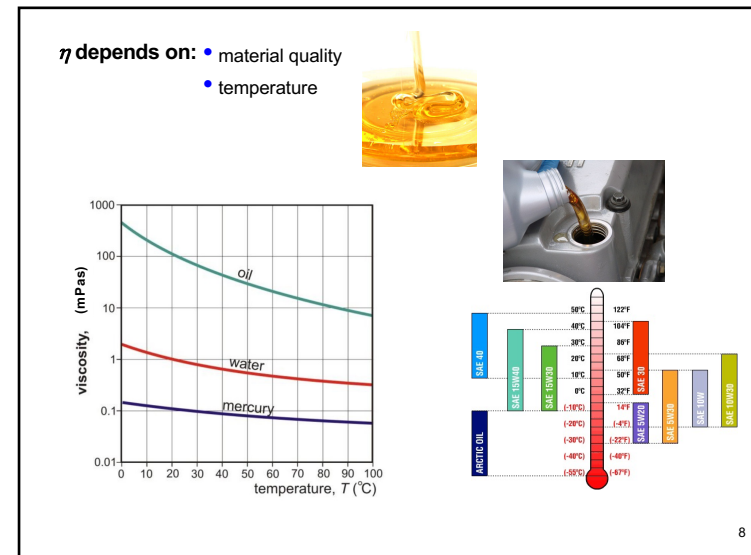
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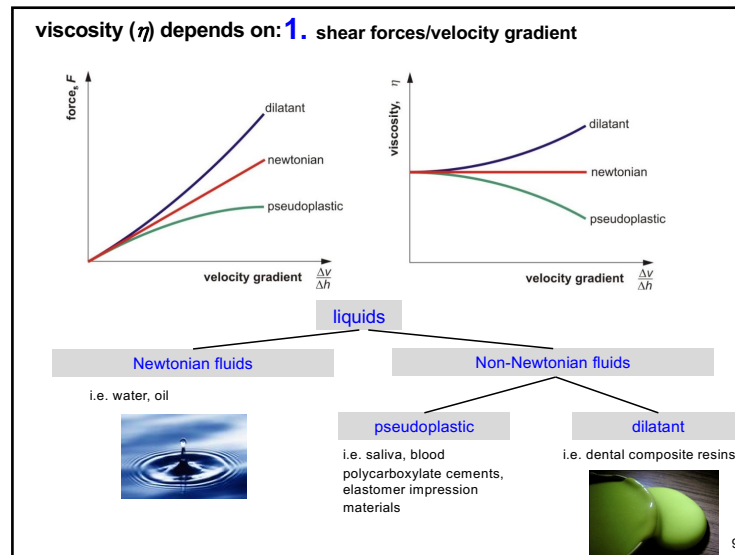
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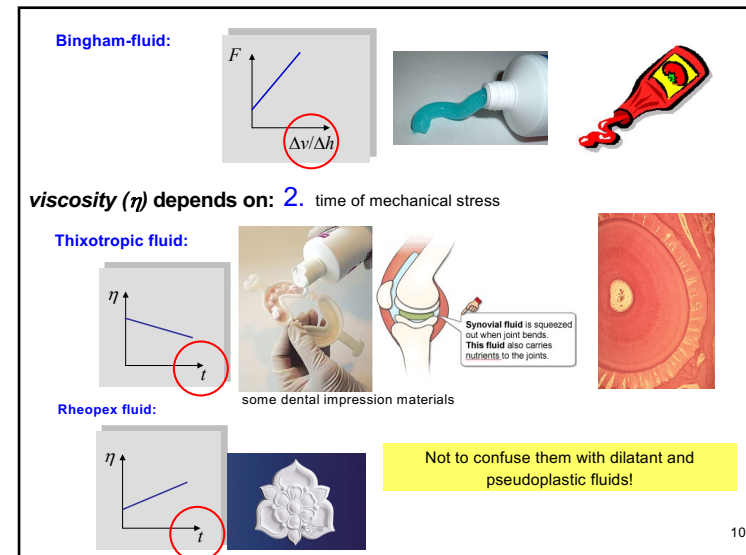
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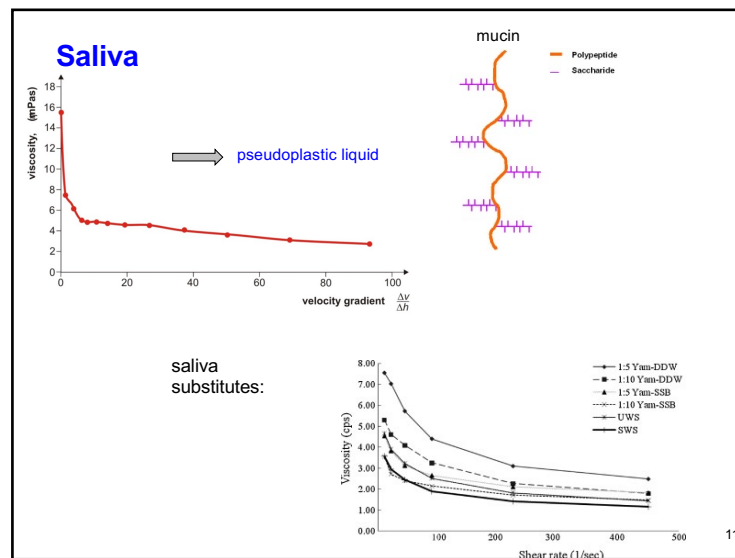
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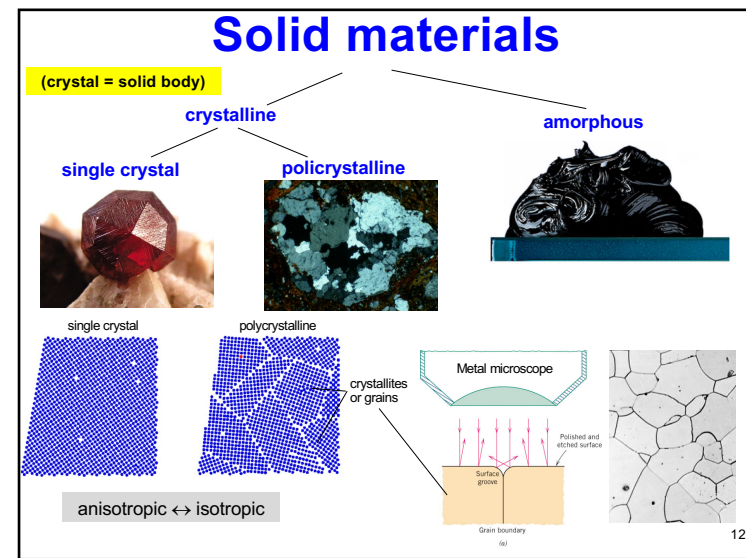
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Apatite

$\text{Ca}_{10}(\text{PO}_4)_6(\text{X})_2$ hexagonal ioncrystal
 $[\text{Ca}_5(\text{PO}_4)_3\text{X}]$

OH⁻: hydroxyapatite
 F⁻: fluorapatite



Dentin, bone: 20-60 nm x 6 nm crystals
 Enamel: 500-1000 nm x 30 nm crystals

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Polymorphism

Examples:

SiO₂

tridymite, cristobalite, quartz

carbon (C)

graphite, diamond, fullerene, nanotube

Tin (Sn)

polymorphism of elements = **allotropy**

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Crystal defects

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

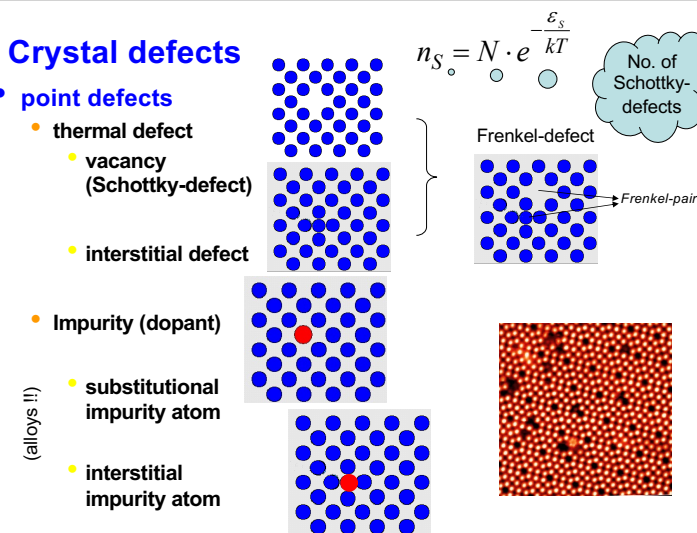
(alloys !!)

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

No. of Schottky-defects

Frenkel-defect

Frenkel-pair



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

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

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Generation and diffusion of point defects:

Thermal defects in biomolecules

$n_{S_0} = N \cdot e^{-\frac{\epsilon_s}{kT}}$

No. of broken H-bonds

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- Line defects
 - edge dislocation
 - screw dislocation

- planar defects

dislocations in titanium alloy

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Lattice defects strongly influence the properties!

i.e. optical properties

Al_2O_3

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

Nal Nal + Ti

Emits light when irradiated by X-ray!

Scintillation crystals for detecting X-ray and gamma rays.

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i.e. mechanical properties

i.e. chemical properties

$\text{Ca}_{10}(\text{PO}_4)_6(\text{OH})_2 \rightleftharpoons \text{Ca}_{10}(\text{PO}_4)_6\text{F}_2$

hydroxyapatite fluorapatite

Lower solubility in acids.

i.e. electronic properties

→ doped semiconductors

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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

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❖ (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)

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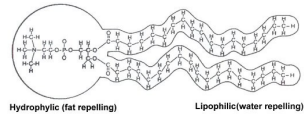
Contact thermography (thermo-optical effect)

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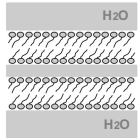
LCD (electro-optical effect)

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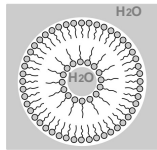
**Lyotropic
liquid
crystals**



Shape of phospholipid molecule



lamellar



liposome

