Physical bases of dental material science

States of materials

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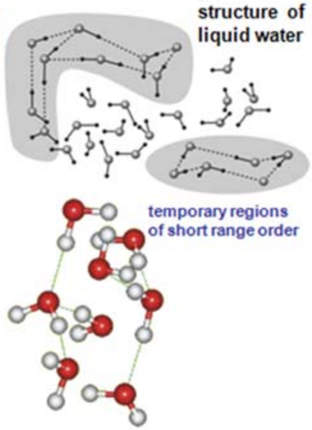
Three broad states of matter: gas (I/3.2.)
liquid (I/3.4., I/4.1)
solid (I/3.3.1., I/3.3.5.)

Fluids



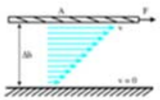
- Temporary regions of short range order within a few molecules
  ~10 nm domain size
- High concentration of structural defects
- No firm volume or shape - liquid
- High motional freedom of particles
- Isotropy

Important properties of fluids

1. Viscosity (η)

– an intrinsic mechanical property

Resistance to shearing motion: frictional force between adjacent layers as they slide past one another



$$F=\eta * A * \frac{\Delta v}{\Delta h}$$

$$[\eta]=Pa*s$$

$\frac{F}{A}$ Shear stress

Newton's law – viscosity is a constant

η depends on - the temperature
- the magnitude of F/A

(η is a constant only up to a certain magnitude of the shear stress)

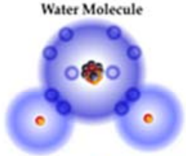
fluidity ~ $1/\eta$

($\Rightarrow$ 2. semester)

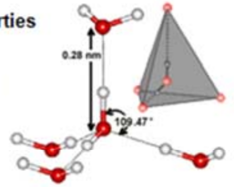
Viscosity of fluids/materials of dental applications

material	η (mPas)
liquid water	1 (20° C)
glycerol	60 (20° C)
methylmethacrylate monomer	0,5 (25° C)
ethylene glycol dimethacrylate monomer	3,4 (25° C)
Zn-phosphate	95 000 (25° C)
Zinc oxide eugenol dental cement	100 000 (37° C)
silicon	60 000-1 200 000 (37° C)

Liquid water has outstanding properties

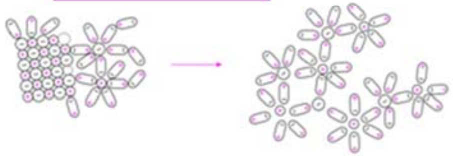


large dipole



strong H-bonding

- high specific heat
- high surface tension
- efficient solvent



Liquid crystals – a mesomorphous state of matter

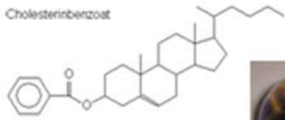
General properties

- Elongated shape of constituting molecules
- Long range order stabilized by secondary bonds
- Deformability, fluidity
- Anisotropy in fluid state
- Secondary bonds are easily perturbed

heat
ionic composition
electric potential

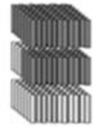
1883 Reinitzer

Cholesterinbenzoat



Thermotropic liquid crystal

1. Thermotropic liquid crystals

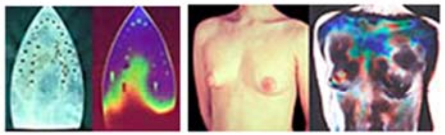
a  smectic

b  nematic

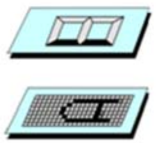
c  cholesteric

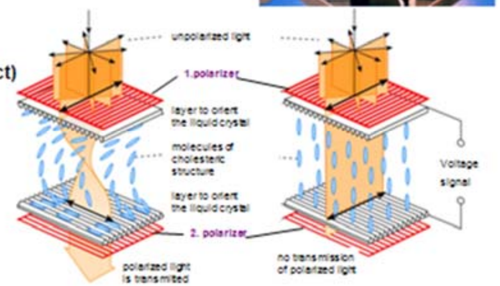
Use of thermotropic liquid crystals

Contact thermography

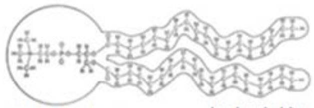


LCD
(electro-optical effect)

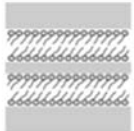




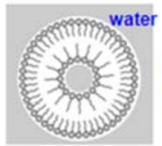
2. Liotropic liquid crystals



phospholipids

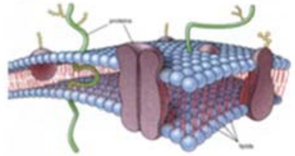


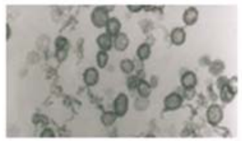
lamellar



vesicular
liposomes

Cellular bi-layer membranes



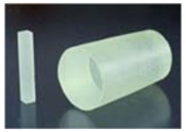


Solid materials

Classification of solid materials

crystalline — amorphous

monocrystal — polycrystal



sapphire

calcite

cuprite

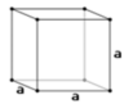
porcelain veneer

moldavite

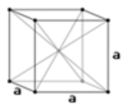
Most important characteristics of solid materials

- definite shape and volume
- macroscopic range order (crystals)
- periodic crystal structure, symmetry
- relatively small number of defects in the structure
- low degree of translational motion of the individual building elements
- frequent anisotropy (the physical properties depend on the direction of the measurement)

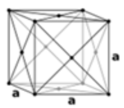
crystal structure: a unique arrangement of atoms or molecules
longe – range order and symmetry
unit cell (lattice) repeted periodically in 3D



simple cubic

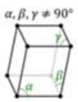


body-centered cubic

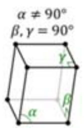


face-centered cubic

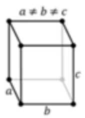
hexagonal



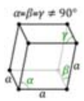
triclinic



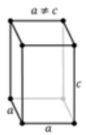
monoclinic



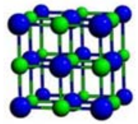
orthorhombic



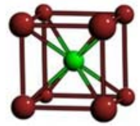
rhombohedral



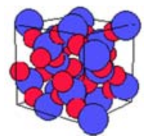
tetragonal



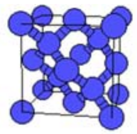
sodium chloride



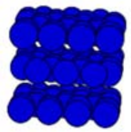
cesium chloride



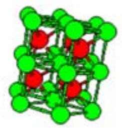
quartz



diamond



graphite



tungsten carbid

Properties of crystalline materials

type of bond	building units	binding energy (kJ/mol)	melting point	rigidity	conductivity
covalent	atoms	100 – 1000	high	+	-
ionic	ions	200 – 1500	high	+	-
metallic	free electrons and ions	70 – 1000	high	ductile	+
H-bond	molecules	15 – 20	low	+	-
van der Waals	molecules	0.5 – 3	low	soft	-


graphite


fluorapatite


gold


ice


sulfur

Polymorphism - allotropy

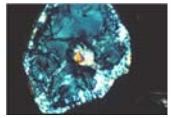
the ability of solid material to exist in more than one form or crystal structure

polymorph forms of SiO_2

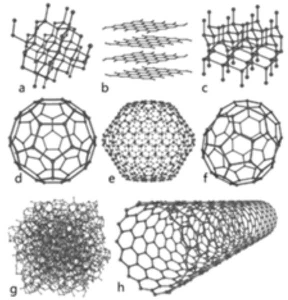

α quartz


tridymite


cristobalite


coesite

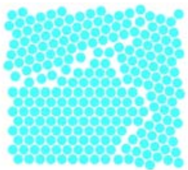
allotrop forms of carbon



a./ diamond
b./ graphite
c./ lonsdaleit
d.-f./ fullerenes
g. amorphous carbone
h./ carbon nanotube

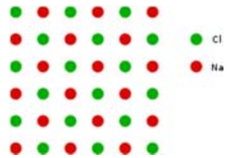
Polycrystalline materials

- no macroscopic range order
- large number of crystallites (microscopic size crystals)
- grain boundaries (interfaces where crystals of different orientations meet)
- crystal defects
- mainly isotrope property



Crystal defects

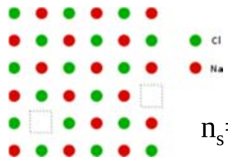
ideal crystal



Point defects

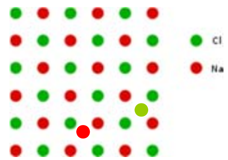
a/ thermal

Schottky – defect (vacancy or hole)



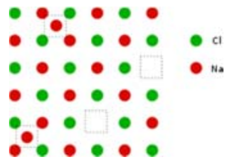
$$n_s=Ne^{-\varepsilon s/kT}$$

interstitium



$$n_i=n_0e^{-(\varepsilon i-\varepsilon 0)/kT}$$

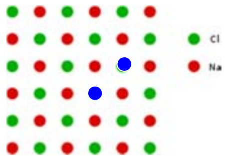
Frenkel – defect (vacancy and interstitia)



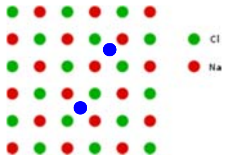
$$n_f=(NN')^{1/2}e^{-\varepsilon f/2kT}$$

b/ doping

substitutional

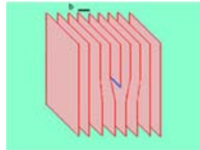


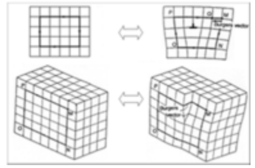
interstitial



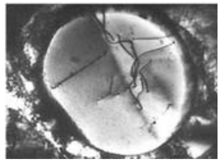
Line defects

edge dislocation



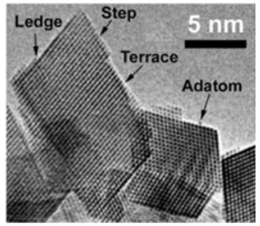


screw dislocation



Transmission electron micrograph of dislocation

Surface defects

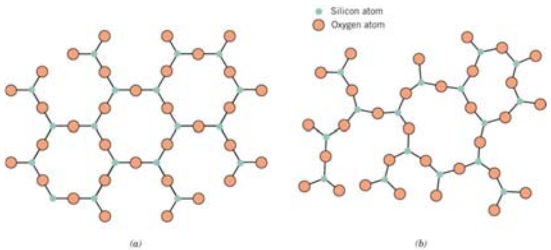


The defects strongly influence the material properties!

Al_2O_3 and $Al_2O_3 + Cr^{3+}$

Properties of amorphous solids:

no longe-range order of the position of atoms



the crystalline and amorphous structure of silica in two dimension

large number of structure defects

no definite shape (large viscosity liquid, supercooled liquid)

mechanical hardness

glass transition temperature T_g (the amorphous material becomes brittle on cooling or soft on heating)

isotrope property