Physical bases of dental material science

Methodes of structure analysis

(Chapter 8.)

Zsolt Mártonfalvi

Why is it important?

The macroscopic and microscopic structure strongly determines the physical, chemical and the biological properties and behaviour of materials.

↓

in order to proper application we should know the structure

The materials can fail:
- fatigue
- fracture
- rupture
- thermal shock
- wearing
- buckling

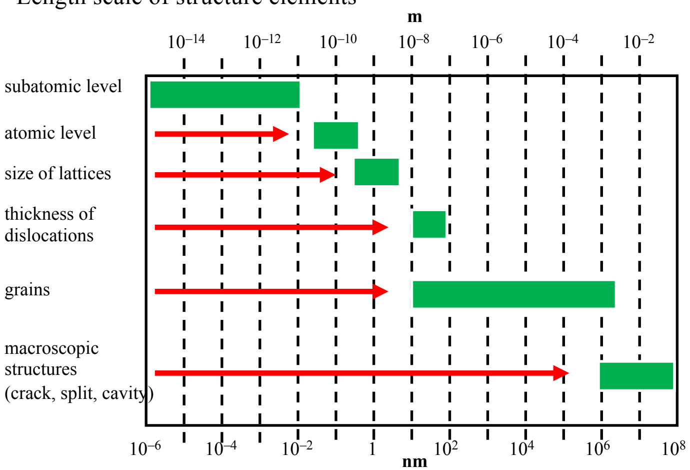
→ we have to recognize it

To improve our knowledge to develope the properties of materials

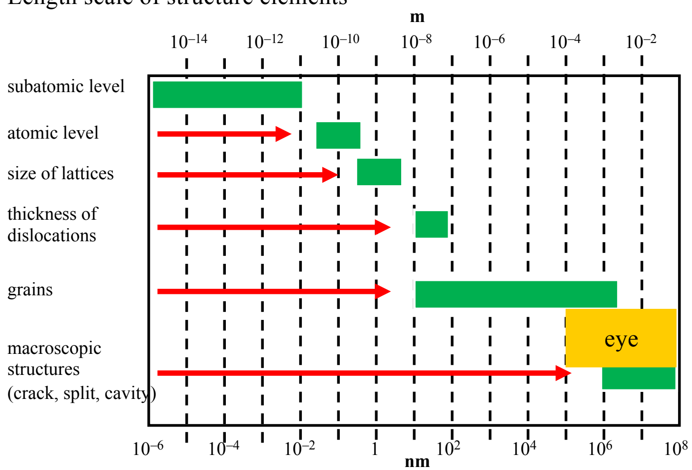
↓

we have to analyse the structure

Length scale of structure elements



Length scale of structure elements

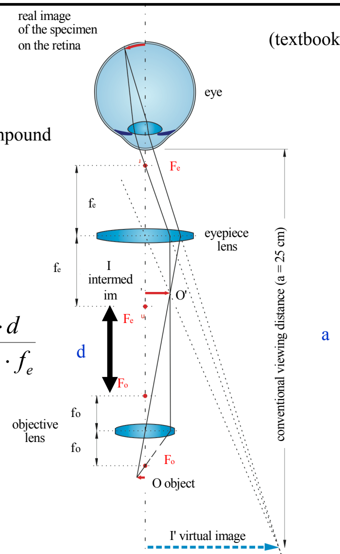


How can we see the smaller details?

Light microscope

(textbook ch. VI/2.1, VI/2.2.)

image formation of the compound microscope



magnification:

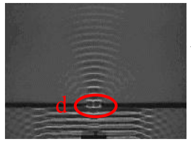
$$M = M_{obj} \cdot M_e = -\frac{a \cdot d}{f_{obj} \cdot f_e}$$

(cc. 2000)

Diffraction (Hygens principle)

(textbook ch. II/1.4, - II./1.6.)

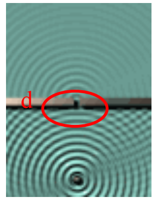
Every point of a wave front may be considered the source of secondary wavelets that spread out in all directions with a speed equal to the speed of propagation of the waves.

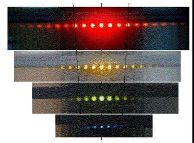


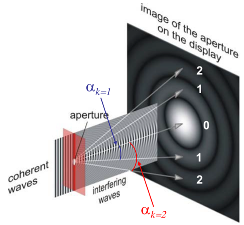
d/λ >> 1
week diffraction

d/λ ~ 1

strong diffraction







$$d \cdot \sin\alpha = k \cdot \lambda$$

k = 0, 1, 2, 3, 4, ... (integer)

Conditions of constructive and destructive interference

constructive interference: Δs=k*λ

destructive interference: Δs=(1+k/2)*λ

the smallest distance resolved with a microscope

wavelength of illuminating light

$$\delta = 0{,}61 \frac{\lambda}{n \cdot \sin\omega} \qquad \delta \approx \frac{\lambda}{NA}$$

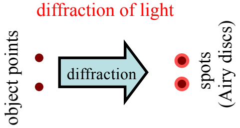
refractive index

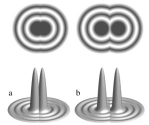
half aperture angle of the objective lens

numerical aperture

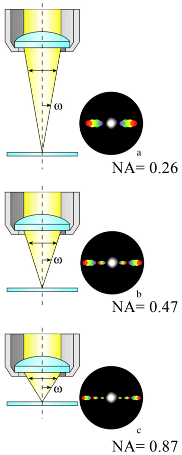
$\delta \approx 200$ nm

the reason of limited resolution: diffraction of light





not resolved just resolved
close points of the object



Metal microscope (for samples that are not transparent)

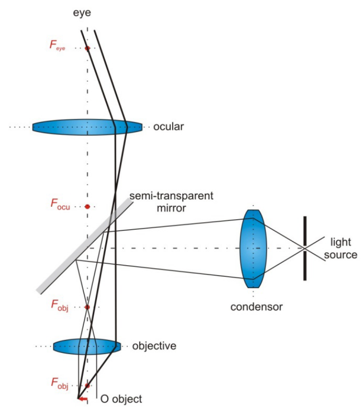
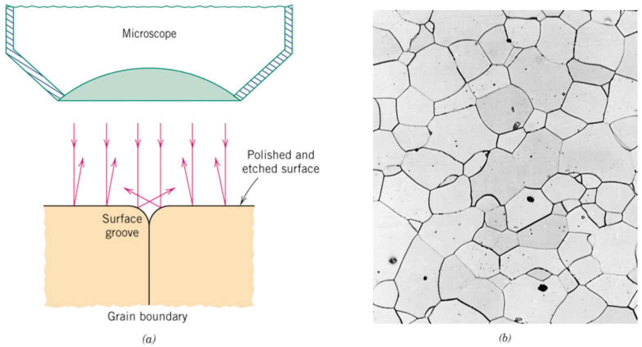
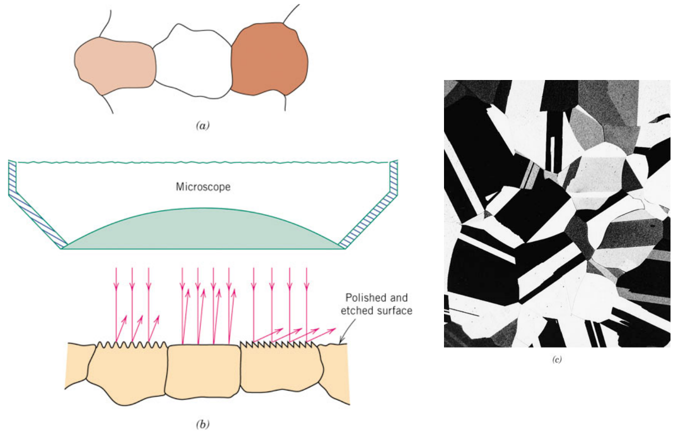


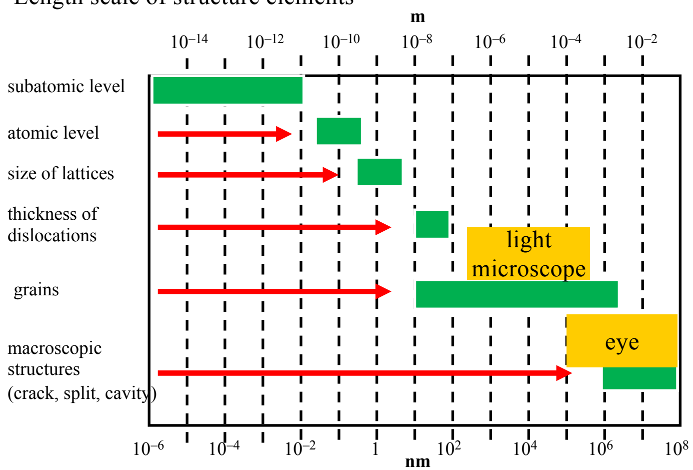
Image formation of a light microscope from a polished reflecting surface



The microscopic image of a partly polished reflecting surface



Length scale of structure elements



How to improve the resolution?

Electron microscope (textbook ch. X/5.)

Theoretical bases of electron microscope

memo: the resolution depends on the wavelength! $\delta \approx \frac{\lambda}{NA}$!

Does the electron have wave character?

de Broglie's idea: $\lambda = \frac{h}{m \cdot v} = \frac{h}{p}$
(1923)

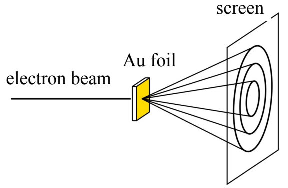
Planck constant (6.63×10^{-34} Js)

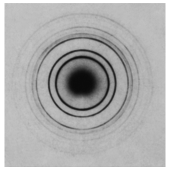
momentum of the electron

The wave nature and a certain wavelength have to be associated to every material mass!

The electron beem should have diffraction!

Experimental verification: Davisson and Germer (1927)





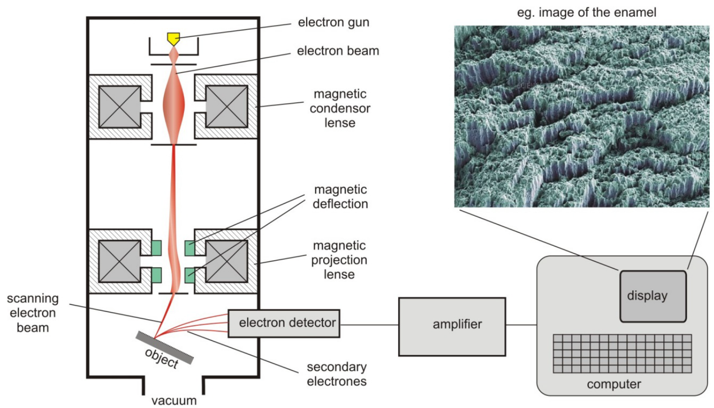
How small is the limit of resolution?

$\lambda \approx 0{,}005$ nm

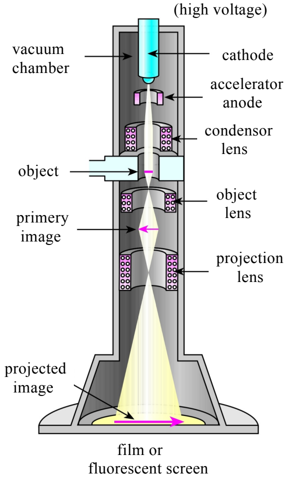
NA $\approx 0{,}03$ → $\delta \approx 0{,}2$ nm

opens up the possibility of imaging sub-cellular details

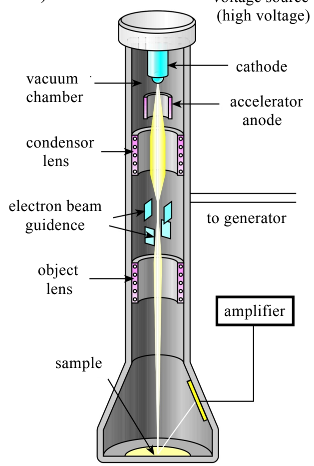
How is it operating?



Transmission electron microscope (TEM)



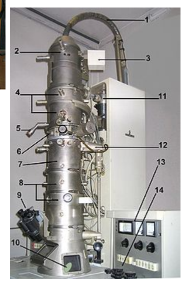
Scanning electron microscope (SEM)



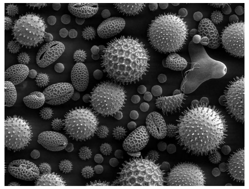
SEM in a Geological Survay

SEM opened sample chamber

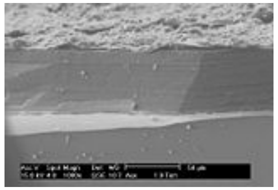
The first TEM (now on display at Deutsches Museum in Munich, Germany)



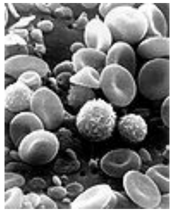
TEM applied nowdays



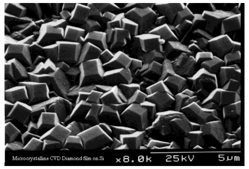
SEM image of pollen grains



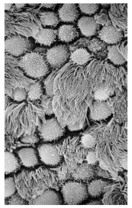
SEM image of corrosion layer on the surface of an ancient glass fragment



SEM image of normal circulating human blood

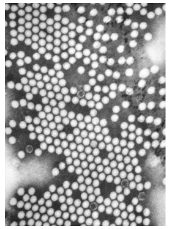


SEM image of microcrystalline diamond film on Si

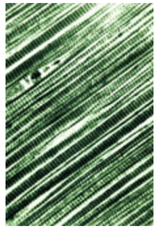


SEM image of trachea epithelium

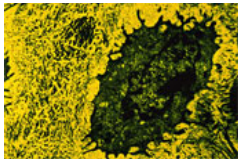
TEM image of heart muscle



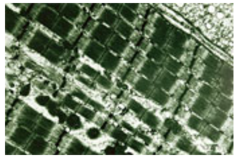
TEM image of polio virus



TEM image of collagen fibers

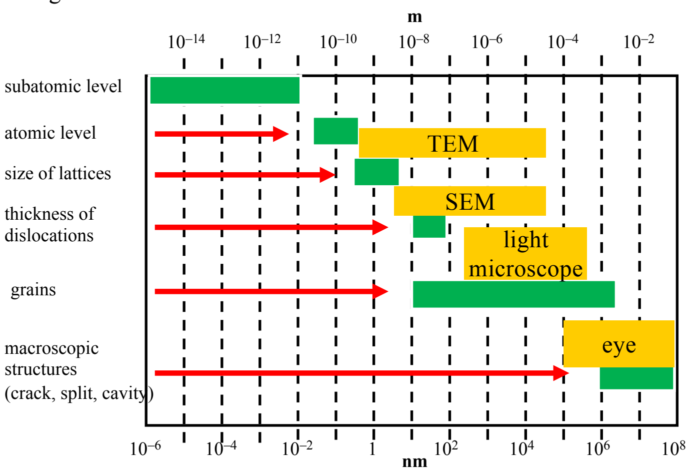


TEM image of bone cells



TEM image of sceletal muscle

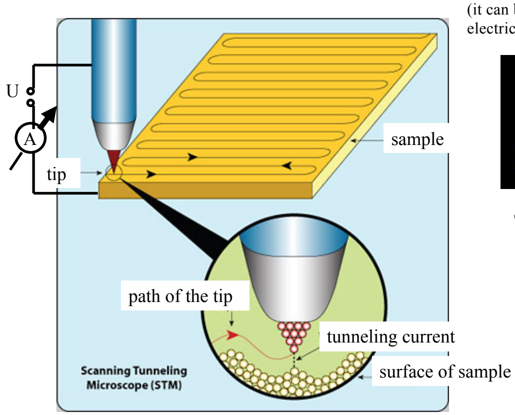
Length scale of structure elements

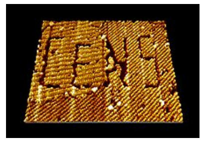


How to analyse the atomic and subatomic level?

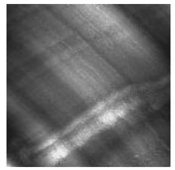
Scanning tunneling microscope (STM)

exploits the tunneling effect of electrons between two conducting surfaces
(it can be used only for electrically coducting materials)





organic semiconductor monolayer on grafit

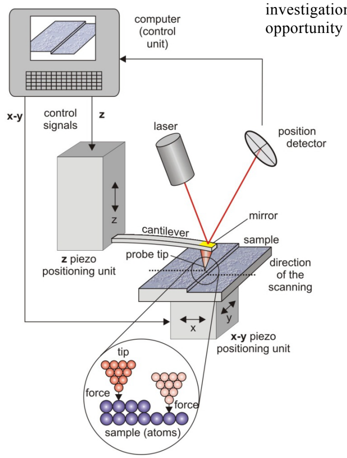


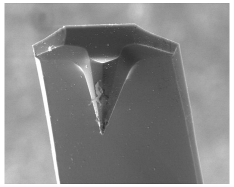
collagen

Atomic force microscope (AFM)

(textbook ch. X/2.)

advantages →
- information of surface thopography of the sample
- high resolution examination of various surface structures
- investigation of structures under the plasma membrane of cell
- opportunity to measure close to physiological conditions





the tip of the cantilever

the measured parameter is the force between the tip and the sample

(Piezoelectricity)

(textbook ch. VIII/4.2.1)

1880 P. and J. Curie (piesmos = pressure, compression)

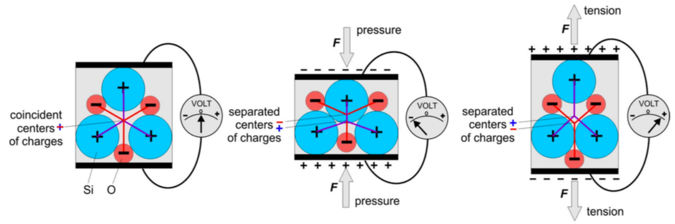
quartz crystal

Piezoelectric effect

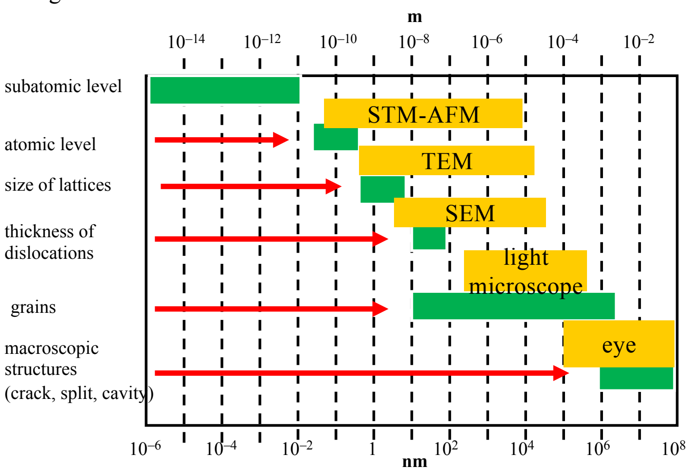
mechanical deformation (preassure) leads to charge separation

Inverse piezoelectric effect

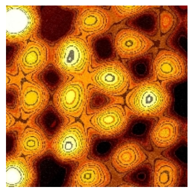
mechanical deformation of the crystal in the electric field



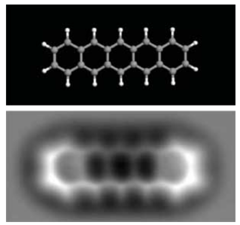
Length scale of structure elements



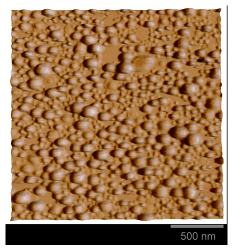
How to analyse the lower levels?



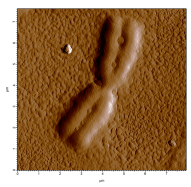
Si crystal (3*3 nm)



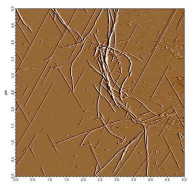
pentacene molecule



liposomes on mica surface



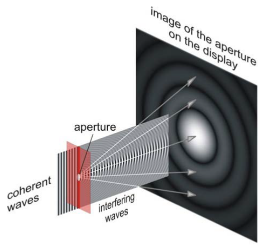
human chromosome



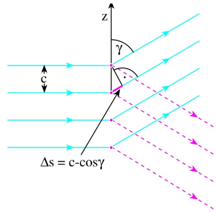
amiloid fibers

Diffraction methodes

(textbook ch. X/6.)



$$d \cdot \sin\alpha = k \cdot \lambda$$

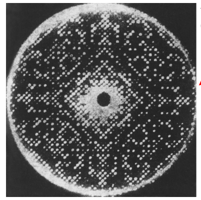


neutron diffraction (λ ~ 0.1 nm)

X-ray diffraction (λ ~ 0.01-01 nm)

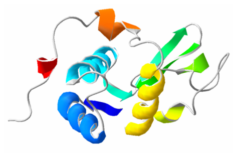
electron diffraction (λ ~ 0.01 nm)

diffraction of X ray on a one dimensional crystal

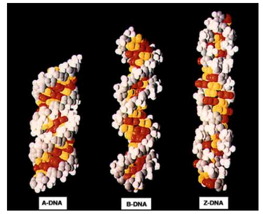


X-ray diffraction image of the crystalized lysozyme enzyme

X-ray diffraction image of the crystalized DNA

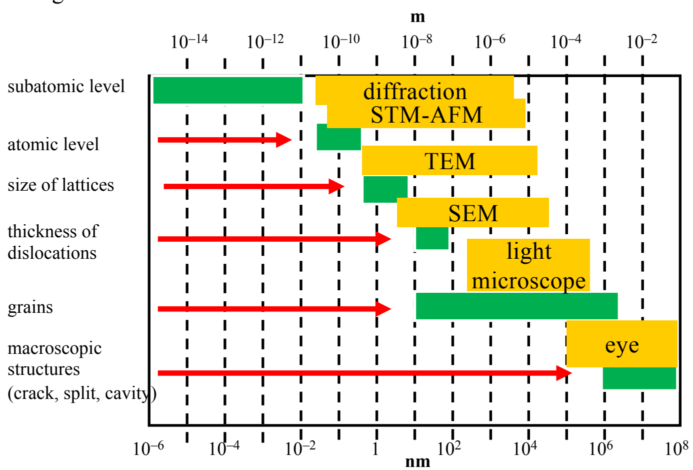


the molecular structure of lysozyme enzyme based on the X-ray diffraction



the molecular structures of DNA based on the X-ray diffraction

Length scale of structure elements



How to go deeper???

Summary of structure analysis

- eye
- microscopy
  - light
  - electron (TEM, SEM)
  - surface scanning (STM, AFM)
- diffraction methodes
  - neutron
  - X - ray
  - electron
- spectroscopic methodes
  - absorption (UV, VIS, IR)
  - emission (fluorescence, phosphorescence, X-ray fluorescence)
  - Raman
  - magnetic resonance (NMR, ESR)
  - CD spectroscopy

How large is the smallest resolved distance in a microscope, if the wavelength of the illumination light is 515 nm, the half angle of the microscope is 72° ?

$$\delta = 0{,}61 \frac{\lambda}{n \cdot \sin \omega}$$

$$\delta = 0{,}61 \frac{515}{1 \cdot \sin 72^{o}} = 330{,}4 nm$$

How this distance will change, if we use a 1,54 refractive index immersion oil instead of the air?

$$\delta = 0{,}61 \frac{515}{1{,}54 \cdot \sin 72^{o}} = 214{,}5 nm$$

How large is the smallest resolved distance in an electron microscope, if the wavelength of the electron beam is 0,01 nm, and the numerical aperture of the microscope is 0,02?

$$\delta = \frac{\lambda}{NA} = \frac{0{,}01}{0{,}02} = 0{,}5 nm$$

How large is the speed of the electrons in this microscope?

$$\lambda = \frac{h}{m \cdot v} = \frac{6{,}6 \cdot 10^{-34}}{9{,}1 \cdot 10^{-31} \cdot v} = 0{,}01 \cdot 10^{-9} (m)$$

$$v = 7{,}25 \cdot 10^{7} (m/s)$$

We examine the gold crystal structure with electron diffraction. The wavelength of the electron beam is 60 pm. The first order interference maximum has 8.5° degree. How large is the distance between the gold atoms?

$$d = \frac{\lambda}{\sin 8{,}5} = \frac{60}{\sin 8{,}5} = 75.1 pm$$