Physical bases of dental material science

Methodes of structure analysis

Irén Bárdos-Nagy

Why it is important?

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

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for the goal of proper application we should know the structure

The materials can failure:
- fatigue
- fracture
- rupture
- thermal shock
- wear
- buckling

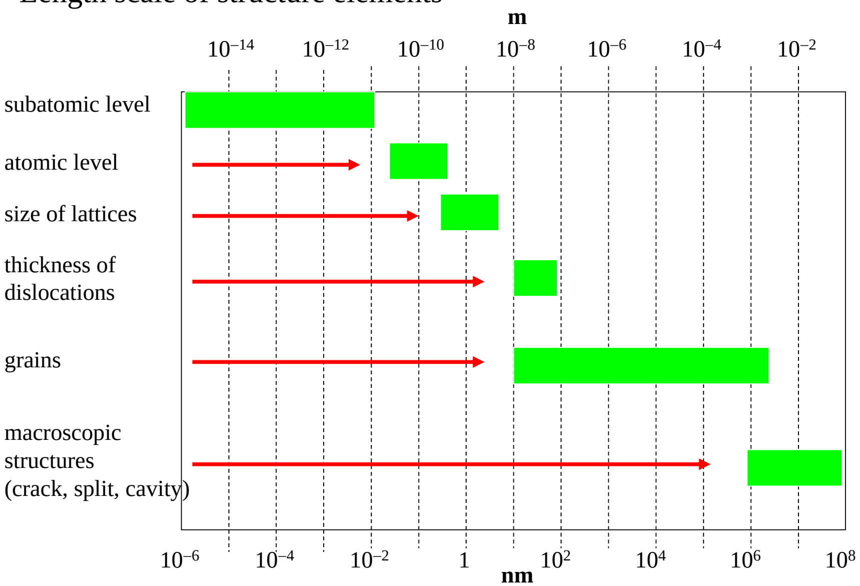
→ we have to recognize it

To improve our knowledge to develope the properties of materials

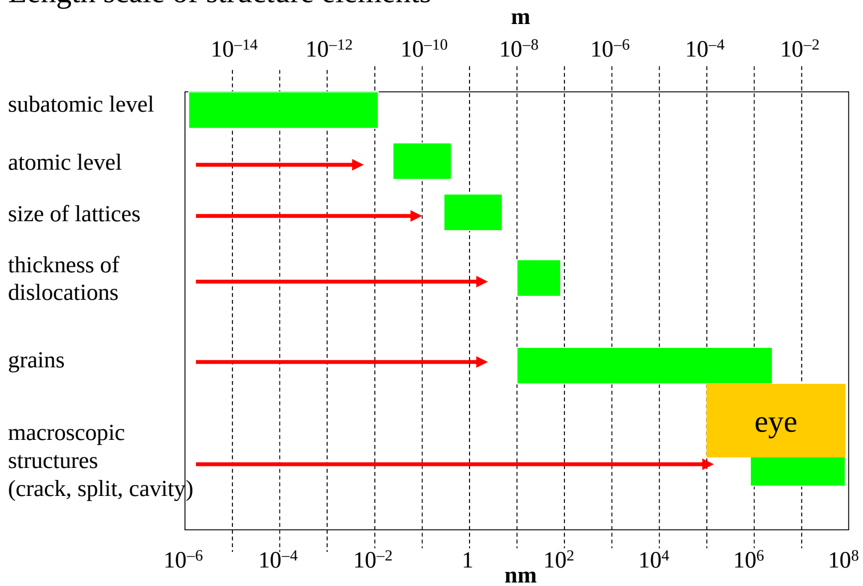
↓

we have to analyse the structure

Length scale of structure elements



Length scale of structure elements

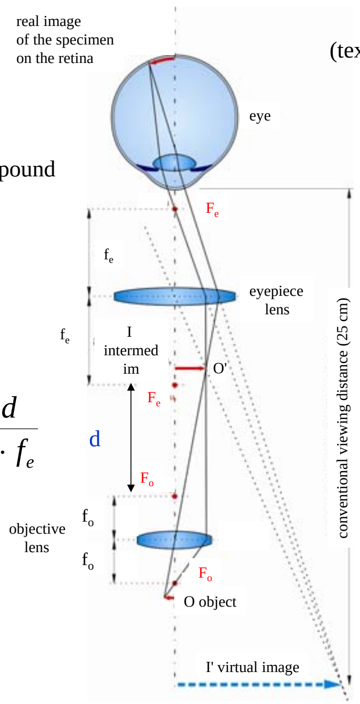


How can we see the smaller details?

Light microscope

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

image formation of the compound microscope

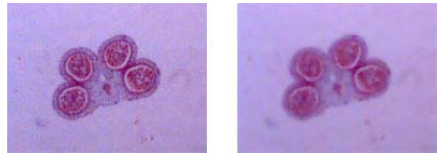


magnification:

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

(cc. 2000)

the smallest resolved distance



wavelength of illumination light

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

$$\delta \approx \frac{\lambda}{NA}$$

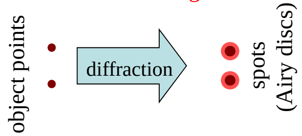
refractive index   half angle of the objective lens

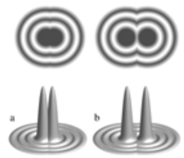
numerical aperture

$\delta \approx 200$ nm

the reason of limited resolution:

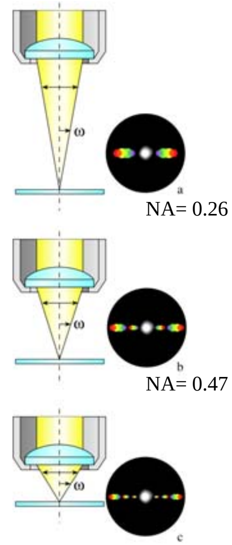
diffraction of light





not resolved   just resolved

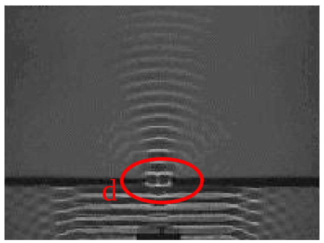
close points of the object



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.

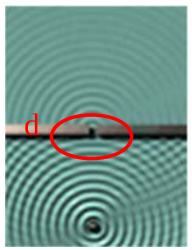


d/λ >> 1

week diffraction

d/λ ~ 1

strong diffraction



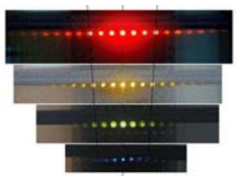
Conditions of constructive and destructive interference

constructive interference:

Δs=k*λ

destructive interference:

Δs=(1+k/2)*λ



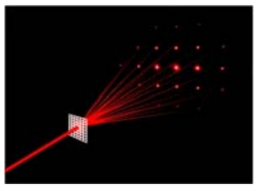
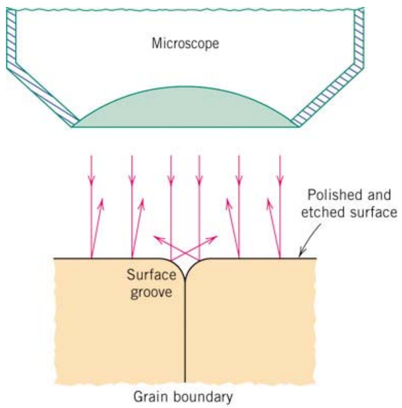
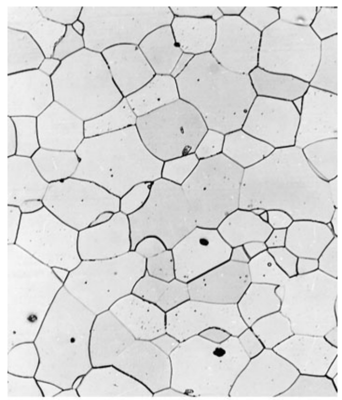


Image formation of a light microscope from a polished reflecting surface

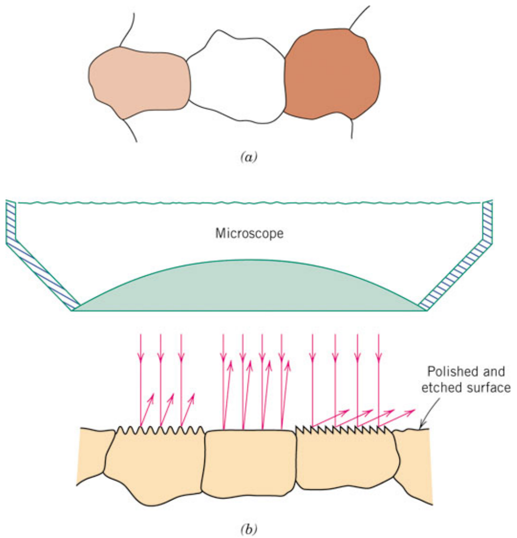


(a)

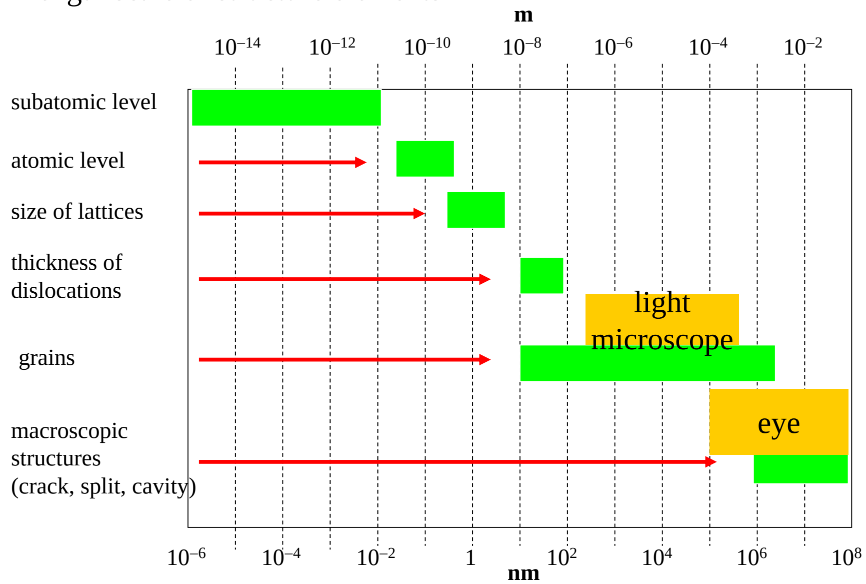


(b)

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!

$$\delta \approx \frac{\lambda}{\mathrm{NA}}!$$

Has the electron wave character?

de Broglie's idea: (1923)

$$\lambda = \frac{h}{m \cdot v} = \frac{h}{I}$$

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!

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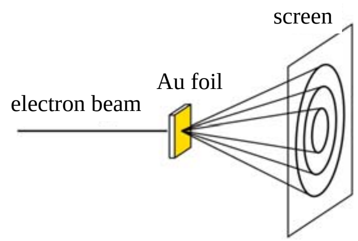
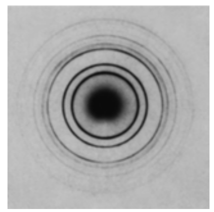
The electron beem should have diffraction!

Experimental verification: Davisson and Germer (1927)





How large can be the resolved distance?

$\lambda \approx$ 0,005 nm

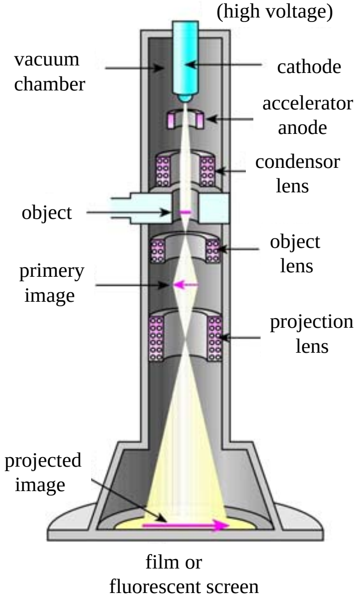
NA $\approx$ 0,03

→ $\delta \approx$ 0,2 nm

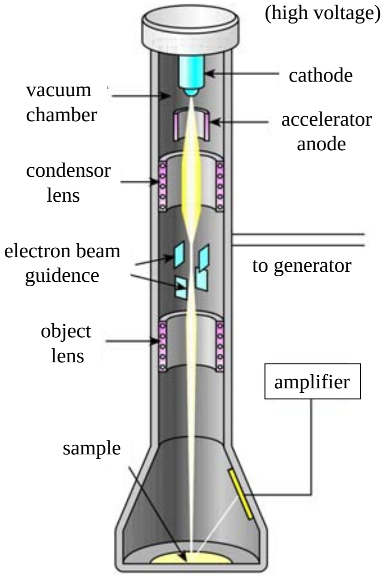
opens up the possibility of imaging sub-cellular details

How it is operating?

Transmission electron microscope (TEM)



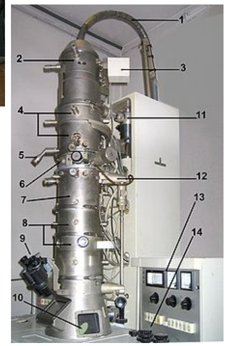
Scanning electron microscope (SEM)



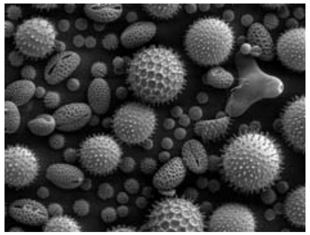
SEM in a Geological Survey

SEM opened sample chamber

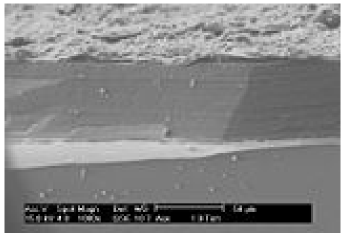
The first TEM (now on display at Deutsches Museum in Munich, Germany)



TEM applied nowdays

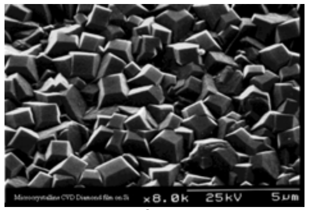


SEM image of pollen grains

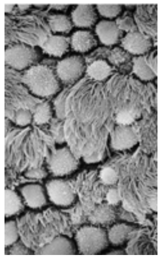


SEM image of corrosion layer on the surface of an ancient glass fragment

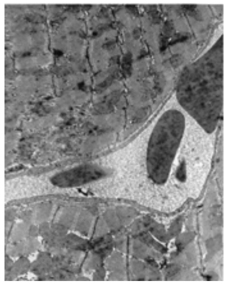
SEM image of normal circulating human blood



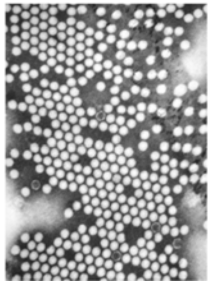
SEM image of microcrystalline diamond film on Si



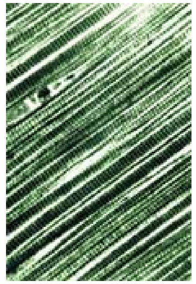
SEM image of trachea epithelium



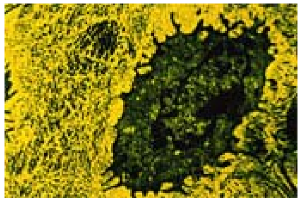
TEM image of heart muscle



TEM image of polio virus



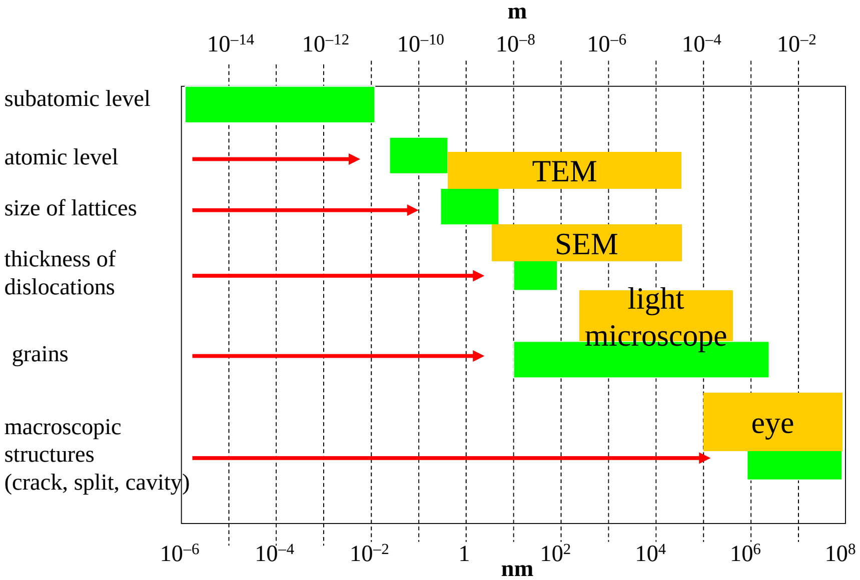
TEM image of collagen fibers



TEM image of bone cells

TEM image of sceletal muscle

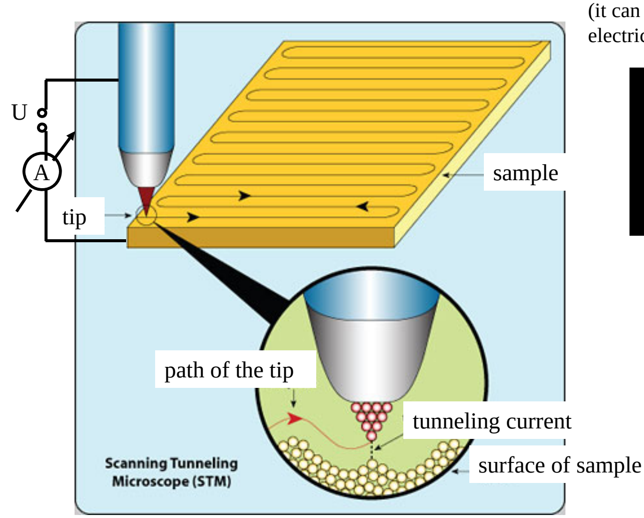
Length scale of structure elements

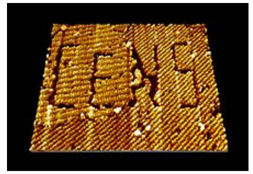


How to analyse the atomic and subatomic level?

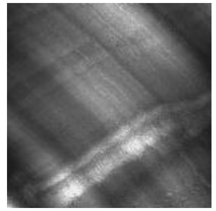
Scanning tunneling microscope (STM)

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





organic semiconductor monolayer on grafit

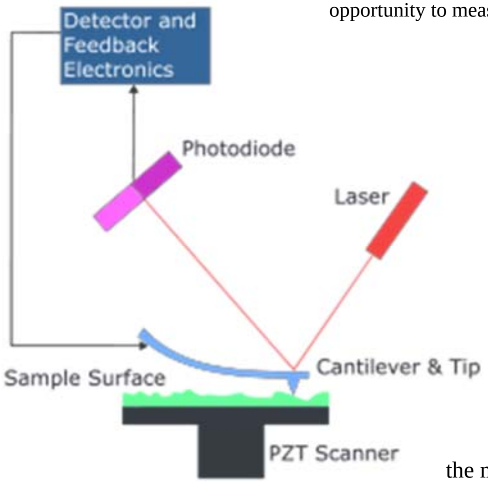


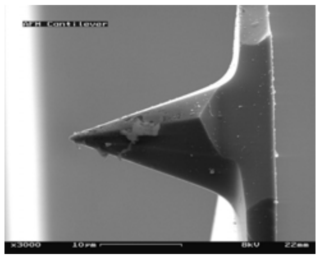
collagen

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 the force between the tip and the sample

(Piezoelectricity)

(textbook ch. VIII/4.2.1)

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

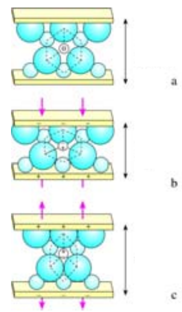
quartz crystal

Piezoelectric effect

mechanical deformation (preassure) leads to charge separation

Inverse piezoelectric effect

mechanical deformation of the crystal in the electric field

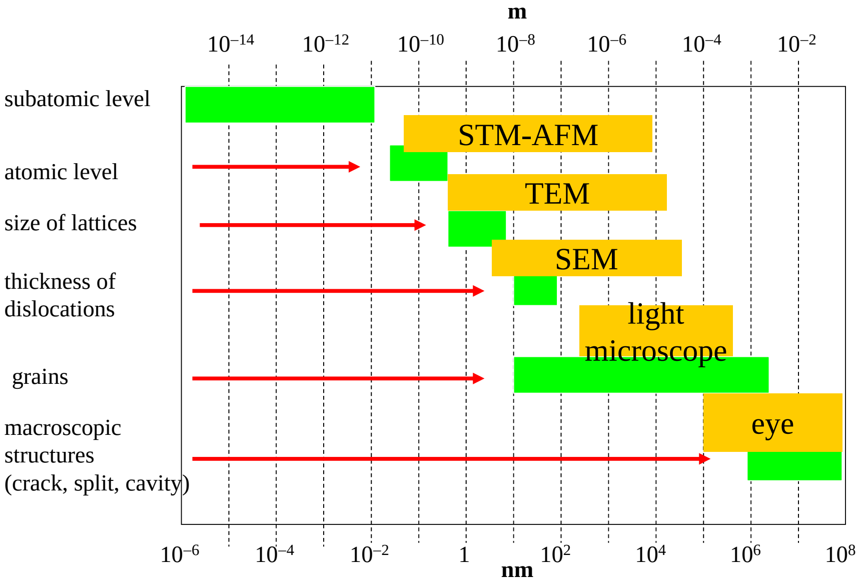


equilibrium state

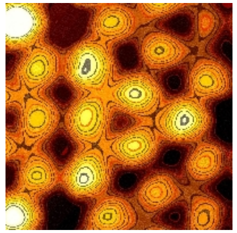
compression

stretching

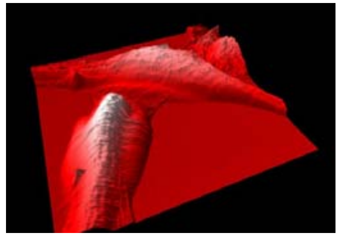
Length scale of structure elements



How to analyse the lower levels?

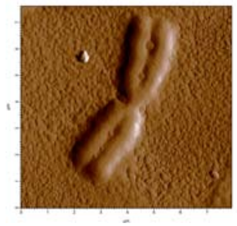


Si crystal (3*3 nm)

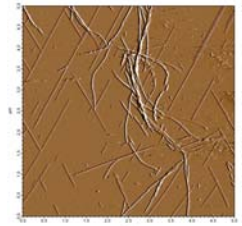


bone cells on Ti surface

liposomes on mica surface



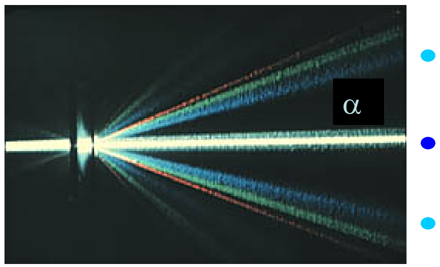
human chromosome



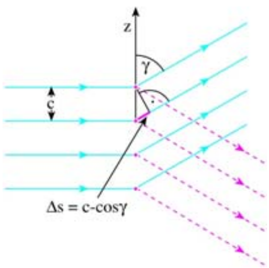
amiloid fibers

Diffraction methodes

(textbook ch. X/6.)



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

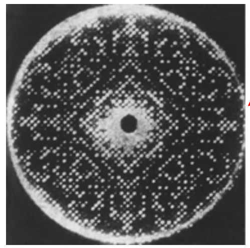


diffraction of X ray on a one dimensional crystal

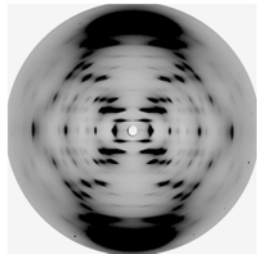
neutron diffraction (λ ~ 0.1 nm)

X-ray diffraction (λ ~ 0.01-01 nm)

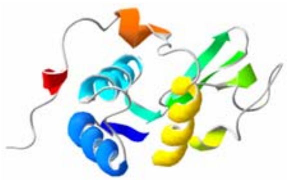
electron diffraction (λ ~ 0.01 nm)



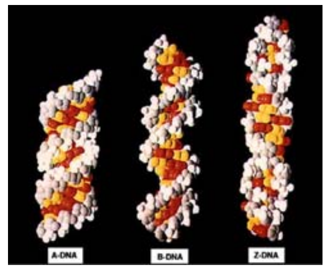
X-ray diffraction image of the crystalized lysozyme enzyme



X-ray diffraction image of the crystalized DNA

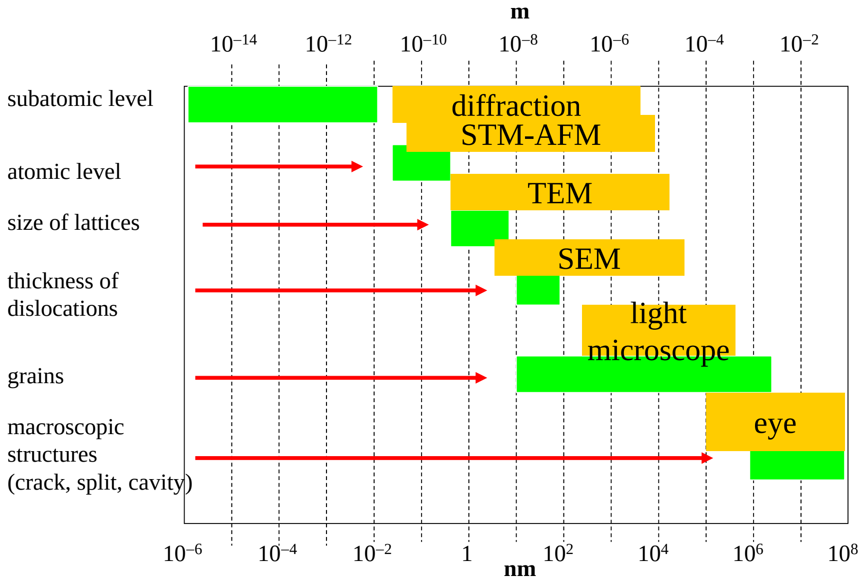


the molecular structure of lysozyme enzyme based on the X-ray diffraction



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 510 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?

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

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