Physical Bases of Dental Material Science 6.

Methods of structural analysis

Keywords:
- ❖ electronmicroscopes
- ❖ Scanning probe microscopes
- ❖ X-ray diffraction

E-book chapter 8.

Problems: 2.1-7, 2.10

Why do we need structural analysis?

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

↓

for proper application we should know the structure

Common material failures: fatigue, fracture, rupture, thermal shock, wear, buckling → we have to recognize it

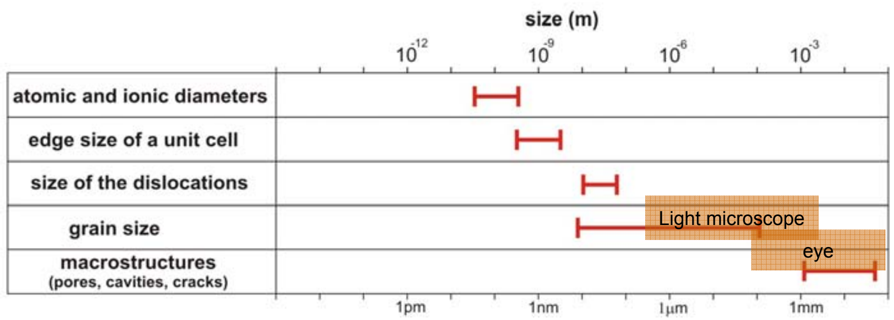
To improve our knowledge to develope the properties of materials

↓

we have to analyse the structure

http://www.htwins.net/scale2/

Size range of material structures



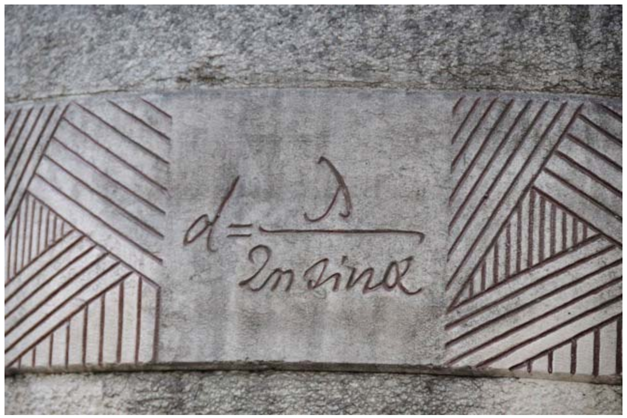
- **eye** limit of resolution: ≈1' ⇒ from a distance of 25 cm ≈0,1 mm
- **light microsope (Biophysics)** Limit of resolution: ≈200 nm

δ: limit of resolution

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

Abbe formula

$$\delta = 0.61\frac{\lambda}{n \sin \omega} = 0.61\frac{\lambda}{\text{NA}}$$



Ernst Karl Abbe (1840-1905) One of the founders of Zeiss company

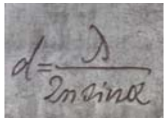
Light microscope

Magnification:

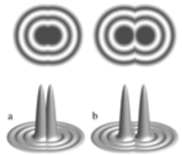
$$M = M_{obj} \cdot M_{oc} = -\frac{d \cdot a}{f_{obj} \cdot f_{oc}}$$

Limit of resolution:

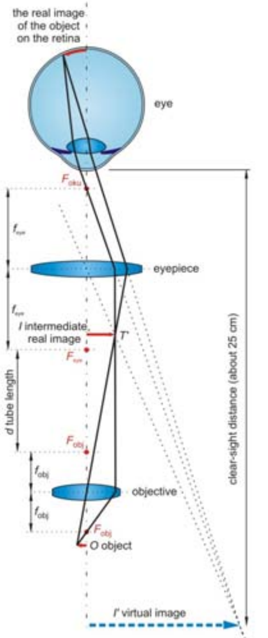
$$\delta = 0.61 \frac{\lambda}{n \sin \omega} = 0.61 \frac{\lambda}{\text{NA}}$$



Abbe formula

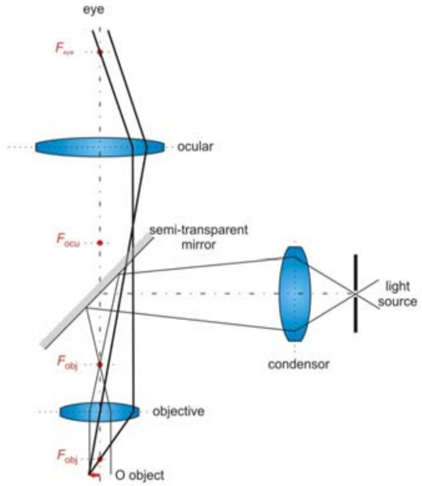


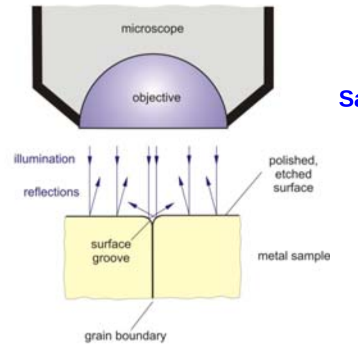
not resolved   just resolved
close points of the object

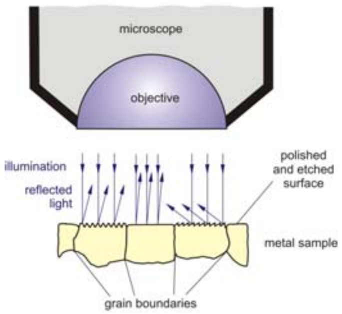


Resolving power: $f = \frac{1}{\delta}$

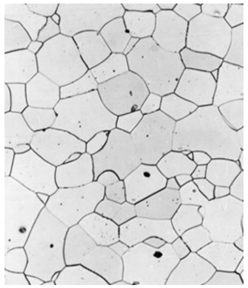
Metal microscope (surface analysis of non transparent materials)







Sample preparation:
- **polishing**
- **etching**



Electronmicroscope

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

Working bases: Electron beam, as matter wave

Theoretical hypothesis:
de Broglie-wavelength
(1923):

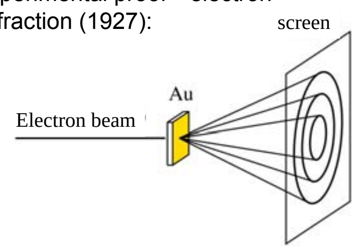
$$\lambda = \frac{h}{mv}$$

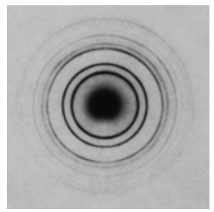
Planck's constant (h = 6,63·10^{-34} J/s)

Momentum of electron

Louis de Broglie
(1892-1987)
physicist

Experimental proof– electron diffraction (1927):

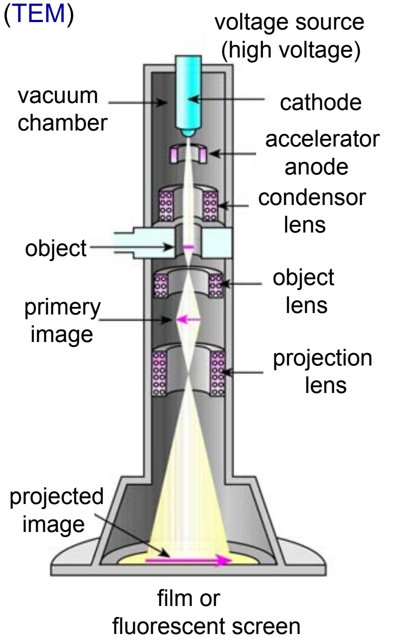




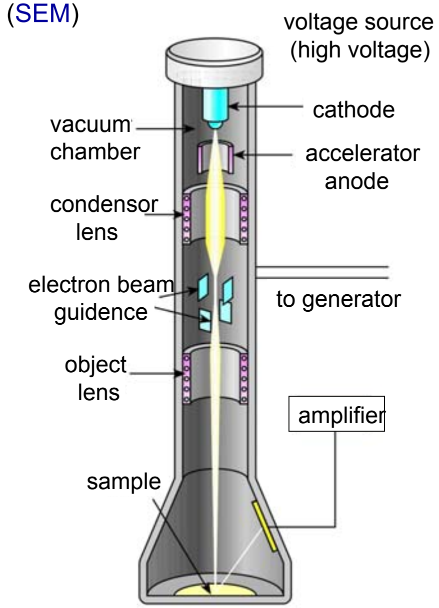
Clinton Davisson
(1881-1958)
Lester Germer
(1896-1971)
physicists

$\lambda \approx$ 0,005 nm
NA $\approx$ 0,03
→ $\delta \approx$ 0,2 nm

Transmission electron microscope (TEM)

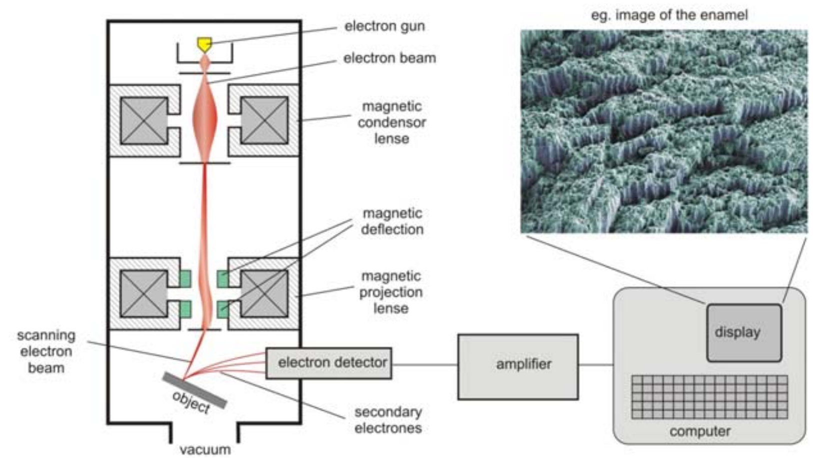


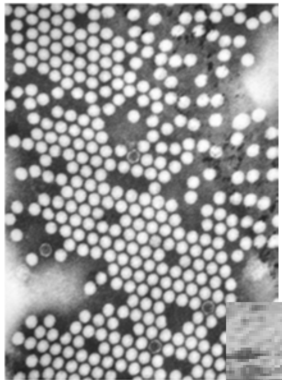
Scanning electron microscope (SEM)



Transmittion electronmicroscope (**TEM**) - Biophysics!

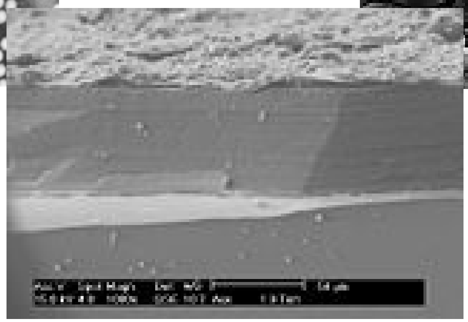
Scanning electron microscope (**SEM**)



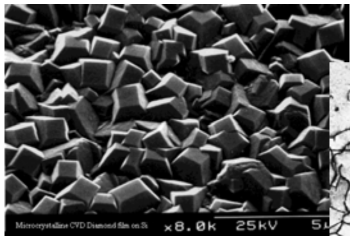


Virus capsids
(TEM)

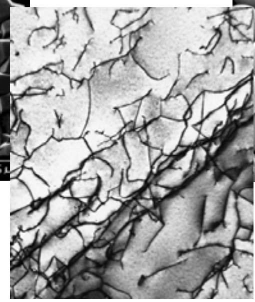
Human blood
(SEM)



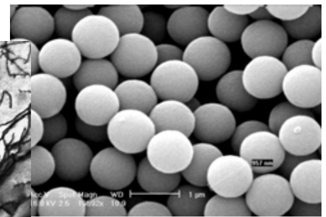
Corrosion layer on the surface of an antient glass piece
(SEM)



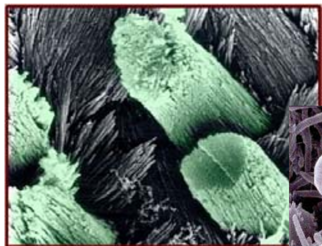
Diamond cristals
(SEM)



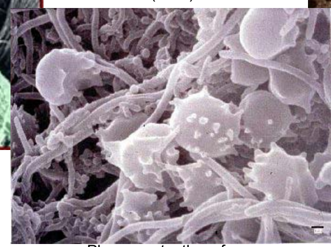
Disslocation in titanium
(SEM)



TiO microspheres
(SEM)

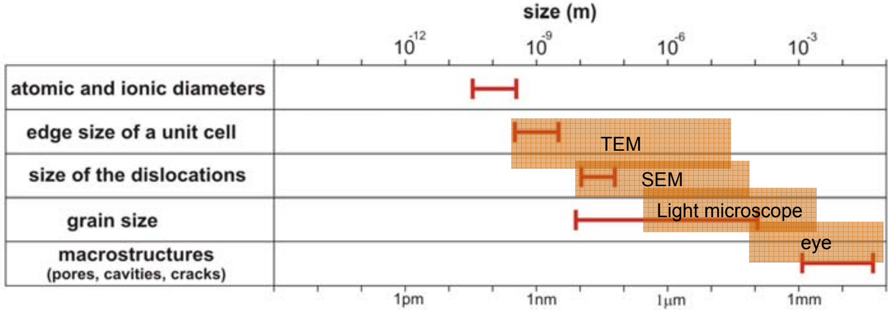


apatite christallites in the enamel
(SEM)



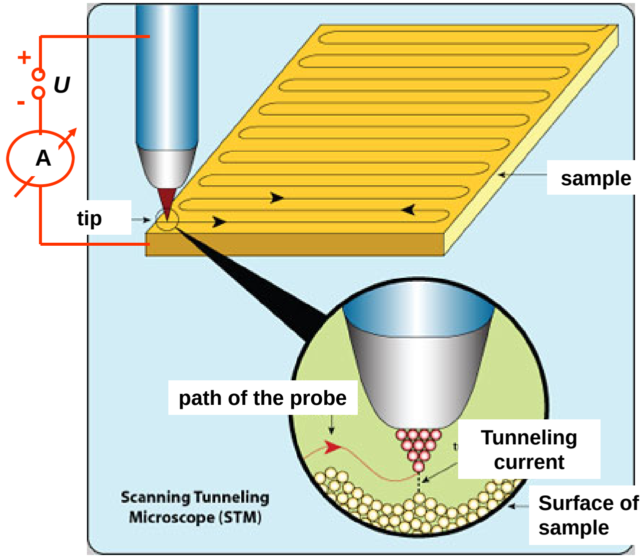
Plaque on tooth surface
(SEM)

dentin chanels with
odontoblast appendages
(SEM)

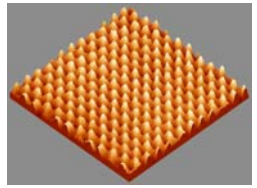


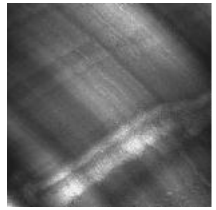
Scanning probe microscopes

Scanning tunneling microscope (**STM**)



graphene

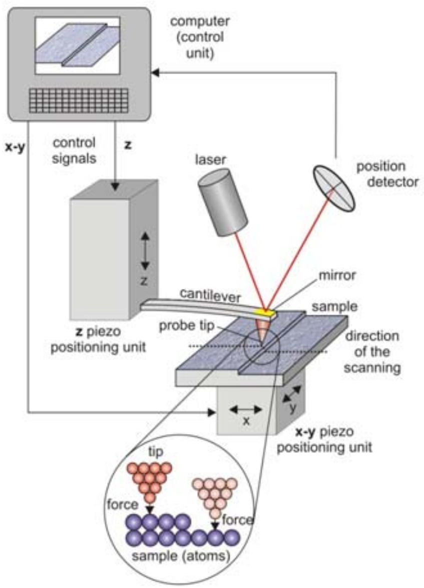


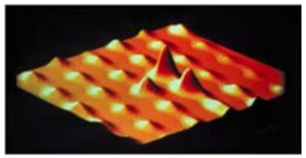


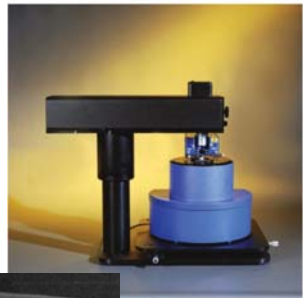
collagen

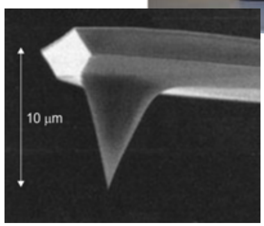
(Bioviphysics – Resonance lab manual!)

Atomic Force Microscope - AFM









Outlook: piezoelectricity

1889 P. Curie (piezein = compress *greek*)

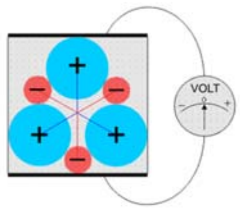
f.e.: quartz

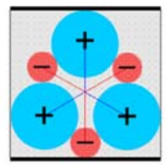
Piezoelectric effect:

deformation ⇒ electric field, voltage

inverse piezoelectric effect:

voltage ⇒ deformation

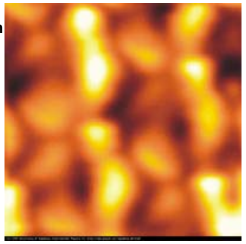




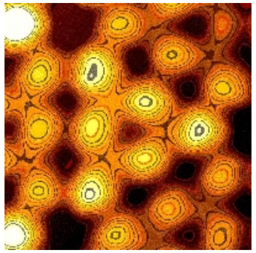
$$U = \delta \cdot \Delta x$$

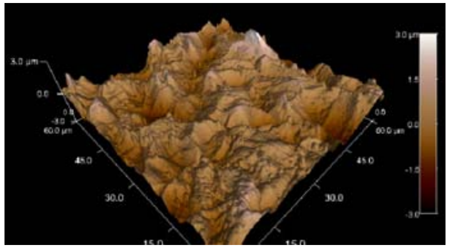
For quartz: $\delta \approx 10^{12}$ V/m

W atom 0,5x0,5 nm

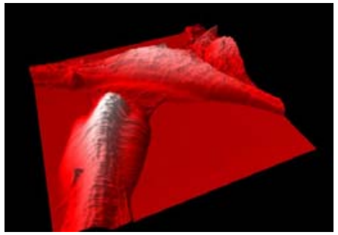


Si chrystal 3x3 nm



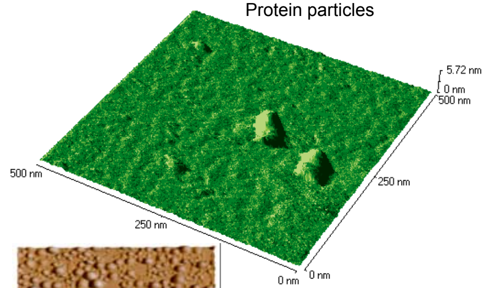


Etched surface of Ti

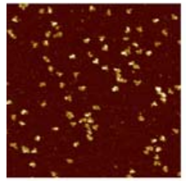


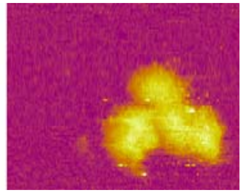
Bone cells on Ti surface

Protein particles



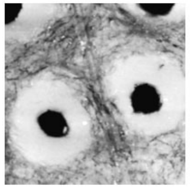
Immunoglobulin

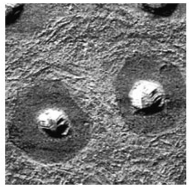


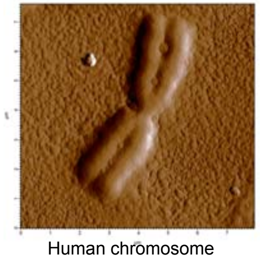


liposomes

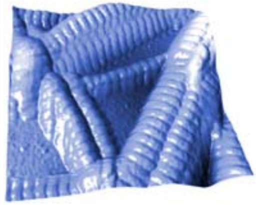
dentin canals



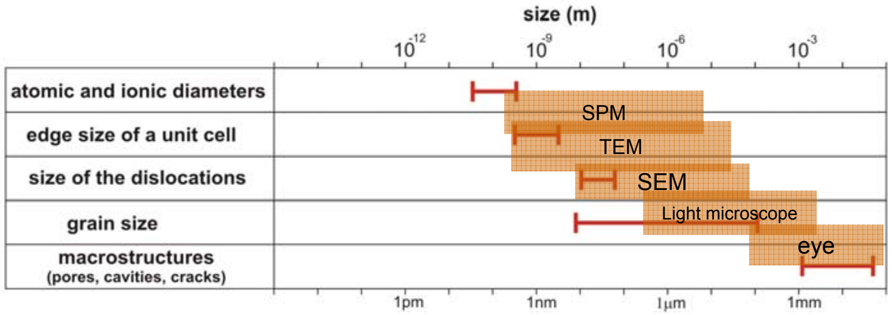




Human chromosome

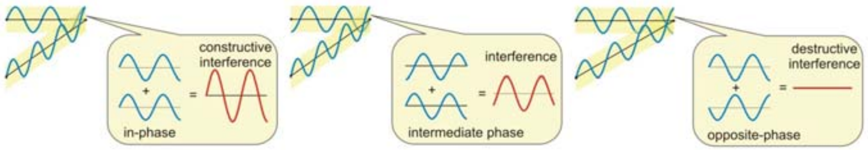


Collagen

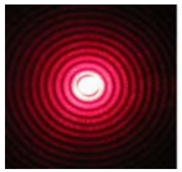


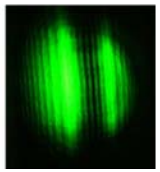
Interference, diffraction

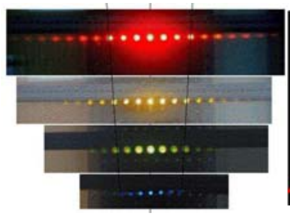
Interference

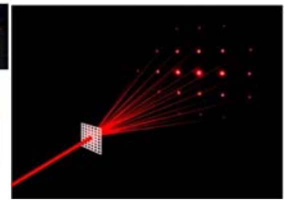


Diffraction









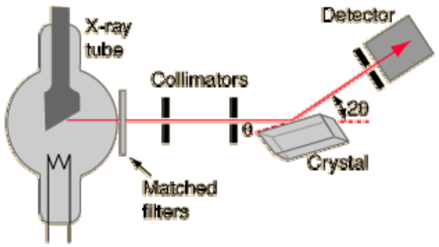
$d/\lambda >> 1$: weak diffraction

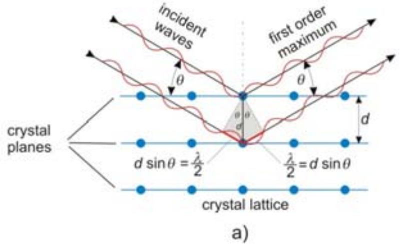
$d/\lambda >= 1$: strong diffraction

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

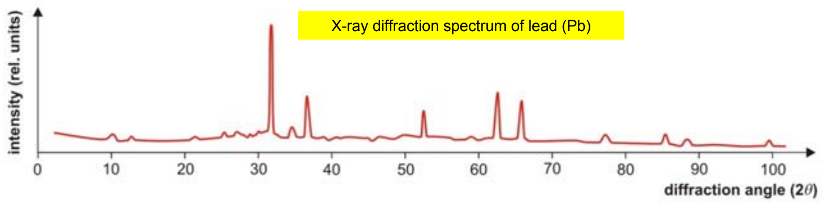
Diffraction methods

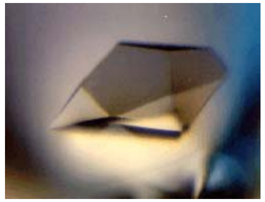
- X-ray diffraction $\lambda \approx$ 0,01-0,1 nm
- Neutron diffraction $\approx$ 0,1 nm
- Electron diffraction $\approx$ 0,01 nm





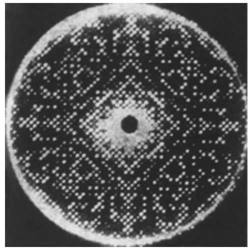
Bragg-equation: $2d\sin\theta = n\cdot\lambda$

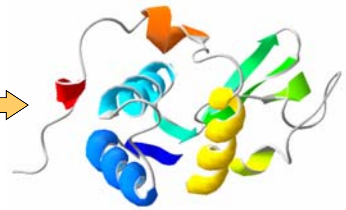


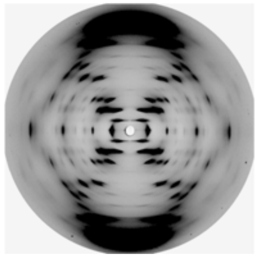


protein christal

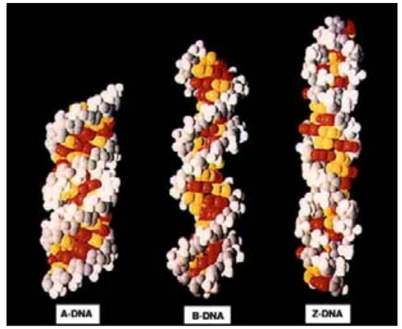
lizozim enzyme



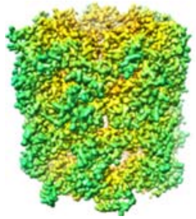




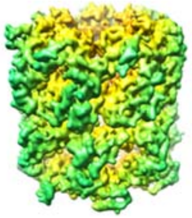
dsDNA



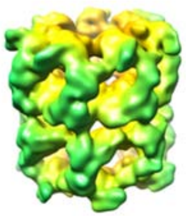
GroEL at different resolution:



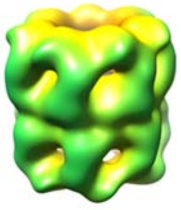
0,4 nm



0,8 nm

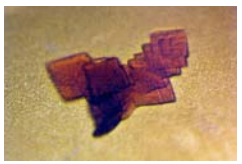


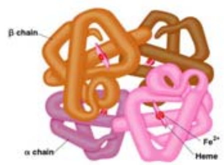
1,6 nm

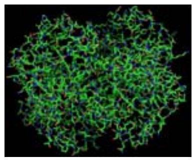


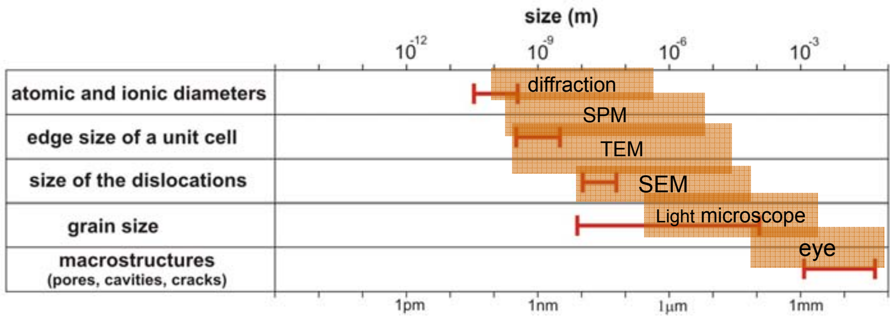
3,2 nm

Hemoglobin:









Calculate the smallest distance resolved in a microscope, if the wavelength of the illuminating light is 515 nm, and the half aperture angle of the microscope is 72° ?

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

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

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

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

Calculate the resolution of a TEM, if the applied high voltage is 5 kV, and the aperture angle of the magnetic lens is 6° ?