I

Introduction to TEM

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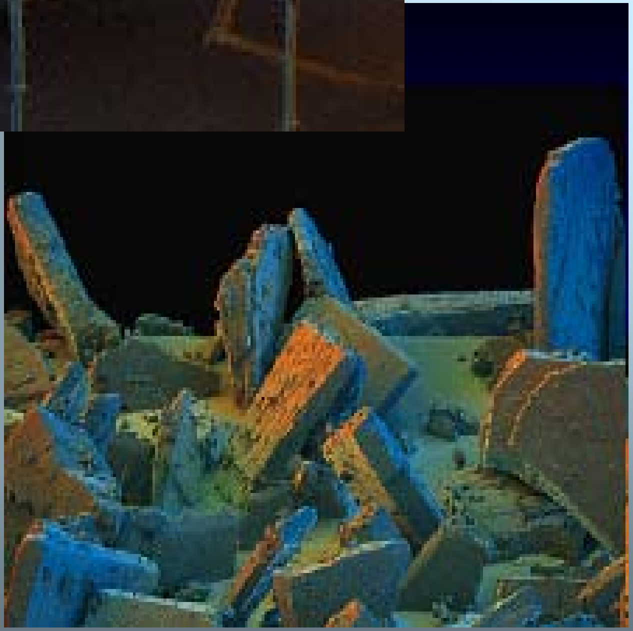
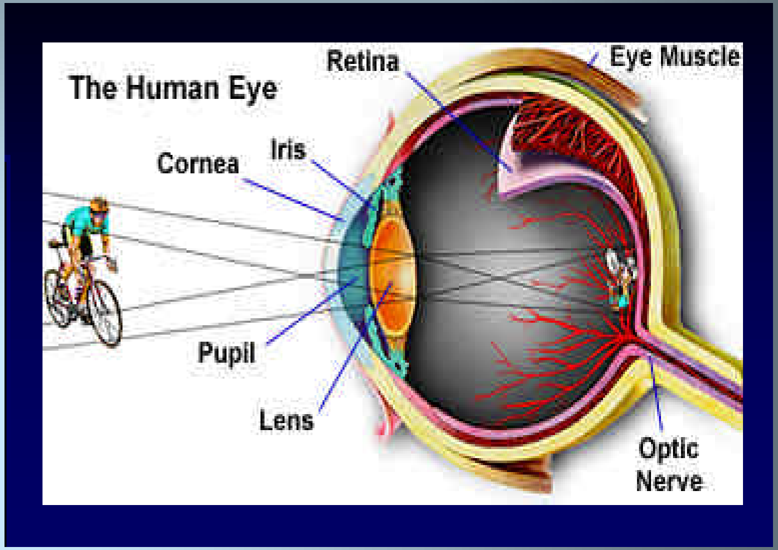
TEM
LAB

IMIM PAN – KRAKÓW – 2019

Why do we need microscopy?





resolution of human eye
0.2~ 0.1 mm

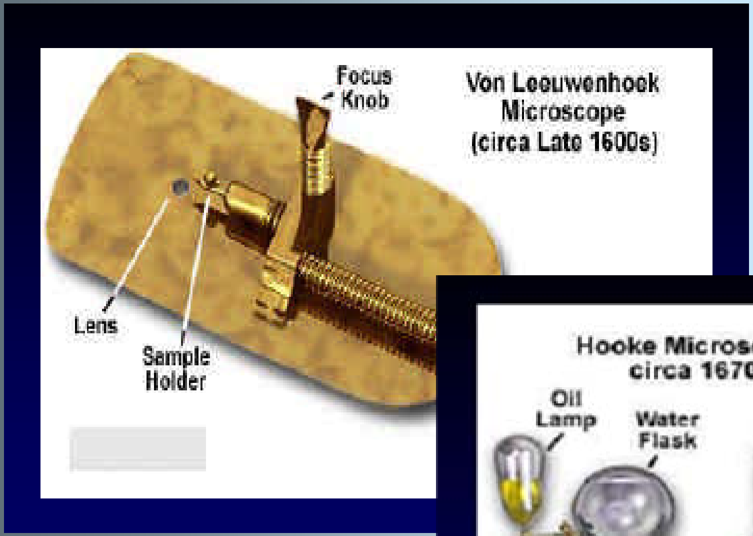
Chronolgy: Part I. Finding out about „mini-world”

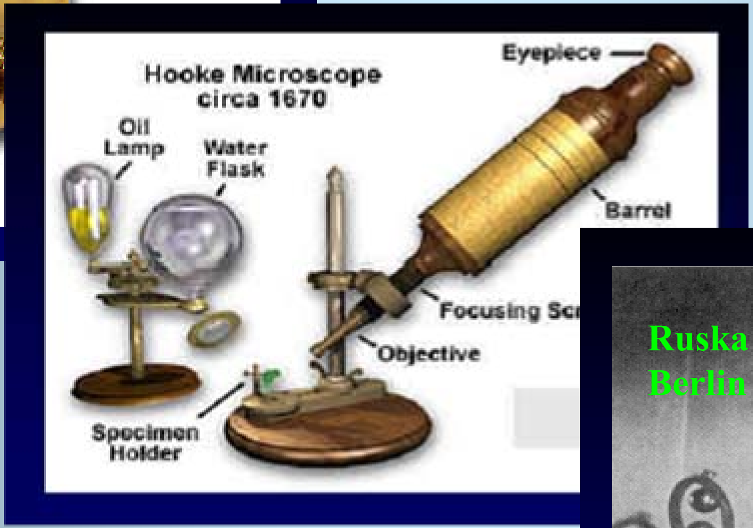
resolution for light microscope is defined by Rayleigh criterion:

$\delta = 0.61\lambda/\mu\sin\beta$ (0.2 μm) λ - wavelength of light (~0.5 μm)

μ- refractive index of glass (~1.5)

β – lens collection semiangle (70°)





$\delta = 0.61\lambda/\mu\beta$ (0.002 mm?)

λ - wavelength 100kV e^- (~0.004 nm)

μ - refractive index of vaccum (~1)

β – semiangle of collection of lens (1°)

Chronolgy: Part II. Finding out about „micro-world”

mini-world → **1960** → **μ-world** → **2000** → **nano-world**

JEOL 5, 6 (70~100 kV)	Philips EM 300 (100~120 kV)	Philips CM 20, 30 (200~300 kV)	Tecnai (200~300 kV)

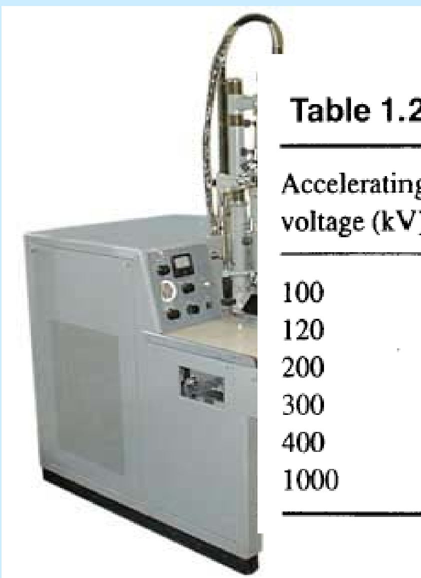
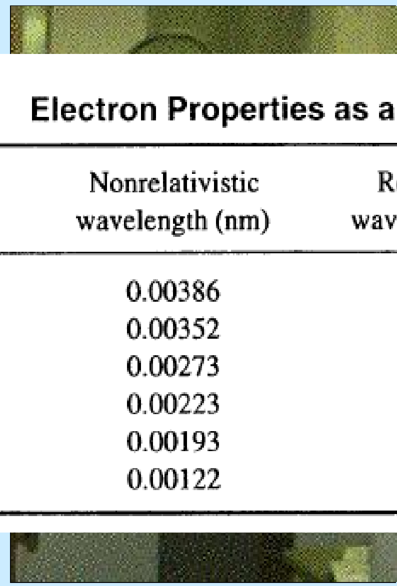
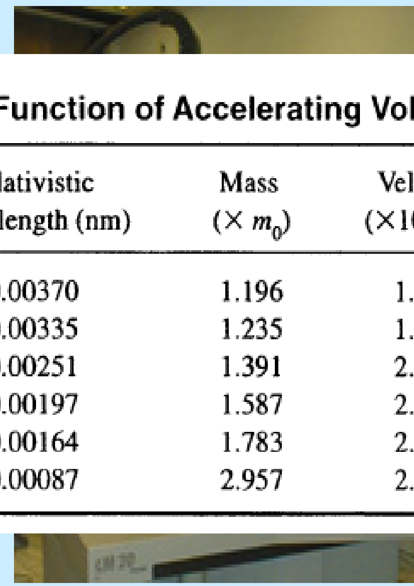
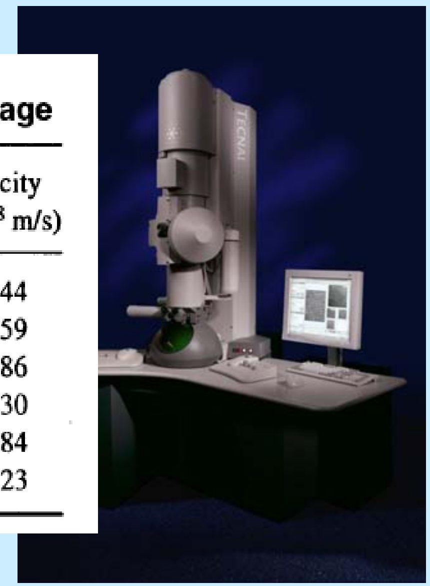





Table 1.2. Electron Properties as a Function of Accelerating Voltage

Accelerating voltage (kV)	Nonrelativistic wavelength (nm)	Relativistic wavelength (nm)	Mass ($\times m_0$)	Velocity ($\times 10^8$ m/s)
100	0.00386	0.00370	1.196	1.644
120	0.00352	0.00335	1.235	1.759
200	0.00273	0.00251	1.391	2.086
300	0.00223	0.00197	1.587	2.330
400	0.00193	0.00164	1.783	2.484
1000	0.00122	0.00087	2.957	2.823

res. ~1 nm /lamps/	res. ~0.3 nm /transistors/	res. ~0.2 nm /int. circuits/	res. ~0.1 nm /int. circuts/

Rrelation magnification - resolution

Magnification: ratio of image size to object size

Powiększenie: stosunek wielkości obiektu do obrazu

Resolution: ability to resolve objects

Rozdzielczość: zdolność do rozróżnienia obiektów

$$\text{Magnification}_{\text{max.sens.}} = \frac{\text{res. of human eye (0.2 mm)}}{\text{res. of microscope (r)}}$$

max „sensible" magnifications:

light/optical microscope (r= 200 nm) => mag. 1 000x

Transmission microscope (r= 0.2 nm) => mag. 1 000 000x

depth of field / depth of focus

depth of field is used in reference to investigated object

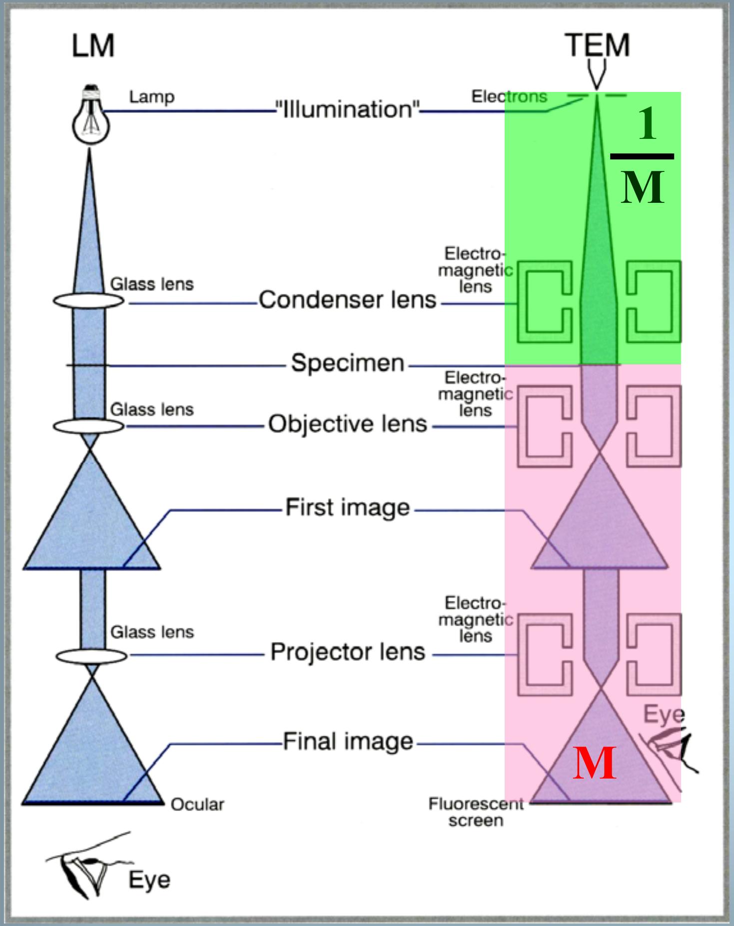
depth of focus is used in reference to the image

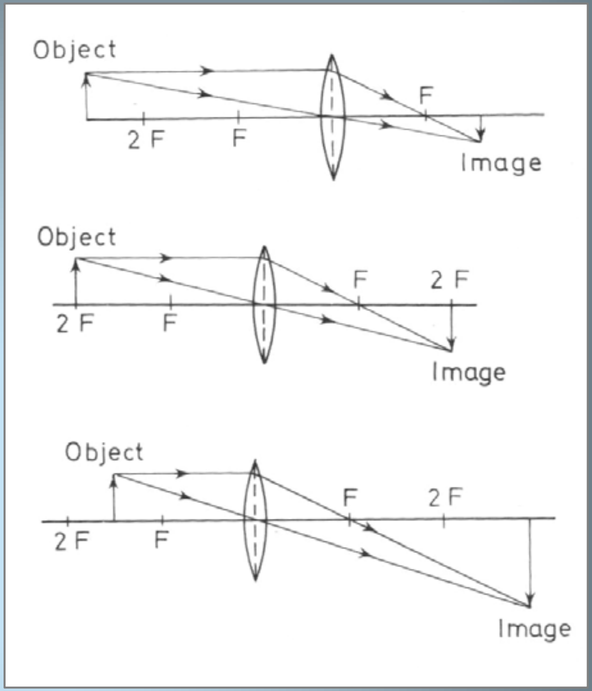
„depth of focus” is defined as a distance along optical axis of the microscope through which one may shift object without a significant losso of image quality

Examplary values of depth of focus [μm]

magnification	light microscope	electron microscope
100 x	8	-
1 000 x	0.2	20
10 000 x	-	2

Scheme of transmission microscope





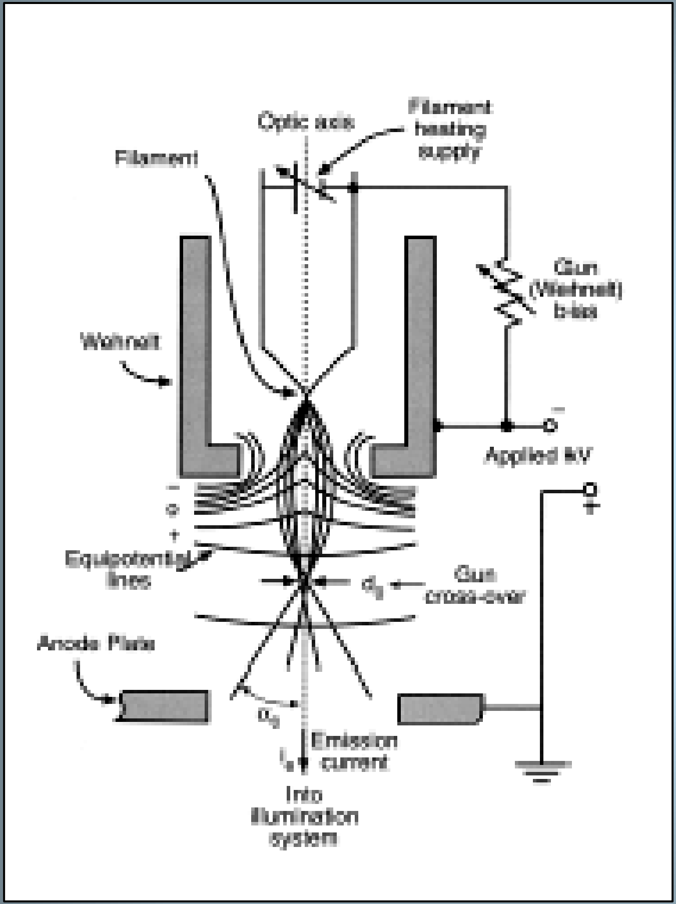
$M_1 = d_{image}/d_{object}$

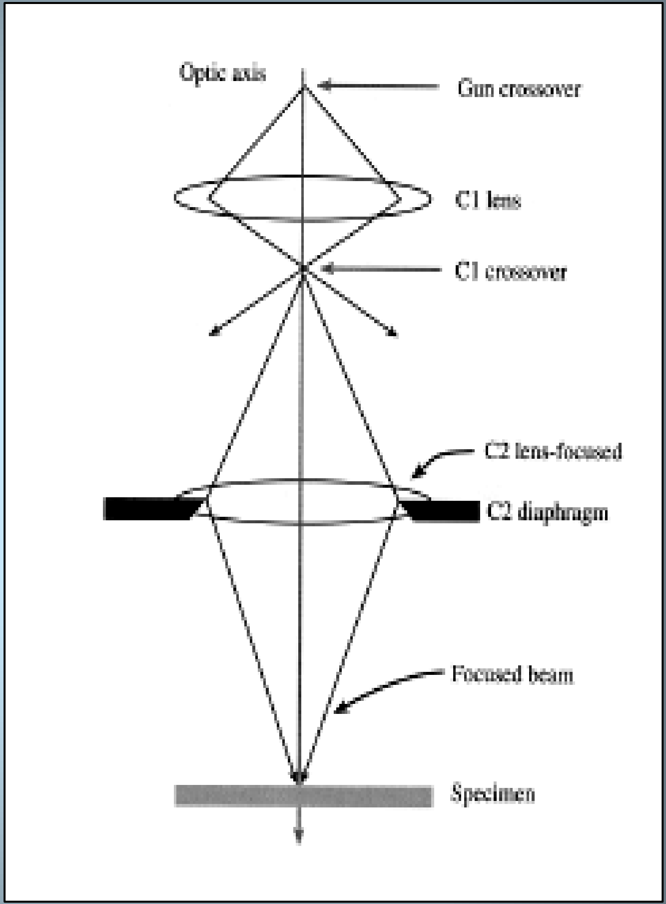
$M_{final} = M_1 * M_2 * ....$

Newton's lens equation:

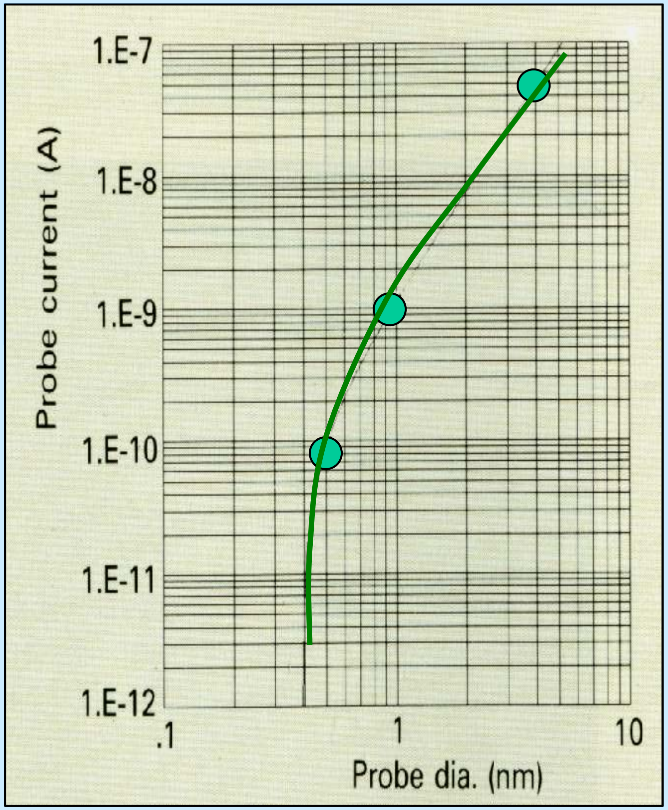
$1/\ d_{object} + 1/\ d_{image} = 1/f$

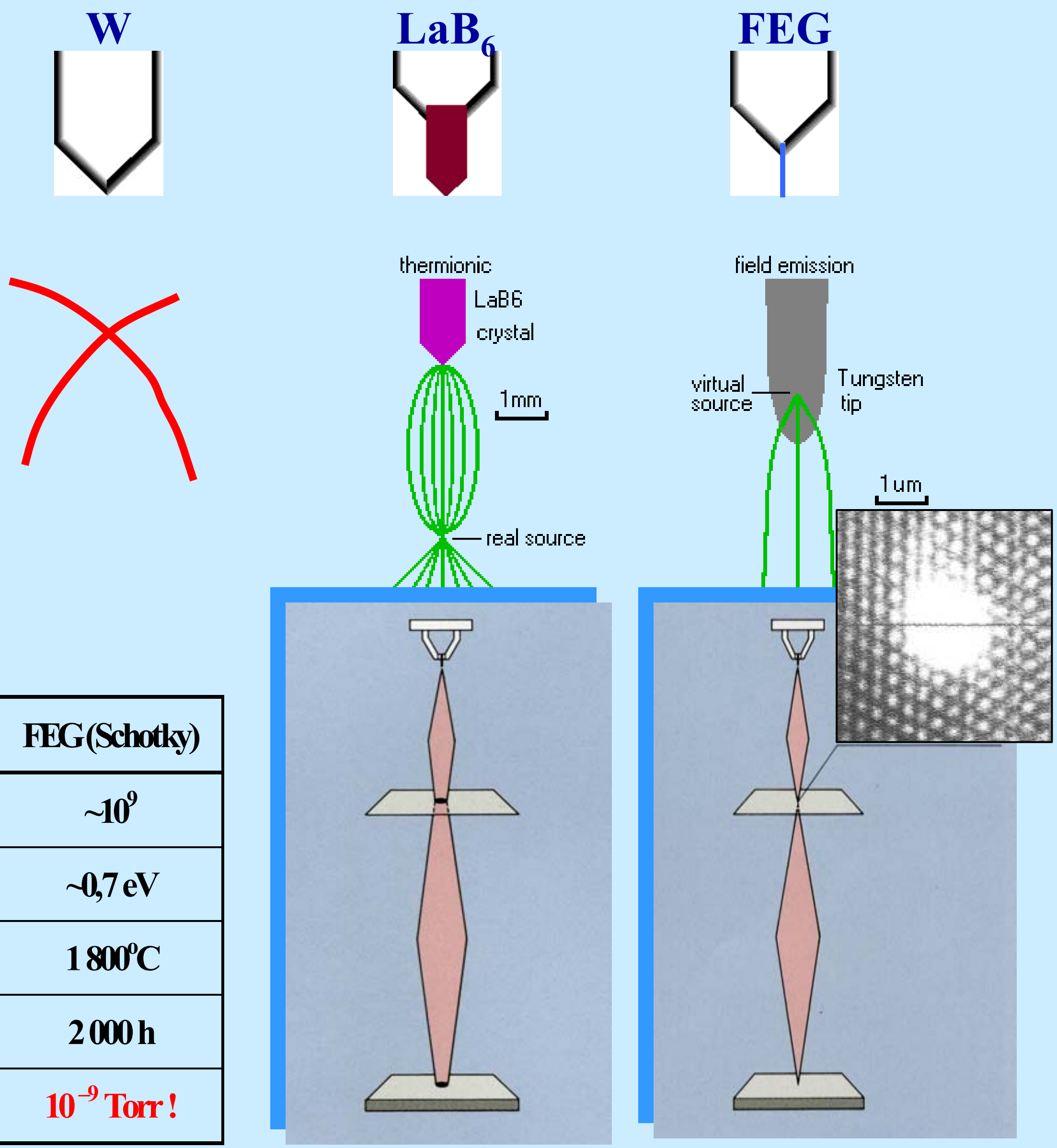
electron gun/condensor





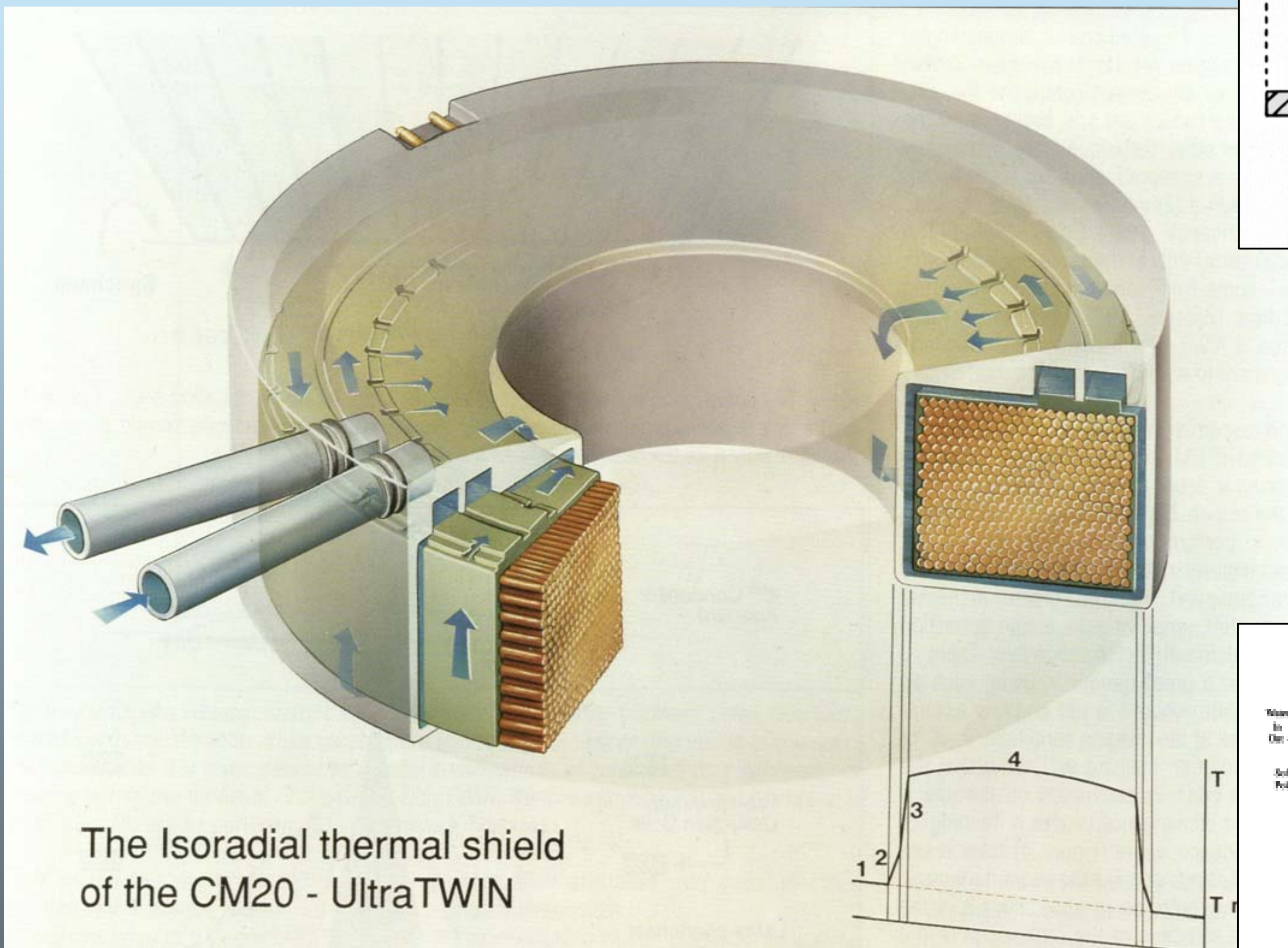
Type of Cathods/ Electron Guns



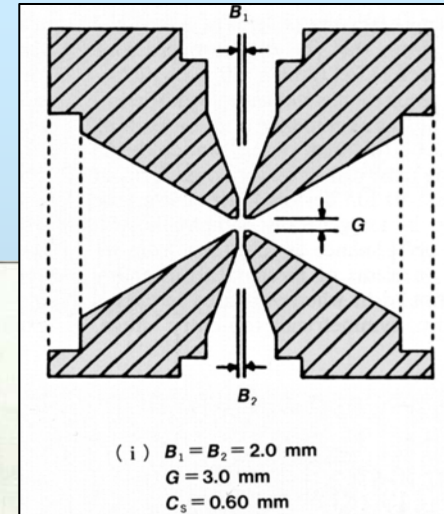


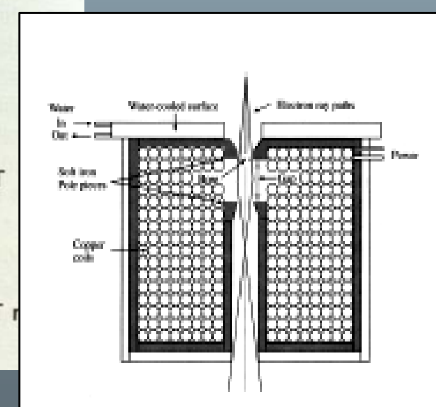
	W	LaB6	FEG (Schotky)
Brightness	~10^5	~10^6	~10^9
Energy Spread	2 eV	1 eV	~0,7 eV
Temperature	2 700°C	2 000°C	1 800°C
Life Time	100 h	1 000 h	2 000 h
Vacuum	10^{-4} Torr	10^{-6} Torr	10^{-9} Torr !

Section of magnetic lenses /pole pieces

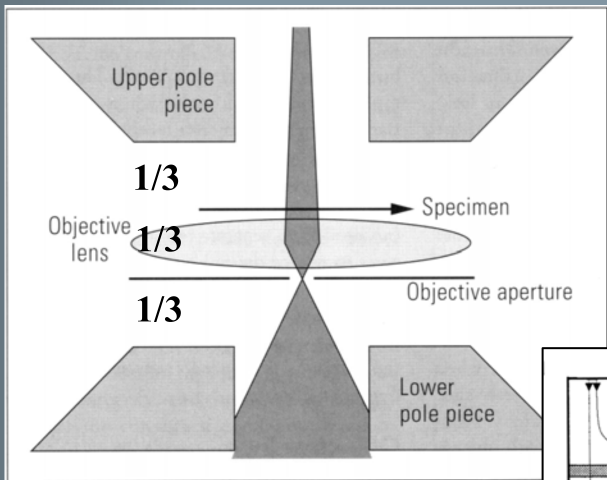


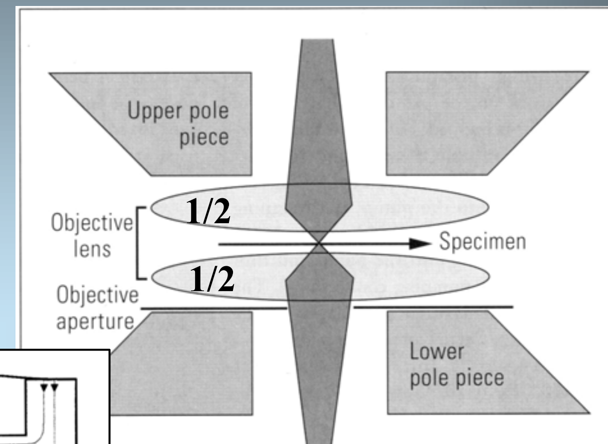
The Isoradial thermal shield of the CM20 - UltraTWIN



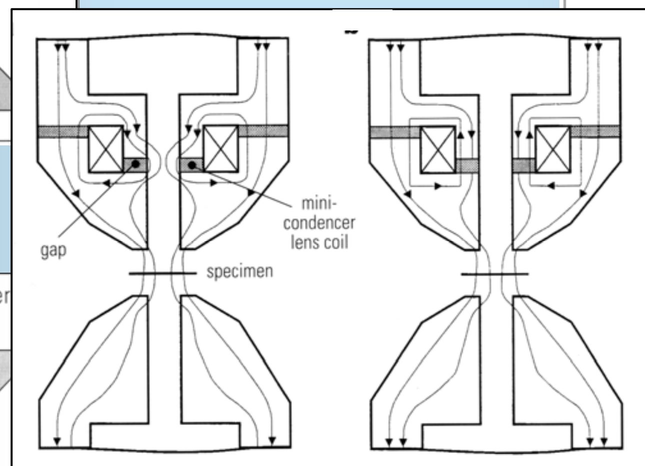


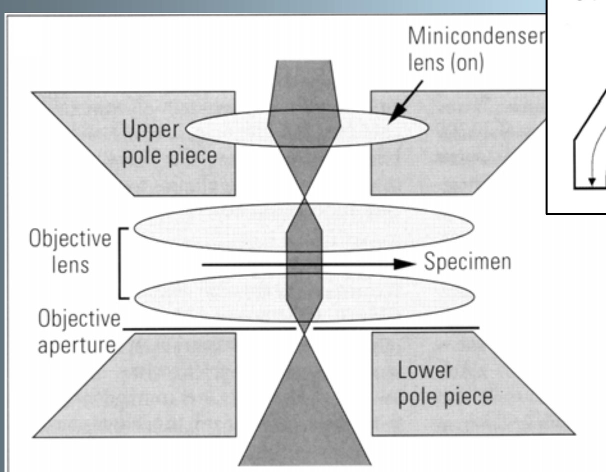
Standard TEM vs. Analytical TEM (AEM)



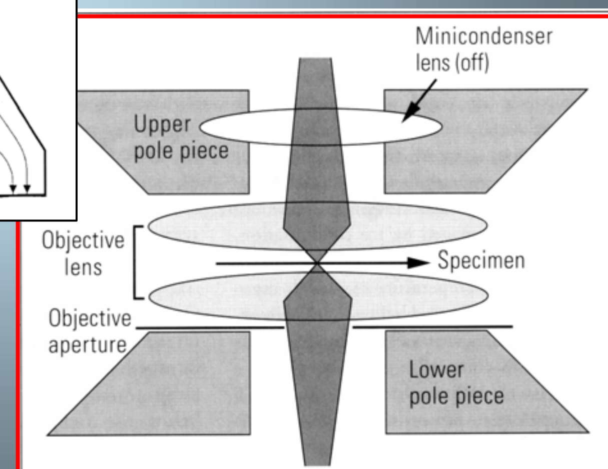


Riecke &Ruska 1966



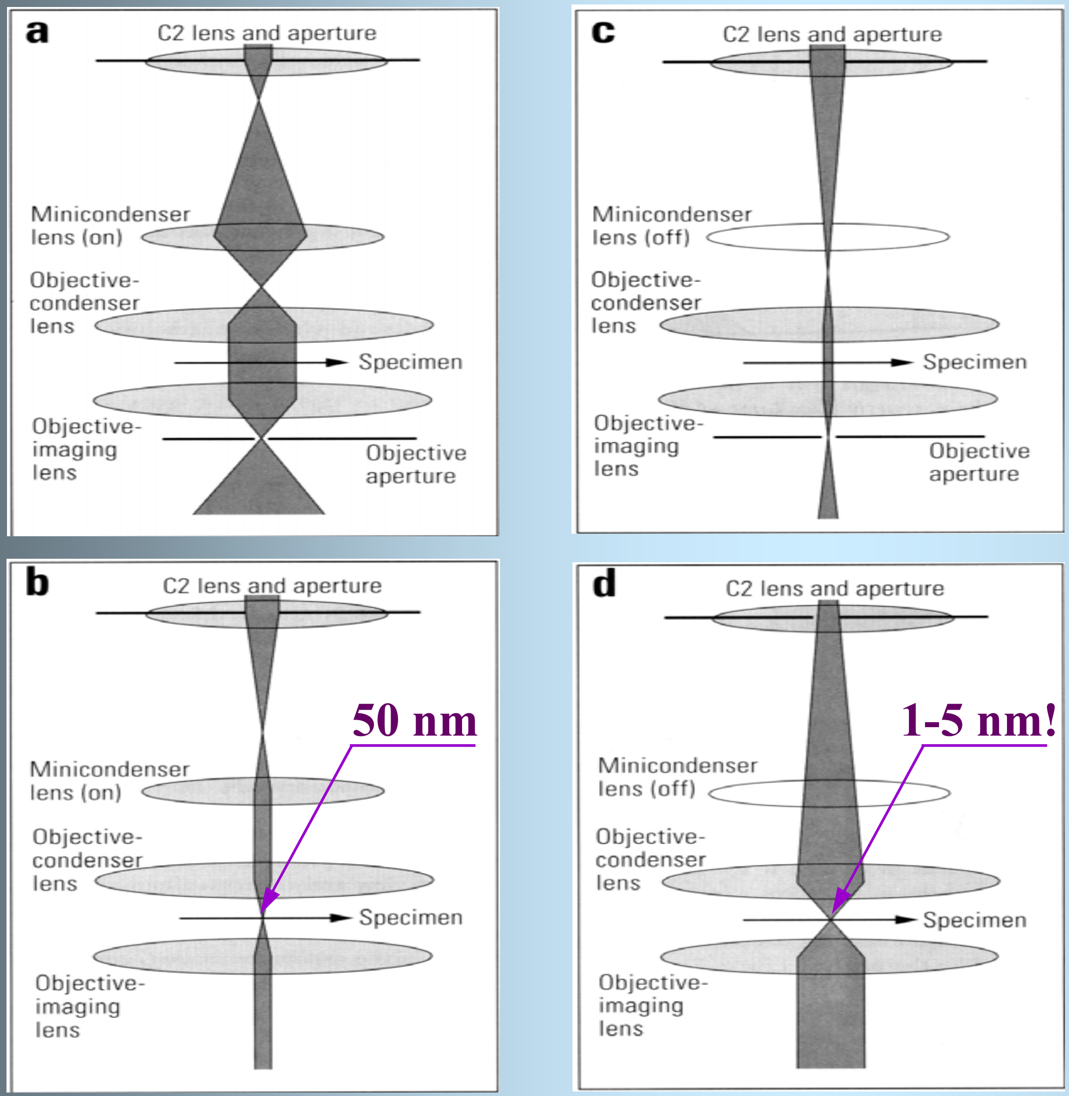


Minicondenser lens
allowed
retaining large field of view
&
formation of small probe

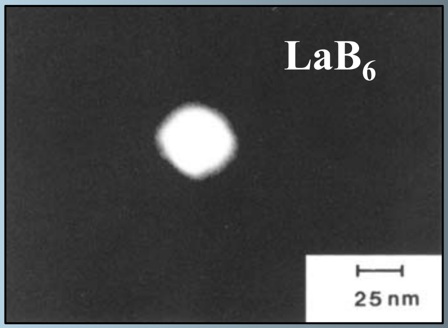


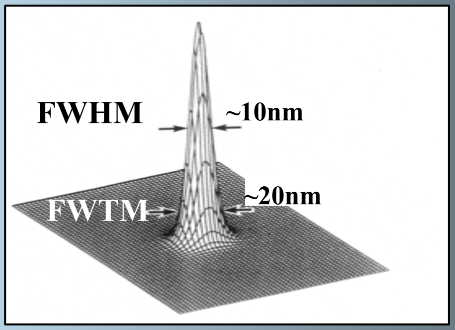
Analitycal TEM (AEM):

micro vs. nanoprobe



Probe size definition

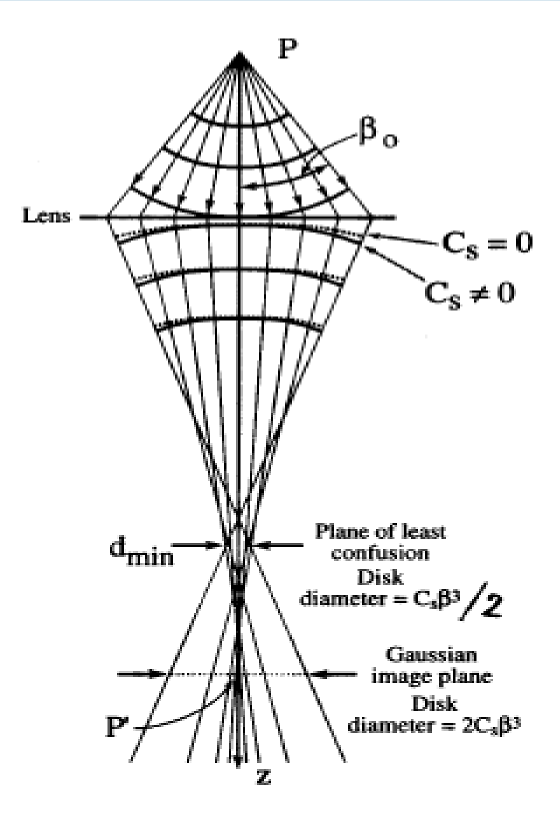


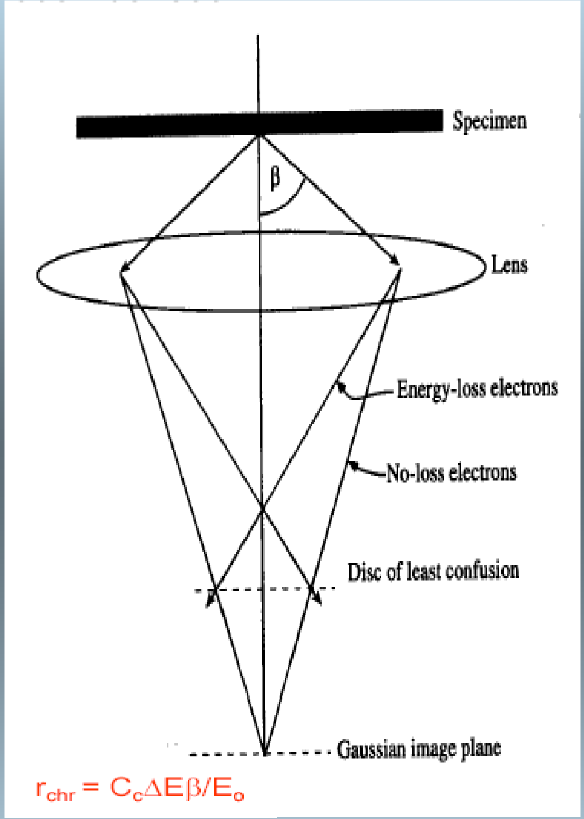


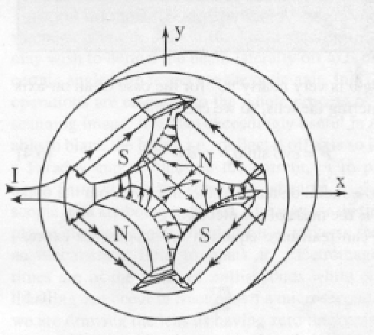
FWHM - Full Width at Half Maximum

FWTM - Full Width at Tenth Maximum

Lens defects: spherical abberation, chromatic abberation and astigmatizm

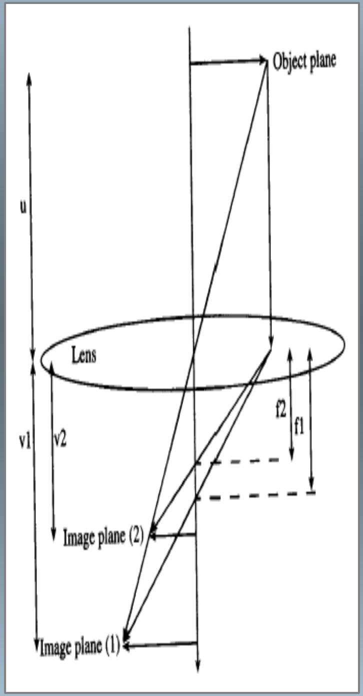


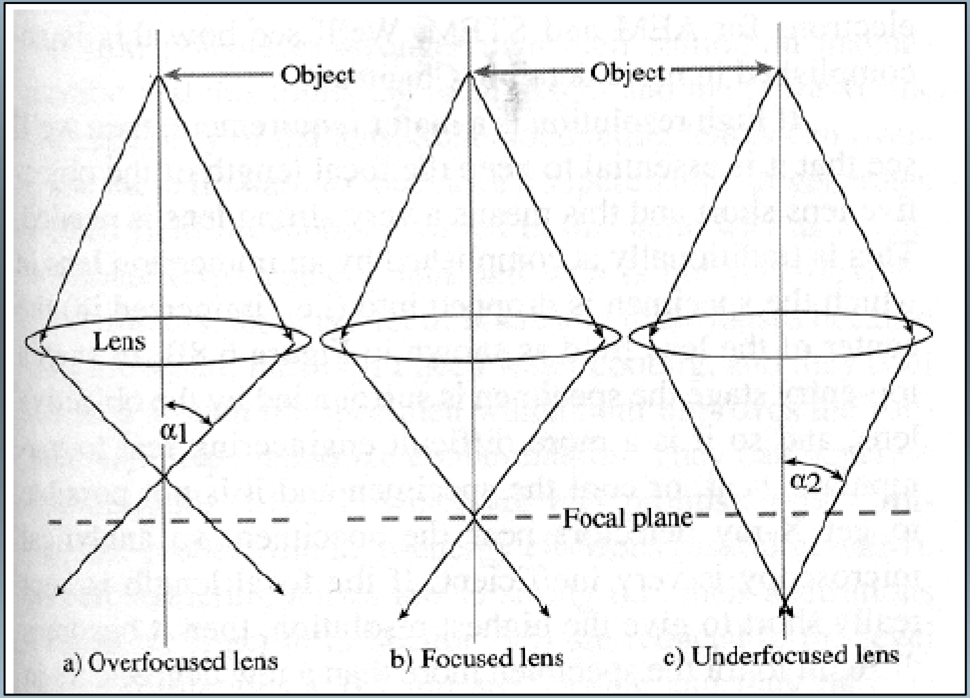




stigmators

Aaction of magnetic lenses



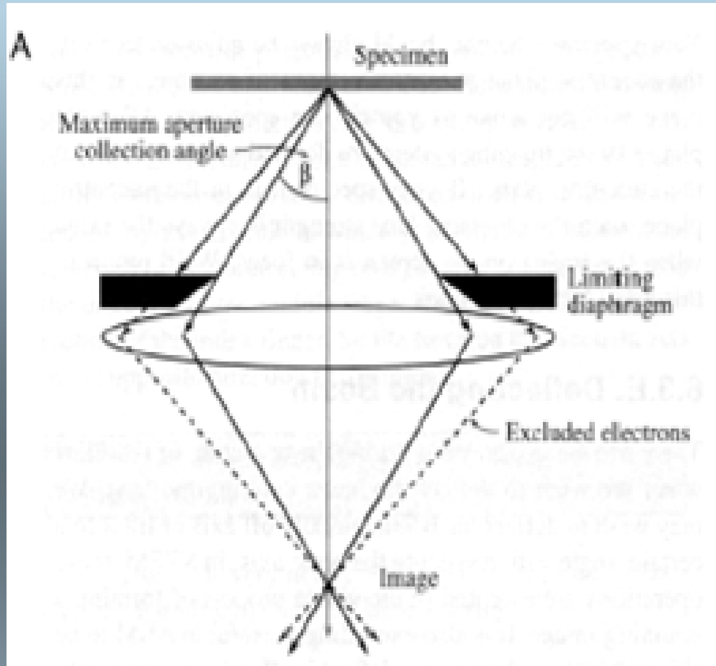


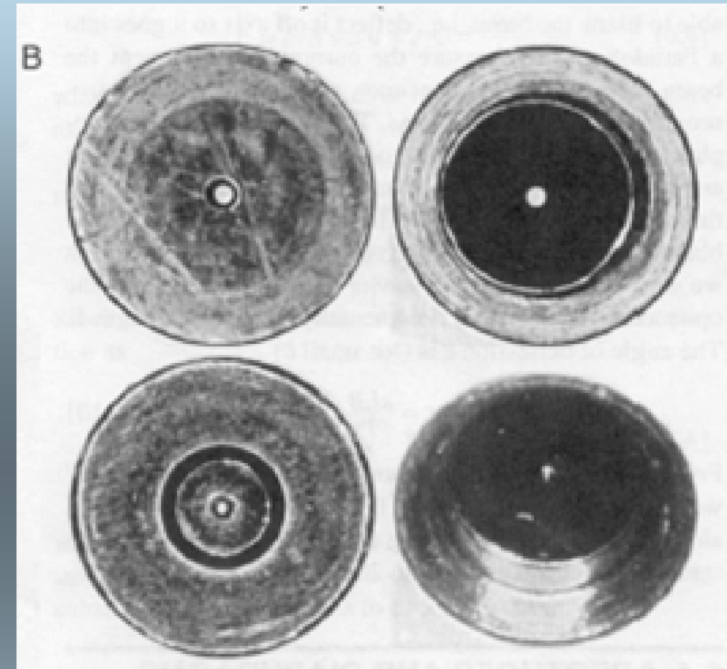
strenghtened - $f_{shorter}$

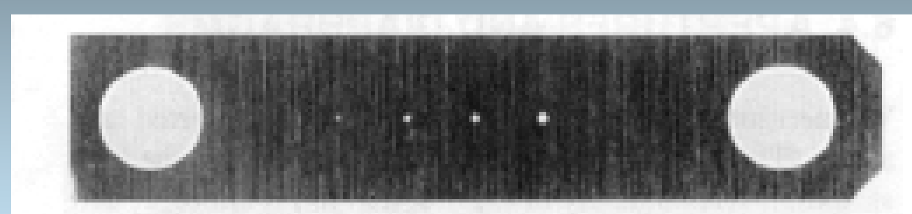
weakened - f_{longer}

"in focus" = Gaussian focus

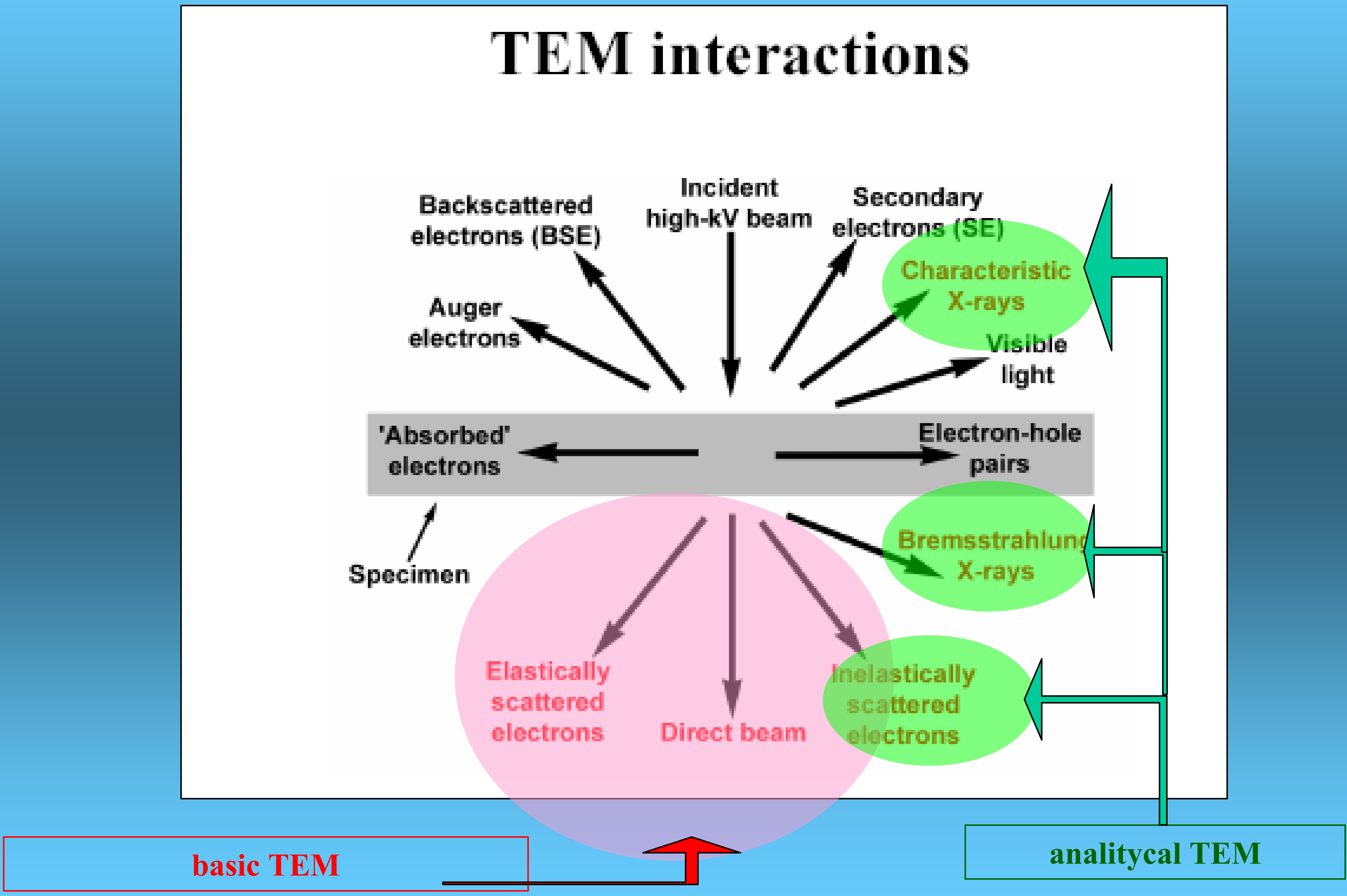
apertures


A
Specimen
Maximum aperture
collection angle
β
Limiting
diaphragm
Excluded electrons
Image


B

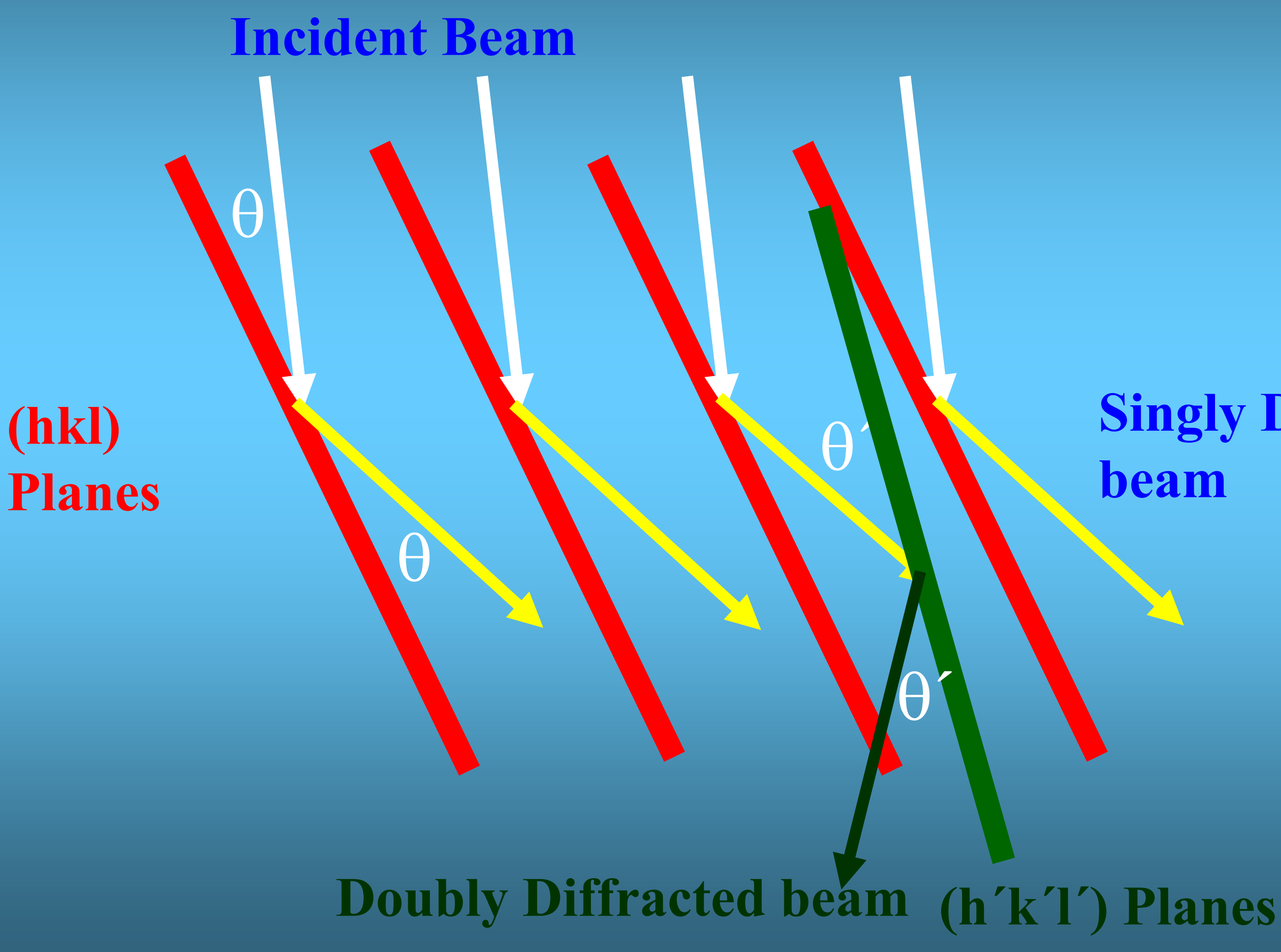


Interaction of e^- beam with a thin foil



Diffraction contrast

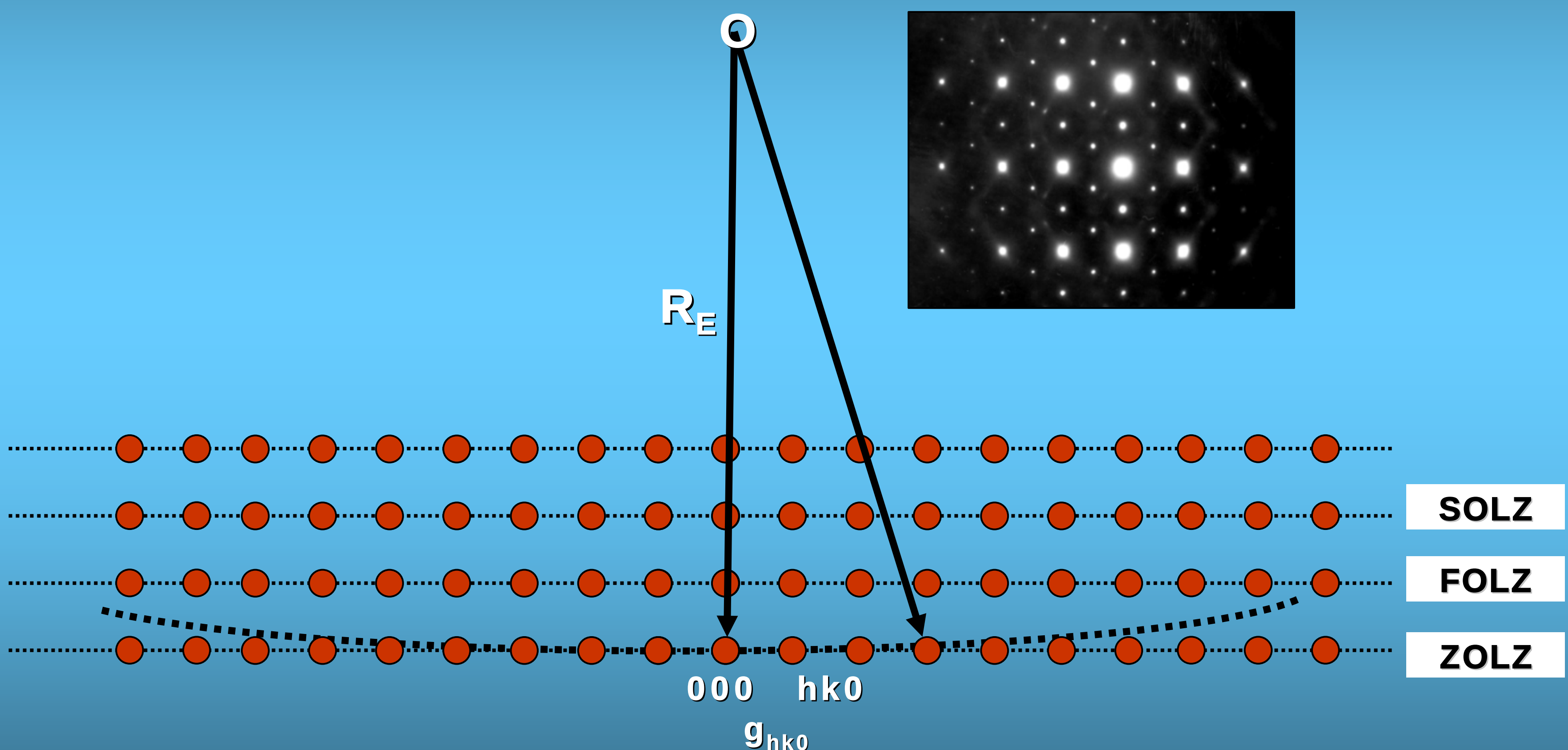
- Intensities of diffracted beams depend on each other (they are COUPLED)
- Single (KINEMATIC) scattering take place only on very thin specimens



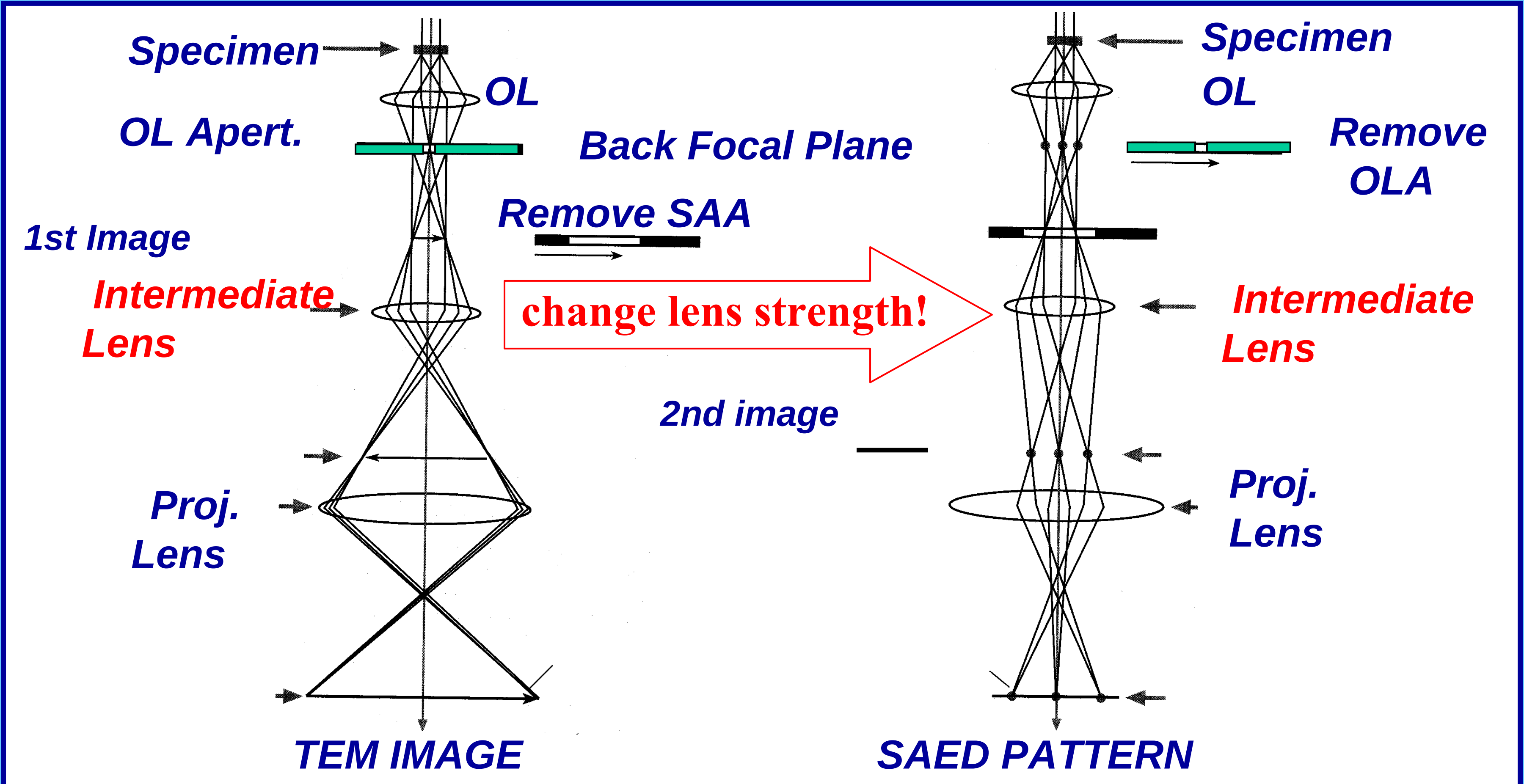
Warunki zajścia dyfrakcji/ sfera Ewalda

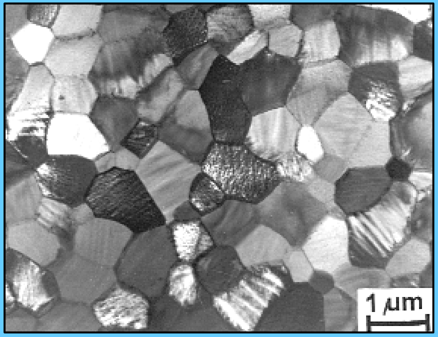
Usual d- spacings (10 Å -1 Å) >>> λ

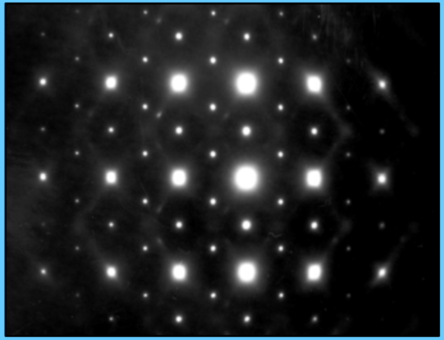
Radius of Ewald sphere (R_E= 1 / λ) >>> g spacings



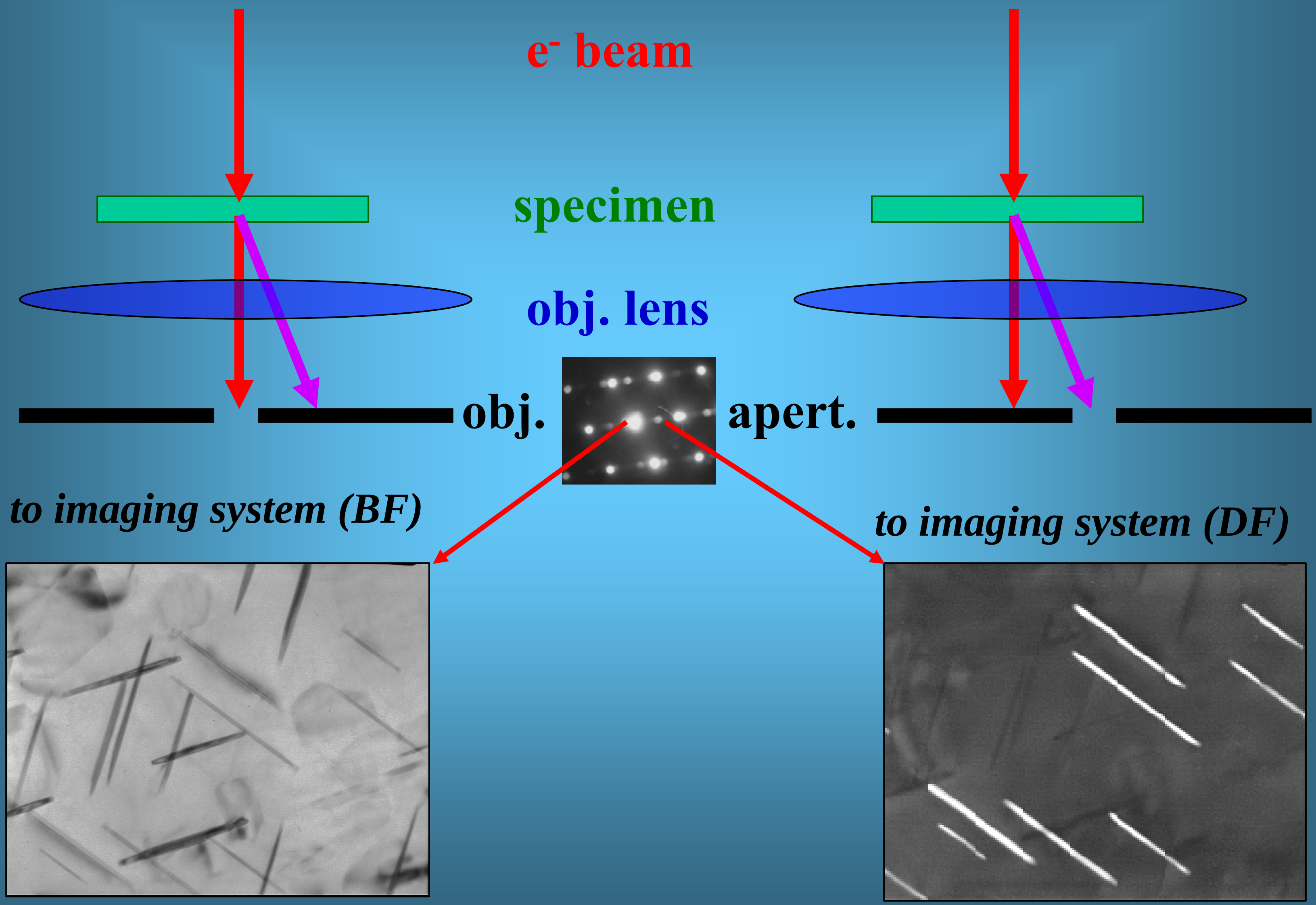
Setting TEM for imaging or diffraction





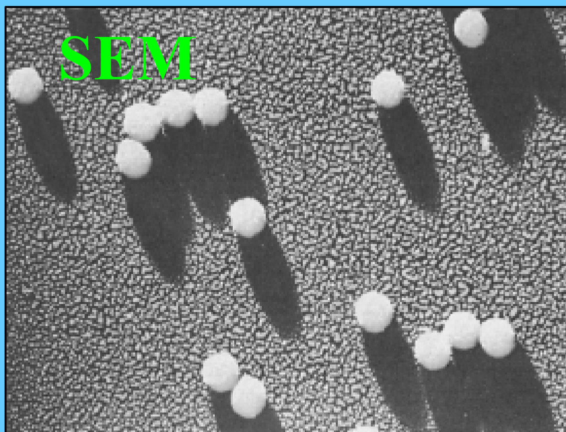


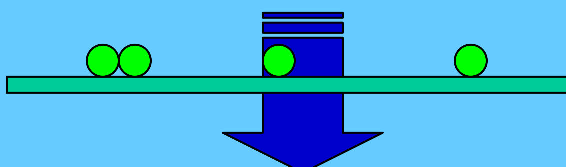
Bright/Dark Field Imaging

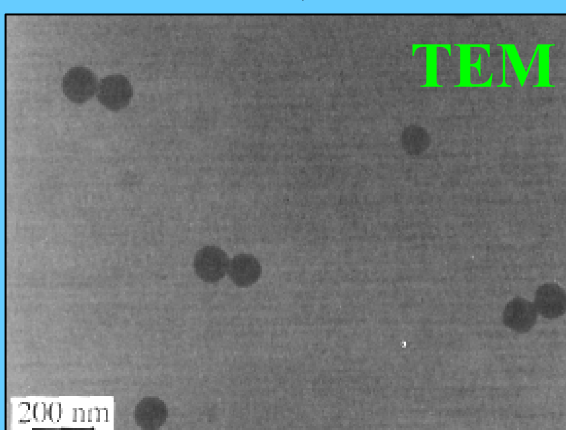


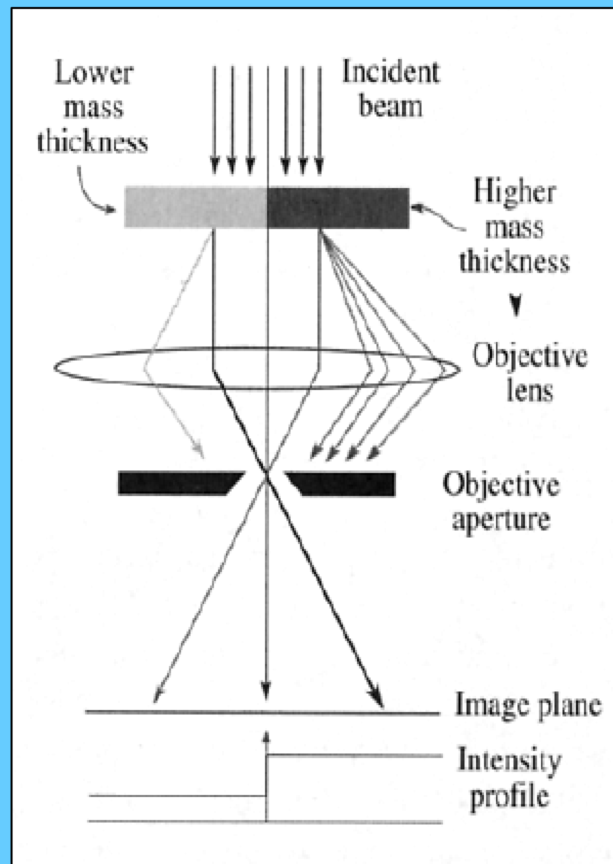
„mass-thickness" contrast

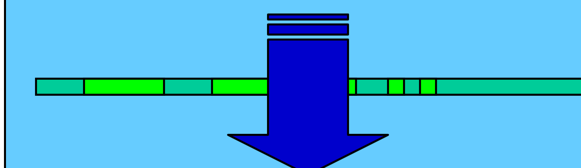
latex ball + carbon foil

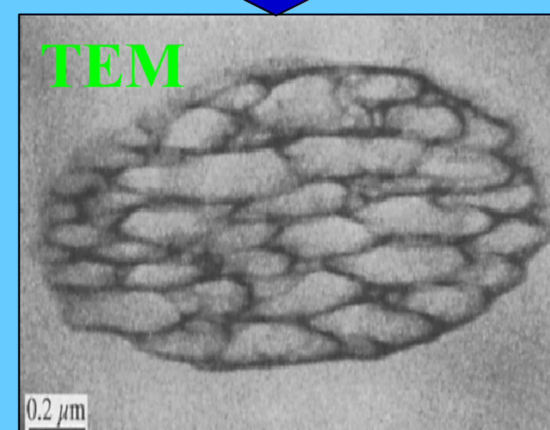




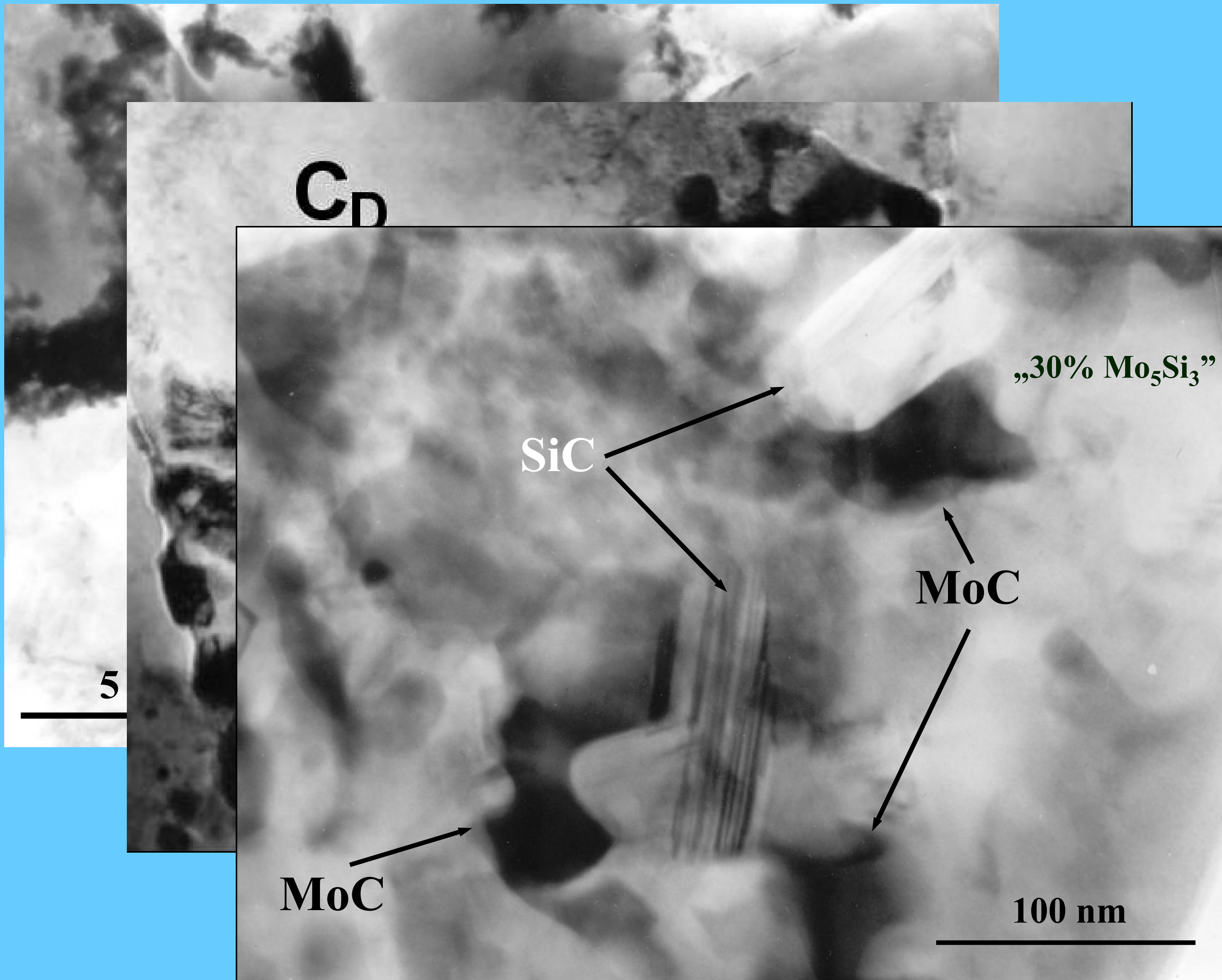




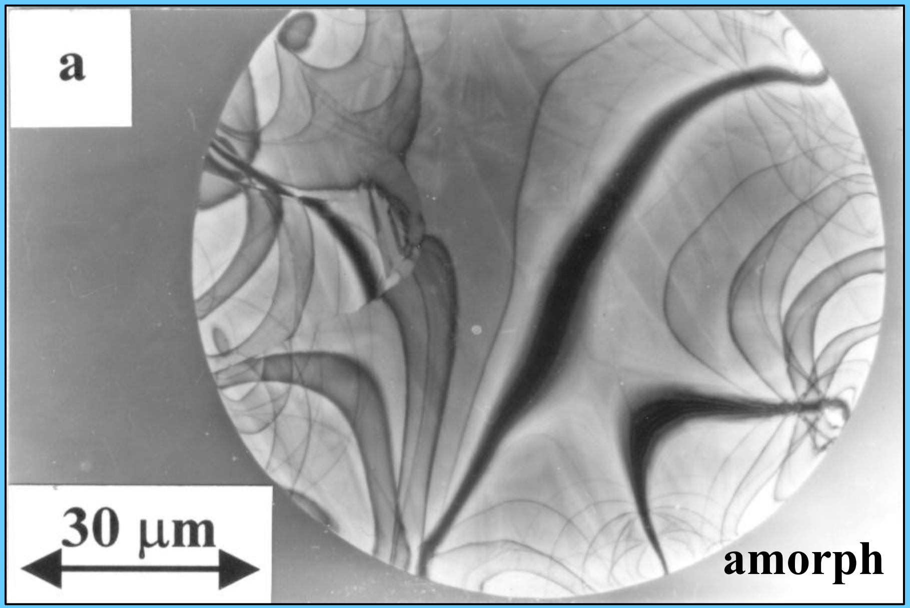




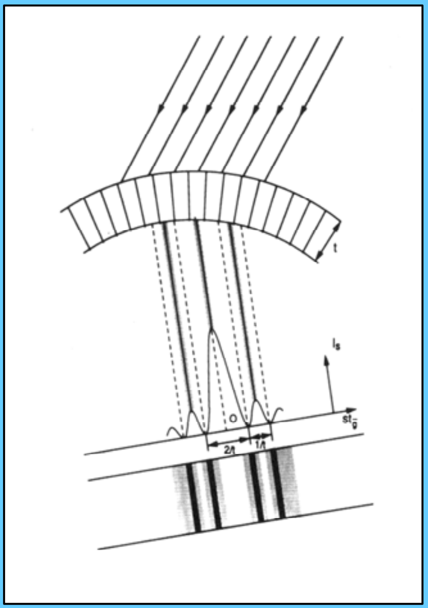
Diffraction + „mass-thickness” contrast



Extinction contours/ bend contours

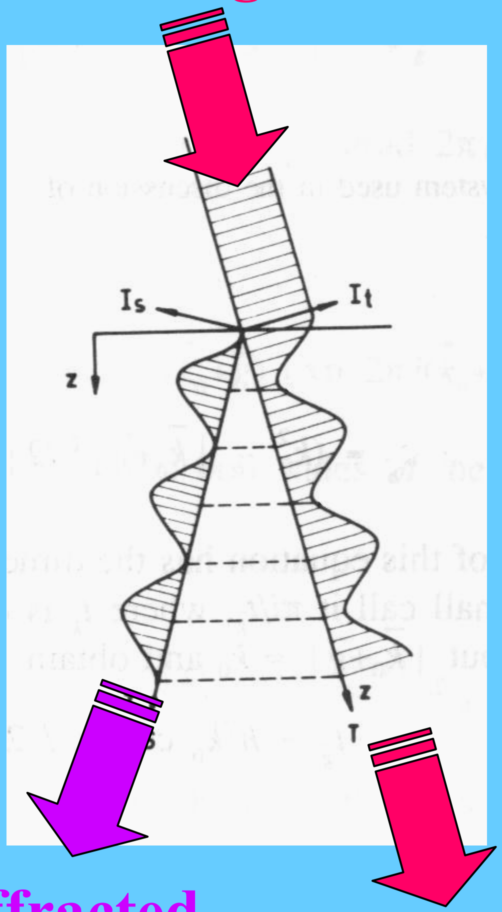


TiNiCu melt spun ribbon



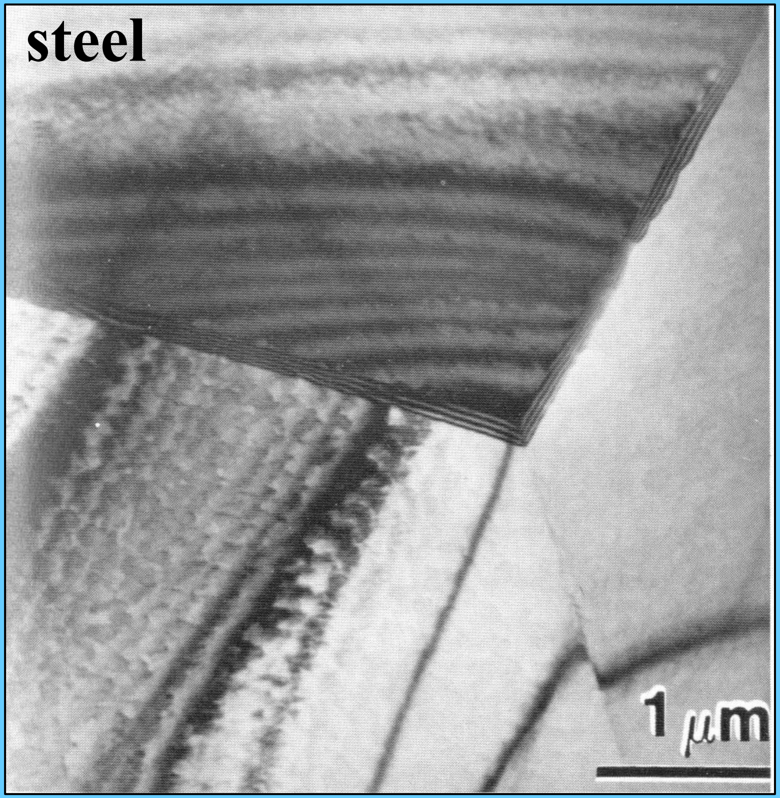
thickness fringes

„incoming” e⁻ beam



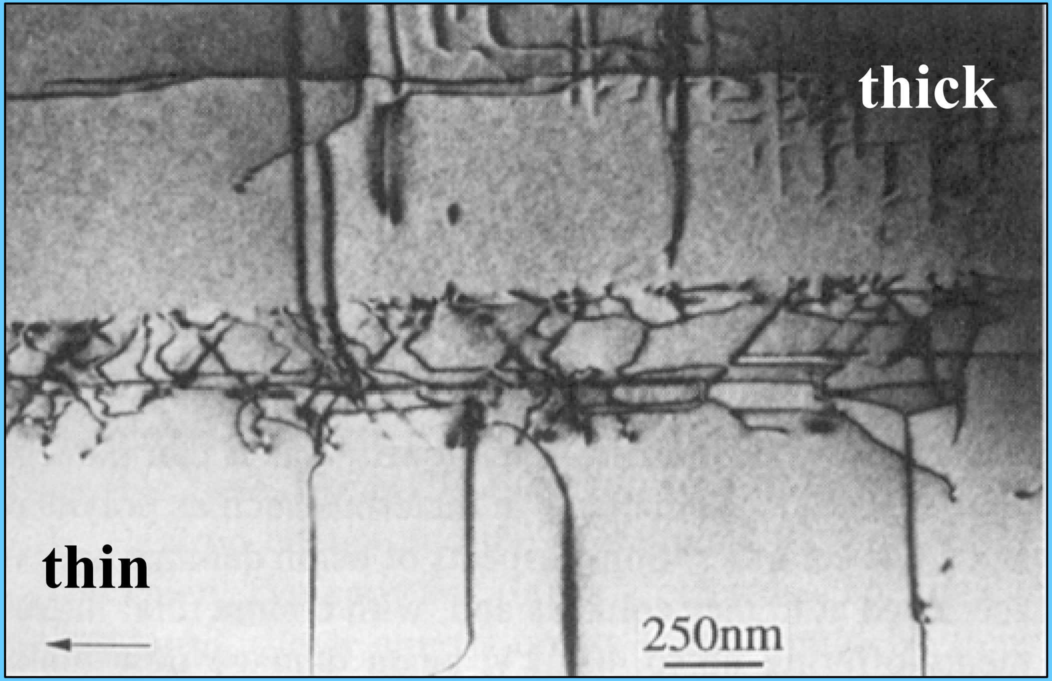
diffracted

transmitted



Significance of large „depth of field” in TEM

- The depth of field of a microscope is a measure of how much of the object we are looking at remains “in focus” at the same time
- In TEM, all of the electron transparent specimen parts are usually in focus at the same time, independent of the specimen topography
- Furthermore, we can record the final image at different positions below the final lens of the instrument and it will still be in focus



GaAs. A band of dislocations threads through the thin specimen from the top to the bottom but remains in focus through the foil thickness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