Středoevropský technologický institut
BRNO | ČESKÁ REPUBLIKA

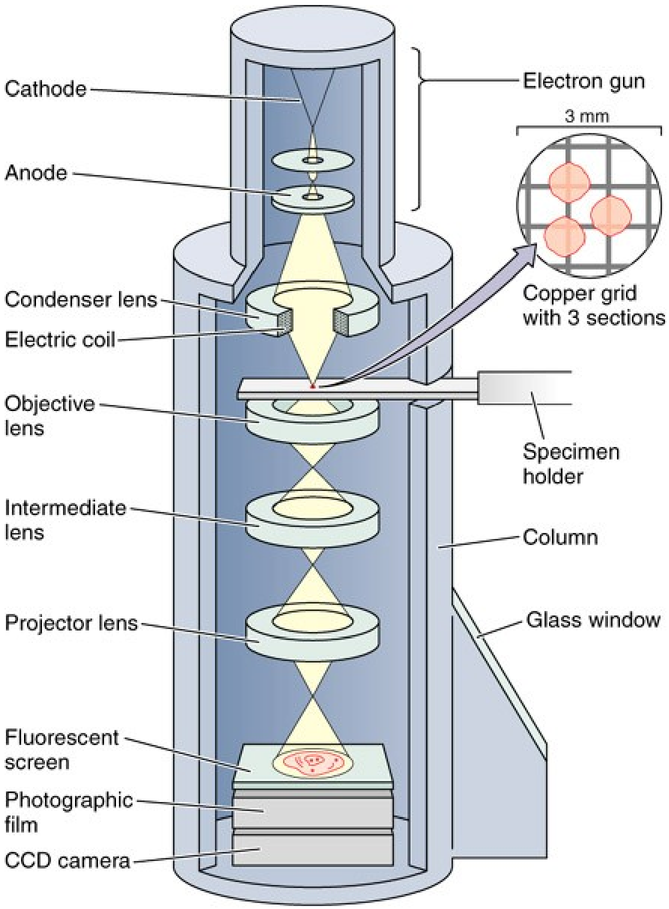
S1007 Doing structural biology with the electron microscope

Lecture 3: Electron Microscope

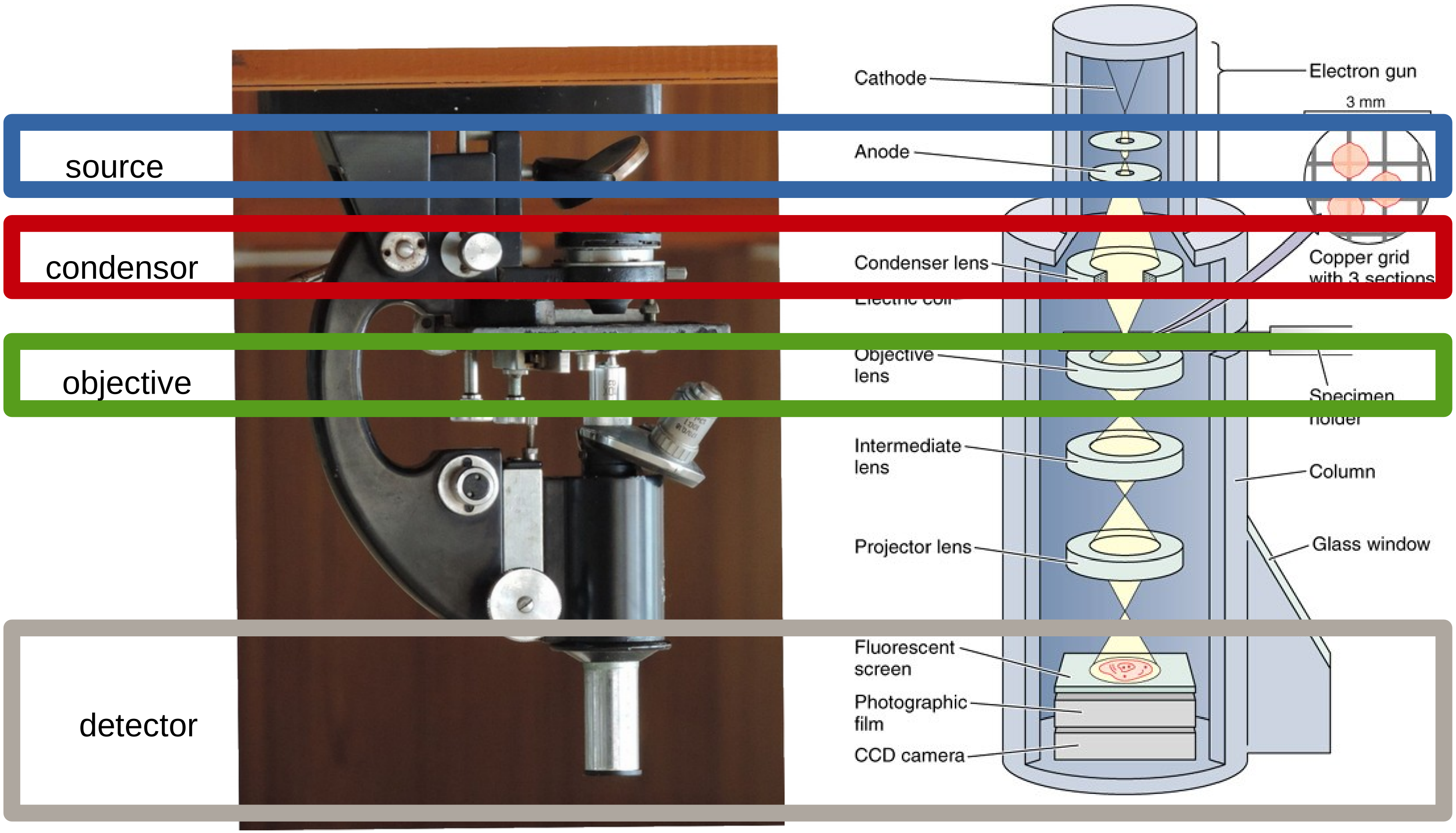
EVROPSKÁ UNIE
EVROPSKÝ FOND PRO REGIONÁLNÍ ROZVOJ
INVESTICE DO VAŠÍ BUDOUCNOSTI

2007–13
OP Výzkum a vývoj pro inovace

Optical vs. TEM microscope



Optical vs. TEM microscope



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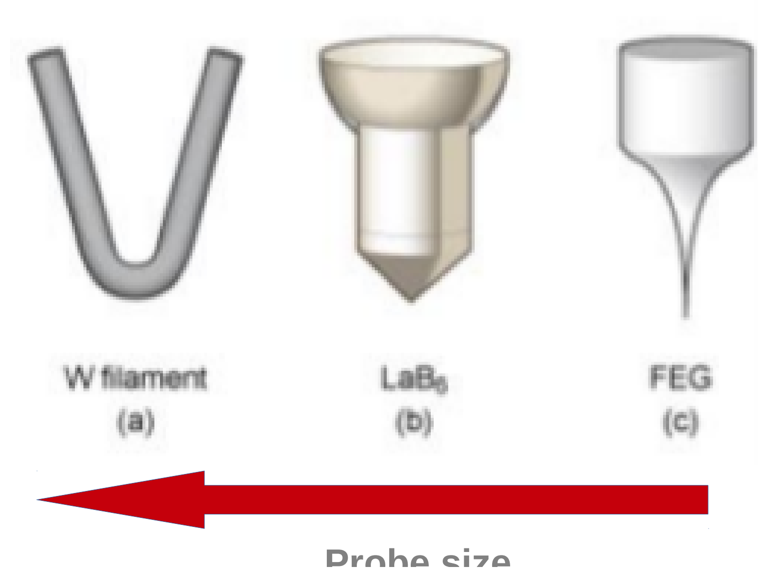
Electron source

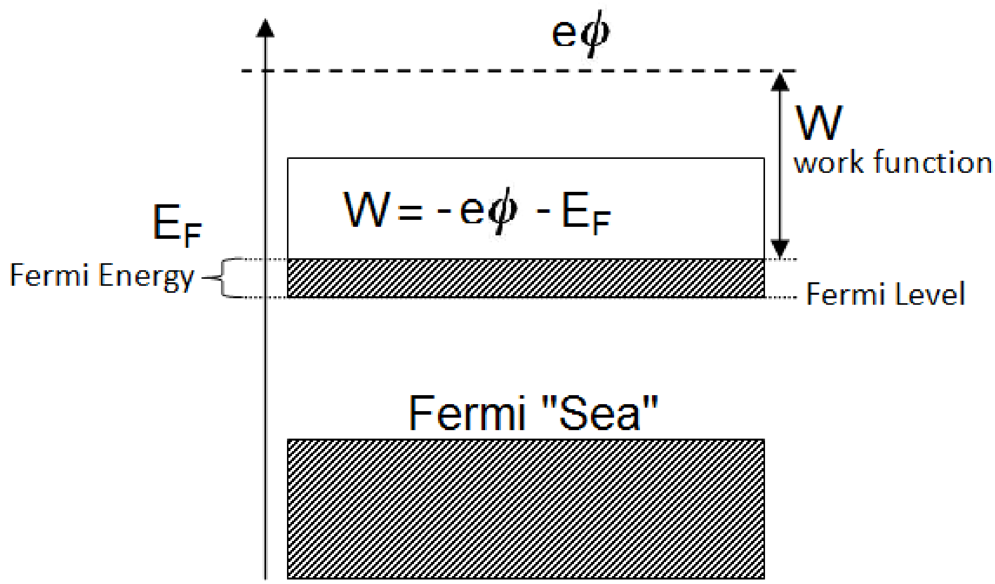
- thungsten filament
- LaB6 crystal
- Field Emission Gun



Work function

$$W = -e\phi - E_F$$

$$\phi = V - \frac{W}{e}$$



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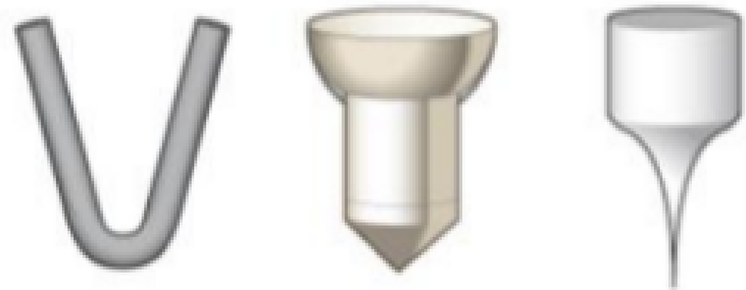
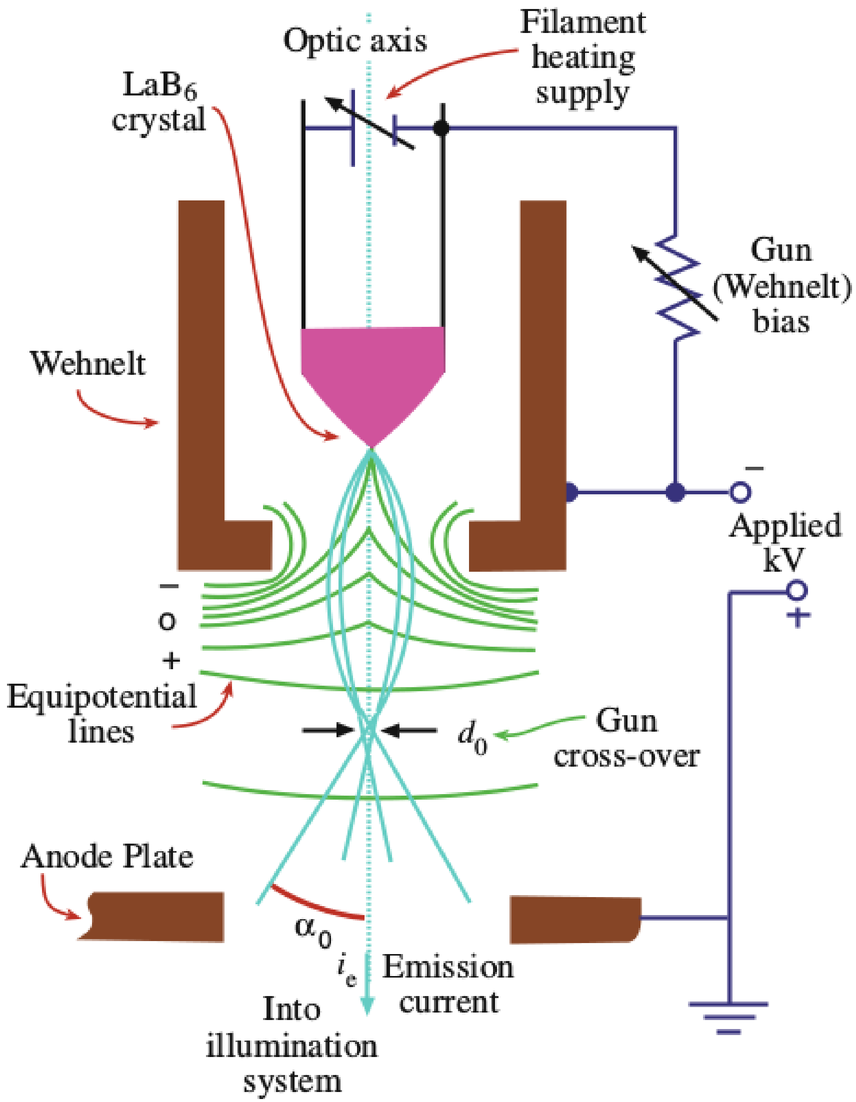
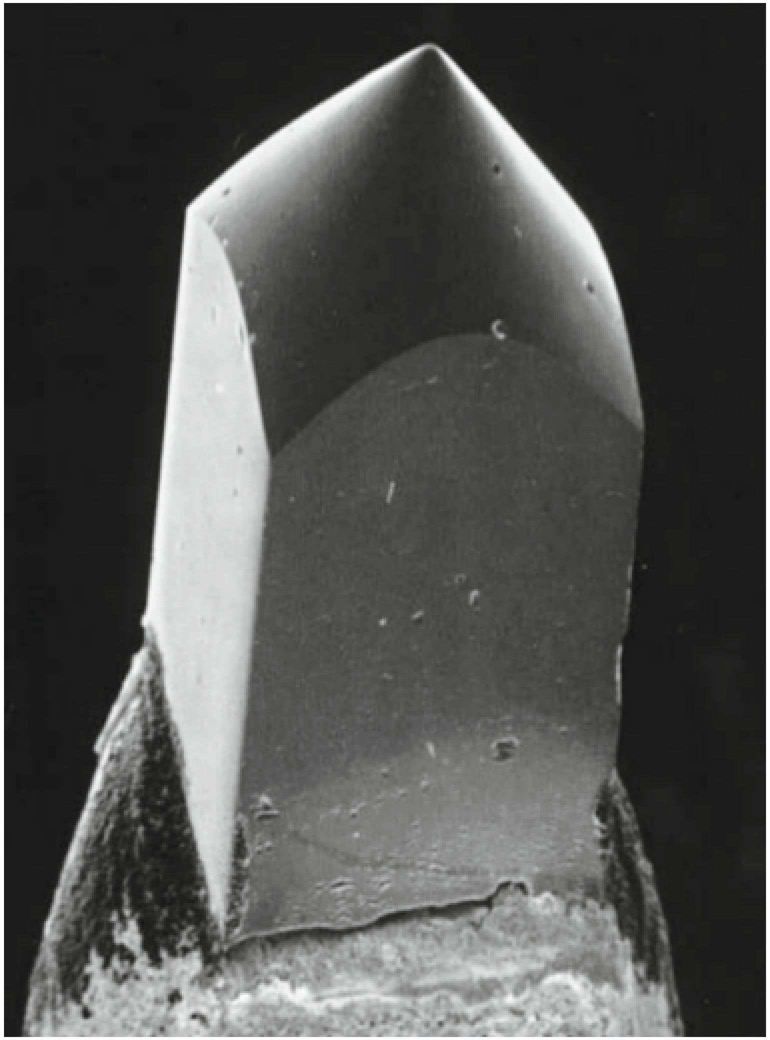


	Units	Tungsten	LaB_6	Schottky FEG	Cold FEG
Work function, Φ	eV	4.5	2.4	3.0	4.5
Richardson's constant	A/m^2K^2	6×10^9	4×10^9		
Operating temperature	K	2700	1700	1700	300
Current density (at 100 kV)	A/m^2	5	10^2	10^5	10^6
Crossover size	nm	$> 10^5$	10^4	15	3
Brightness (at 100 kV)	A/m^2sr	10^{10}	5×10^{11}	5×10^{12}	10^{13}
Energy spread (at 100 kV)	eV	3	1.5	0.7	0.3
Emission current stability	%/hr	<1	<1	<1	5
Vacuum	Pa	10^{-2}	10^{-4}	10^{-6}	10^{-9}
Lifetime	hr	100	1000	>5000	>5000

Electron source - LaB6





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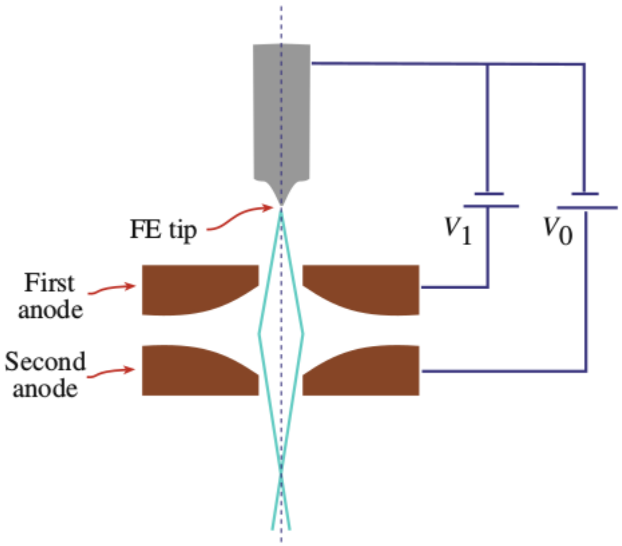
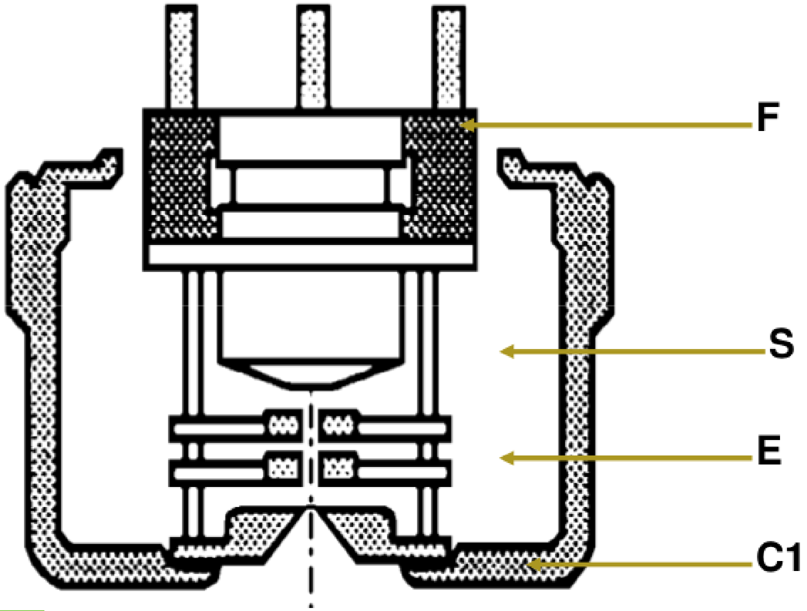
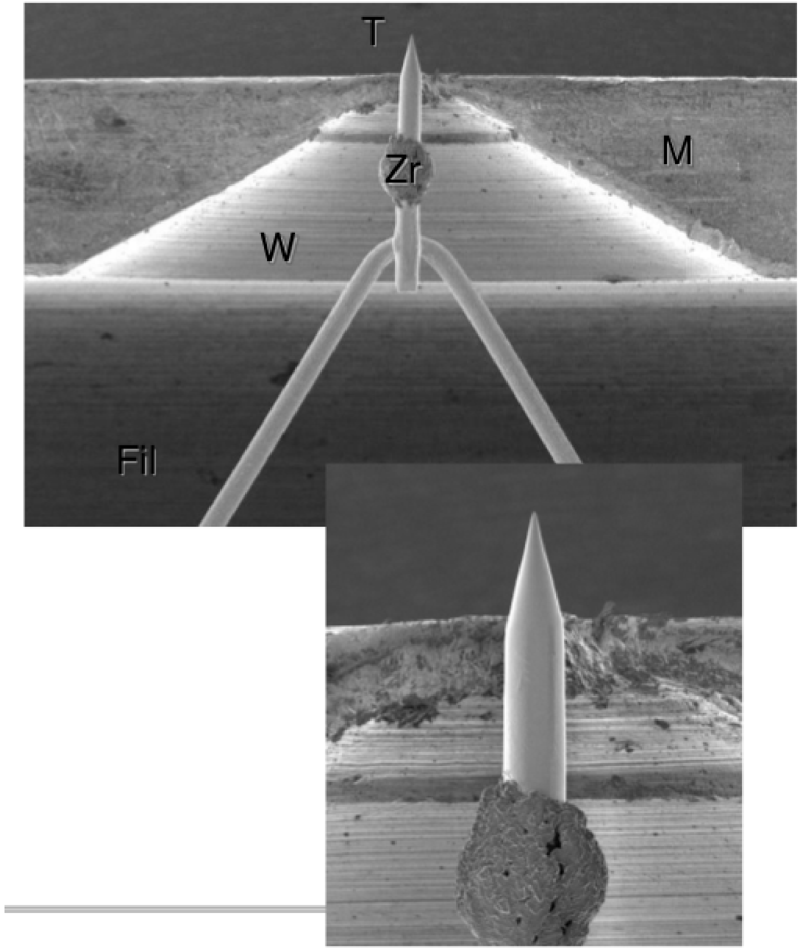
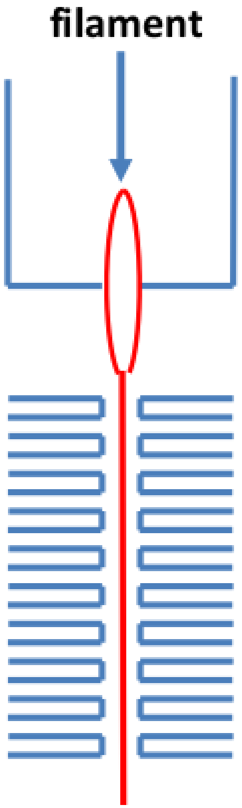
Electron source - FEG

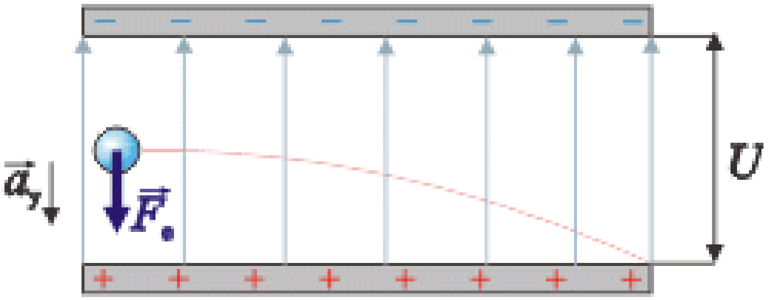






Electron source - accelerator





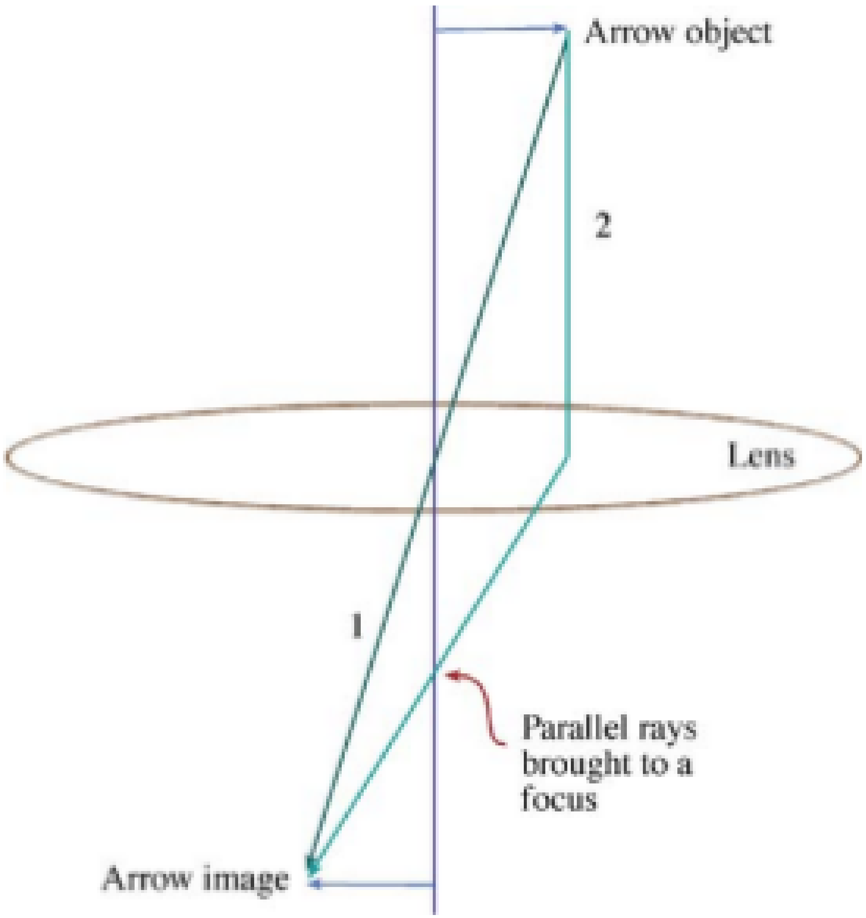
E=U.e

$$E_k = \frac{1}{2}mv^2$$

$$E_k = \frac{p^2}{2m}$$

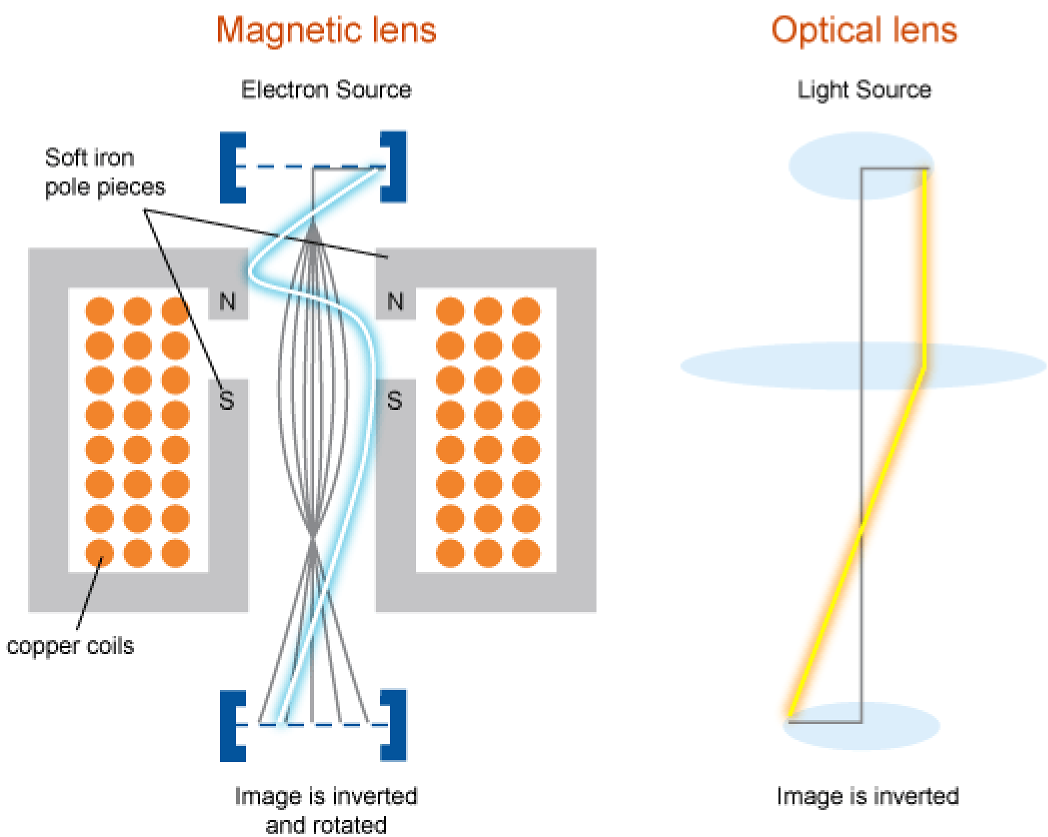
U=300kV => λ=1.97pm
U=200kV ??

Lenses – ray diagram



Electromagnetic lenses

Lorentz force: $\mathbf{F} = q(\mathbf{E} + \mathbf{v} \times \mathbf{B})$



Magnetic lenses rotate image

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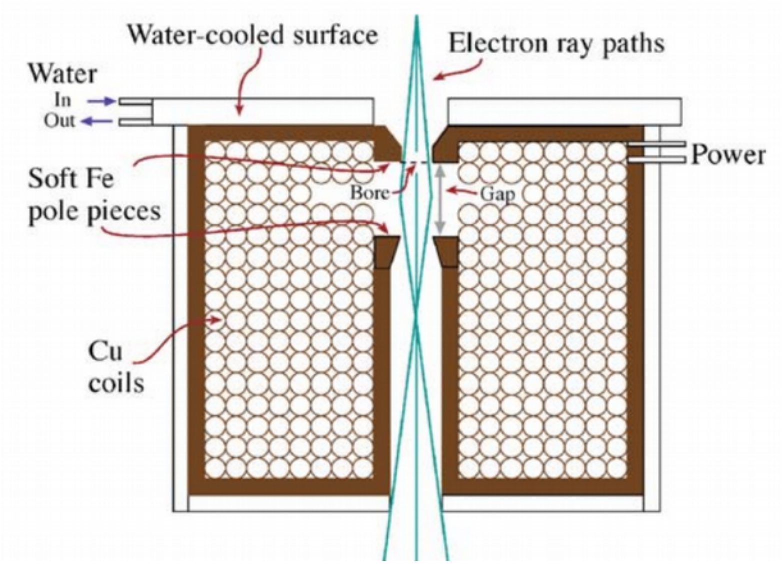
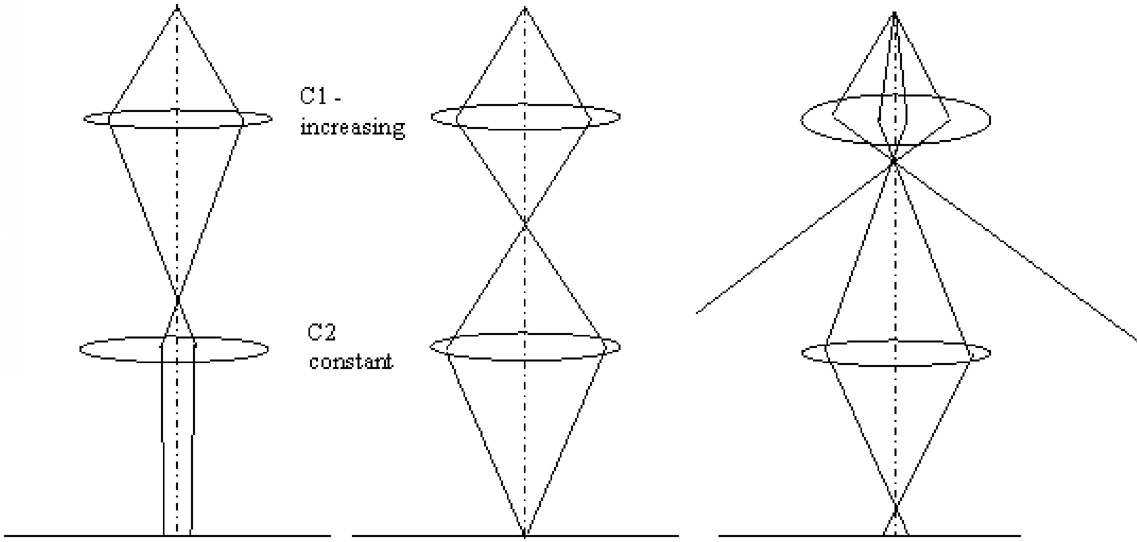
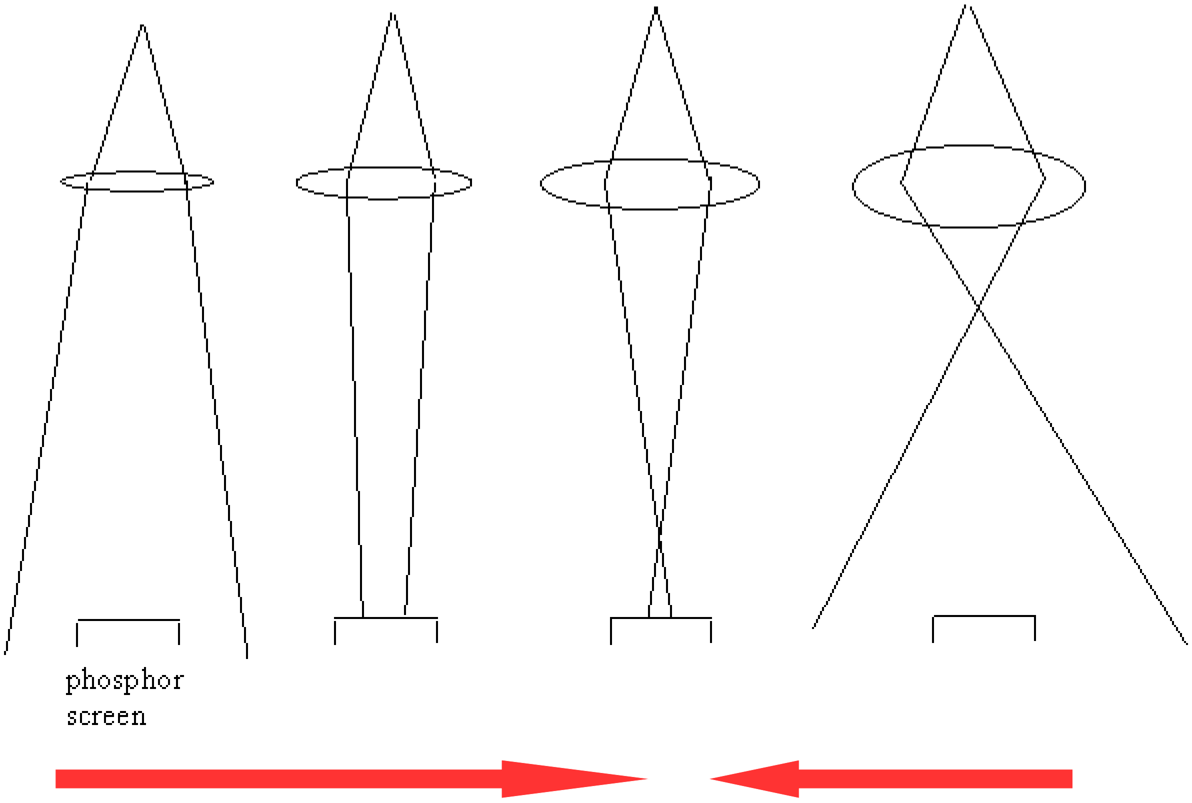
Electromagnetic lenses





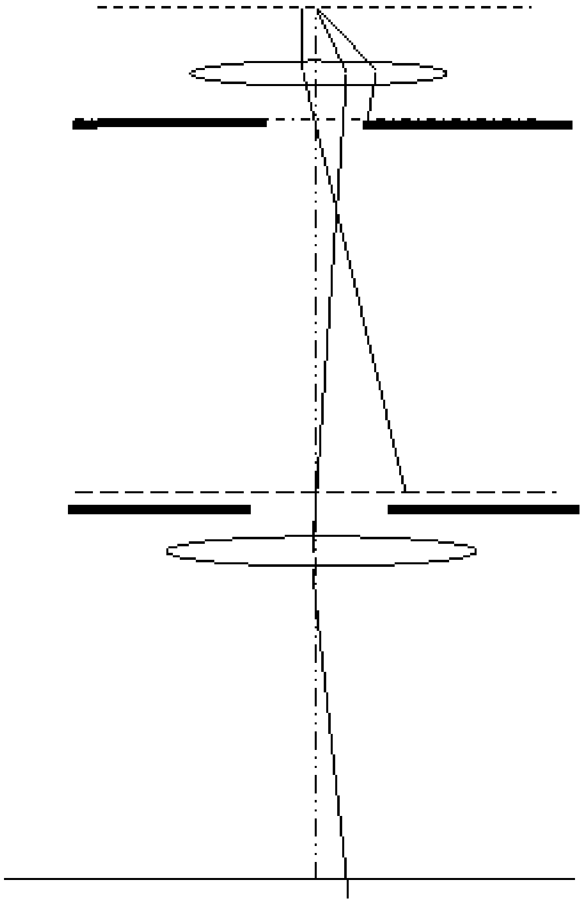
Power of the magnetic lens can be changed

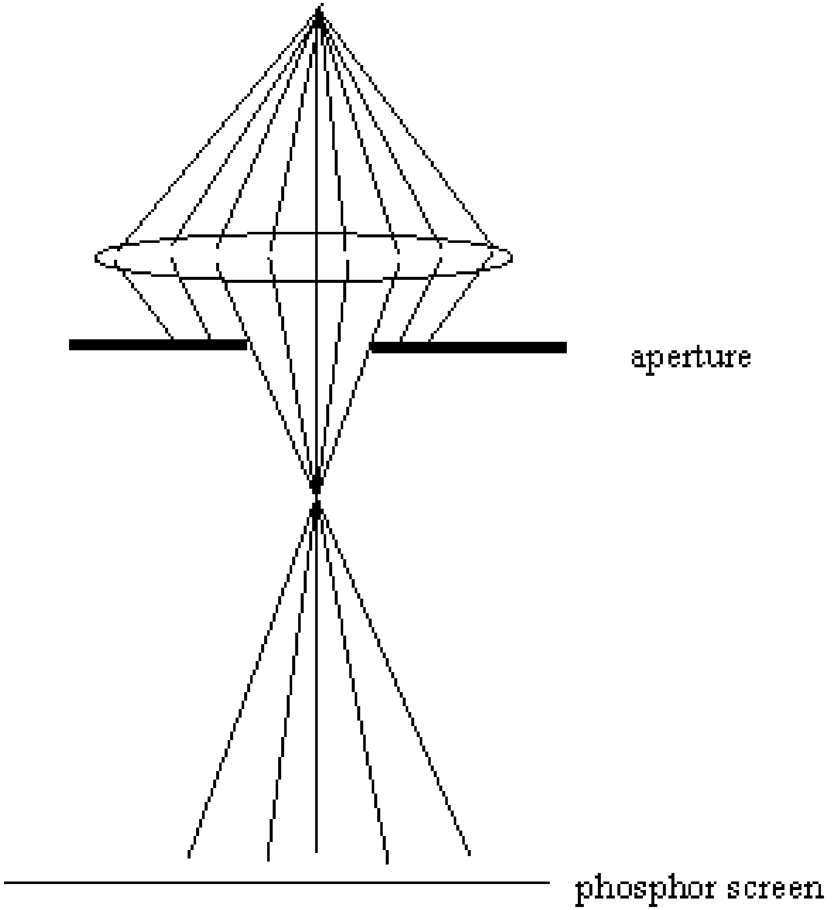
Electromagnetic lenses



Illumination on the detector changes with change of lens power

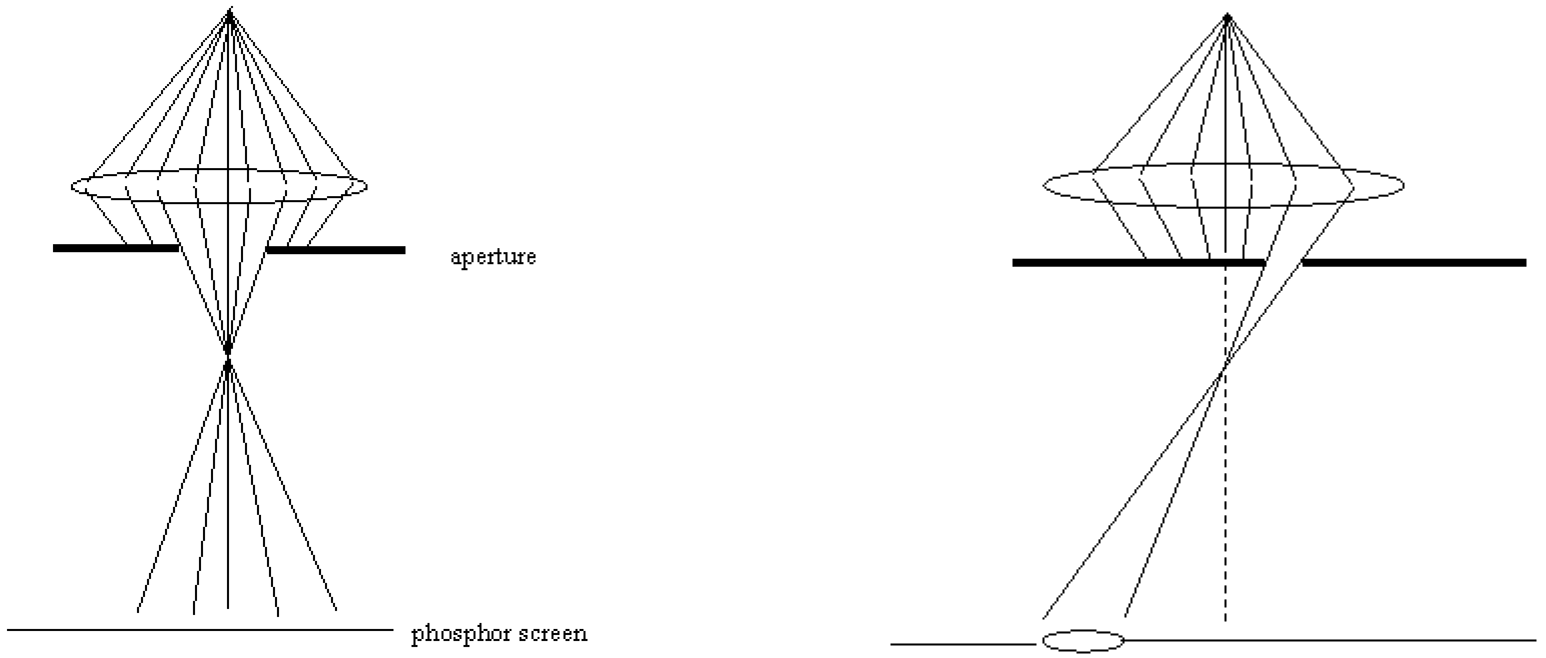
Lens assembly - appertures





Apperture size: ~100um

Lens assembly - appertures



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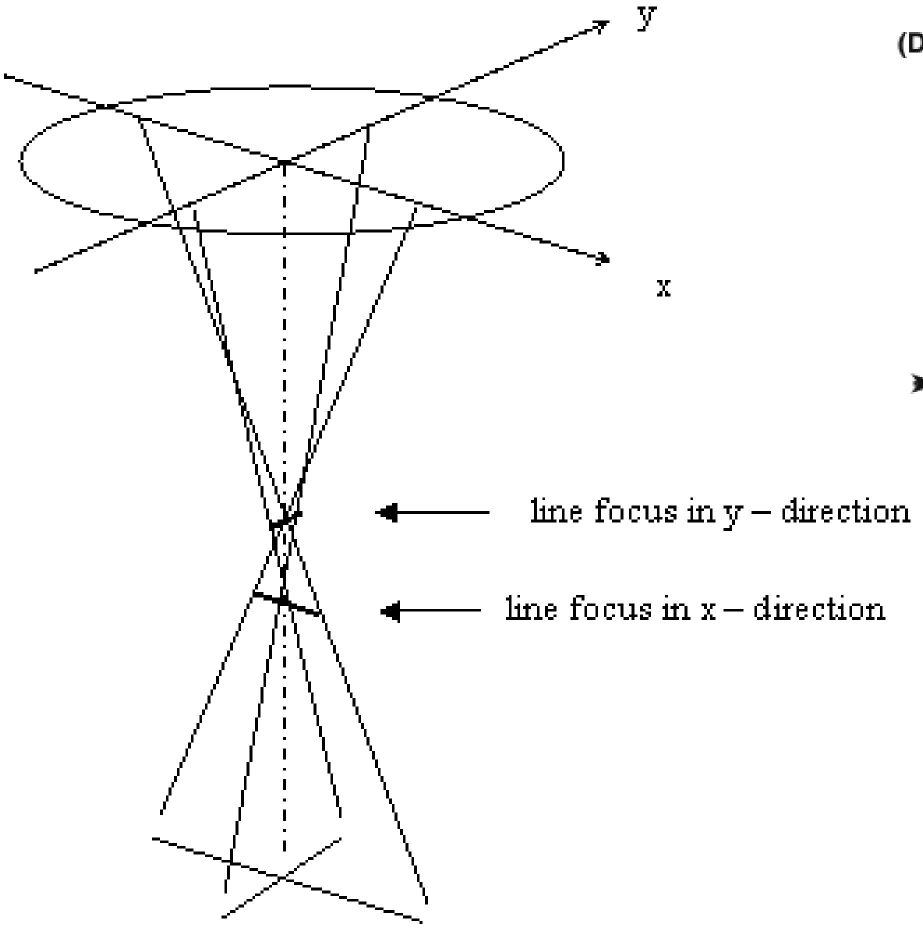
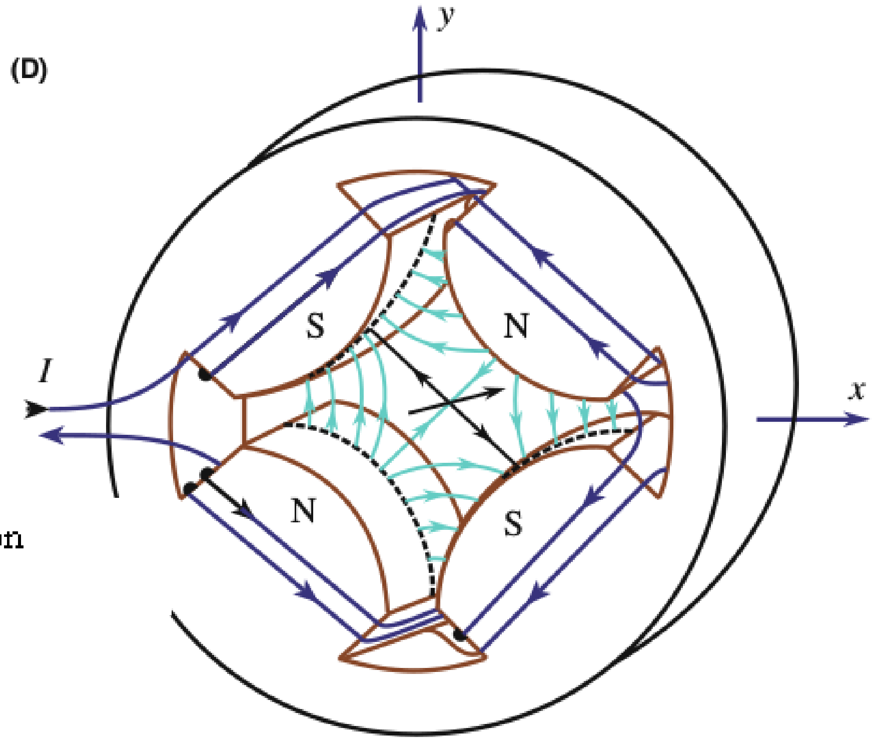
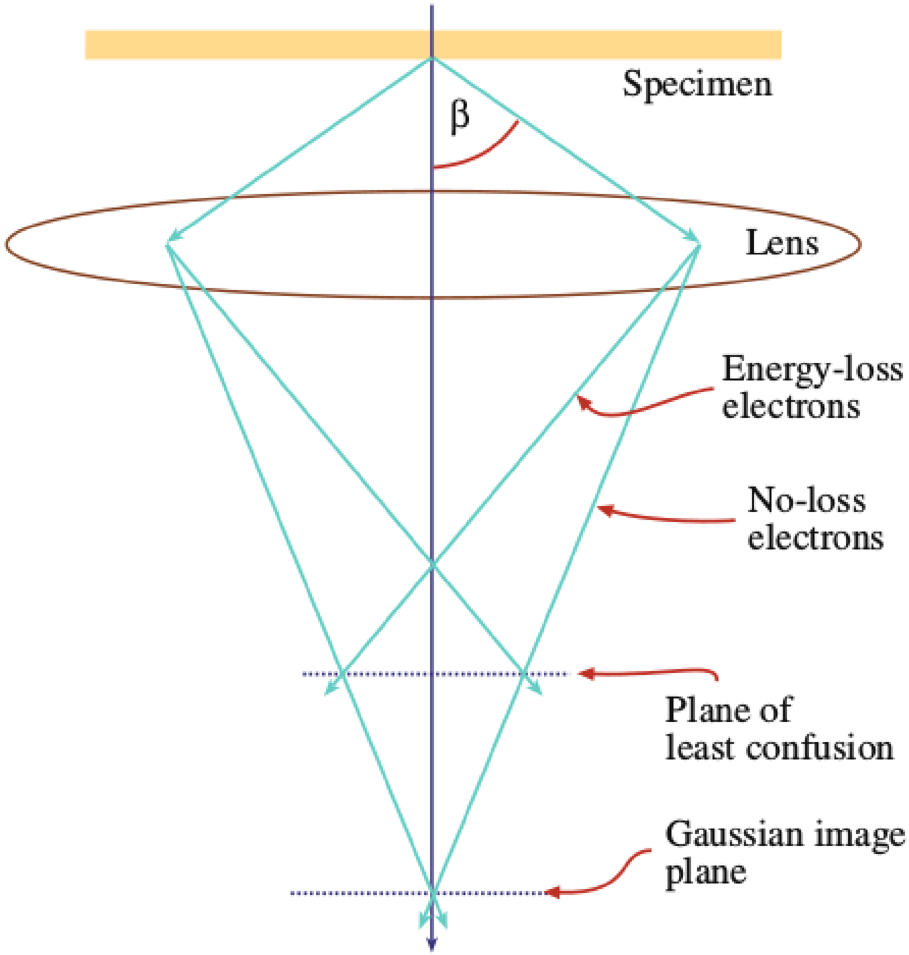
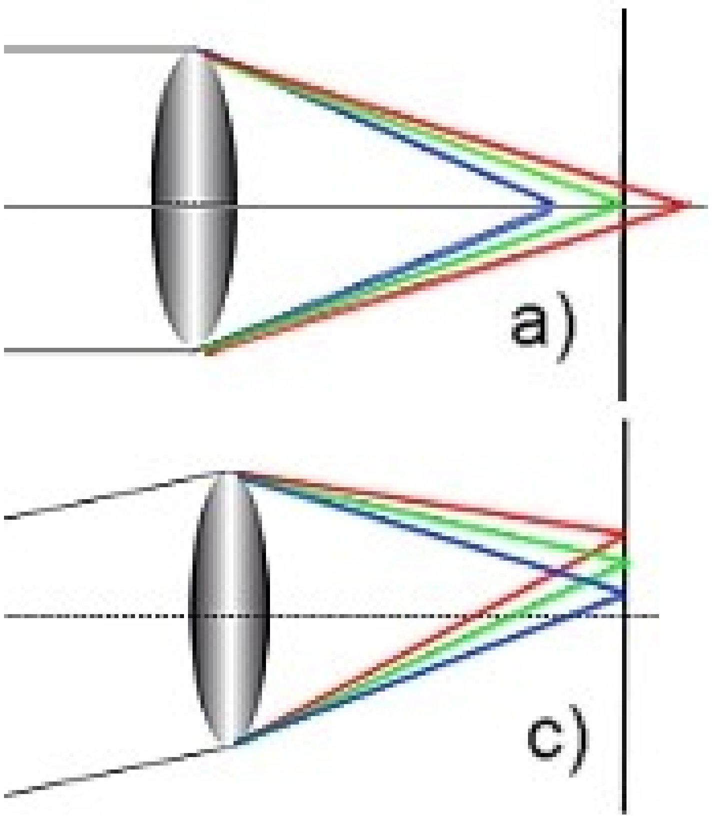
Lens assembly - stigmators



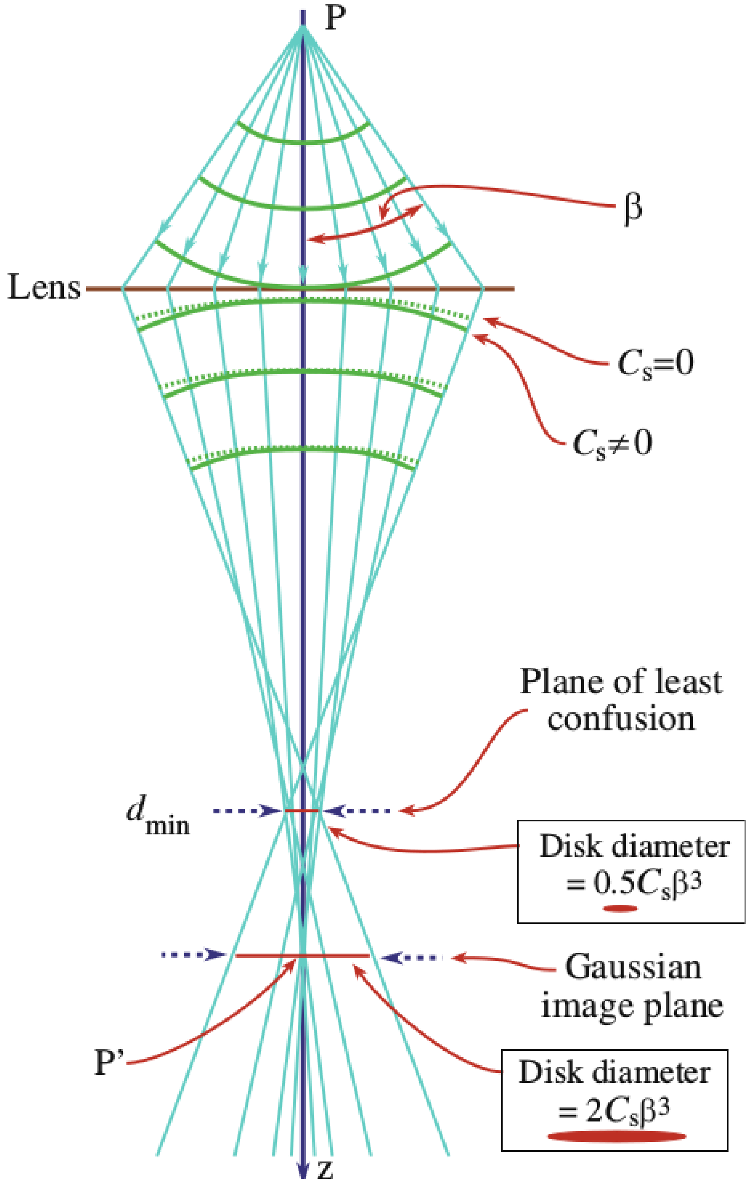


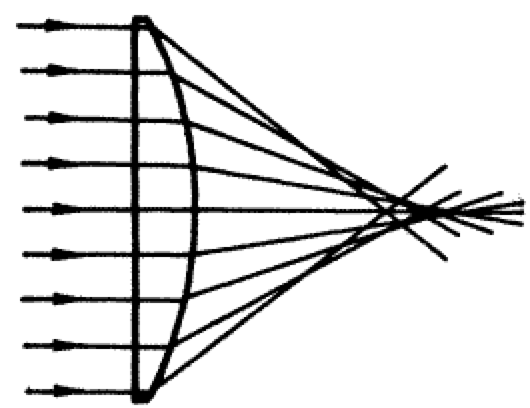
Lens aberrations - chromatic





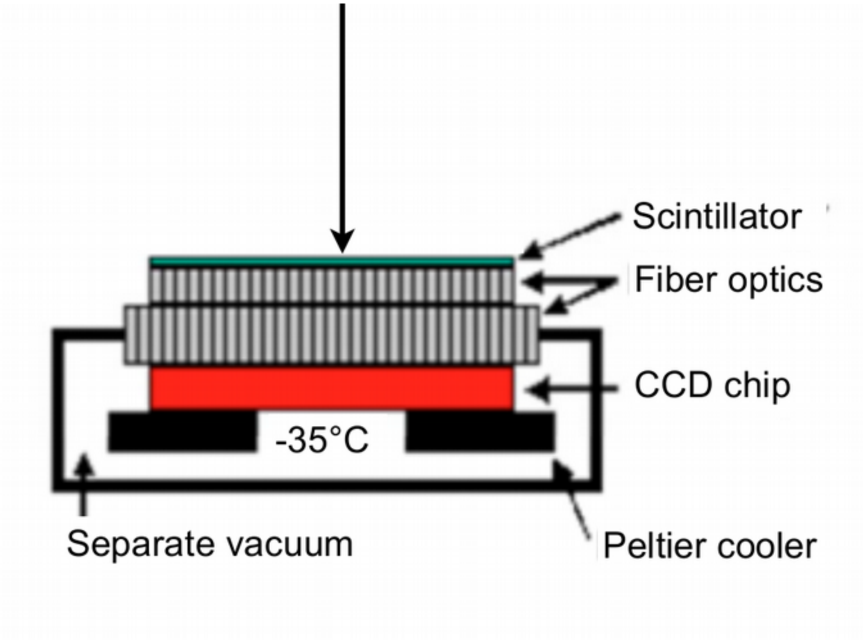
Lens aberrations - spherical



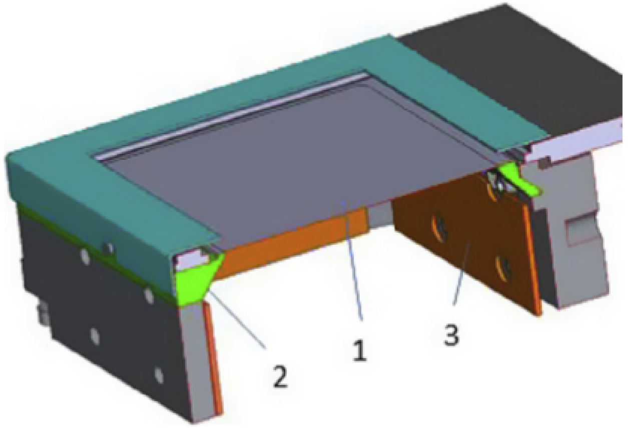


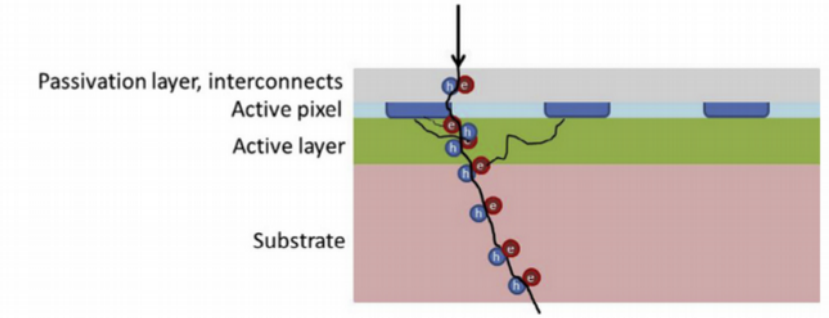
(a)

Detectors



CCD – charge coupled device





CMOS – complementary metal oxide semiconductor

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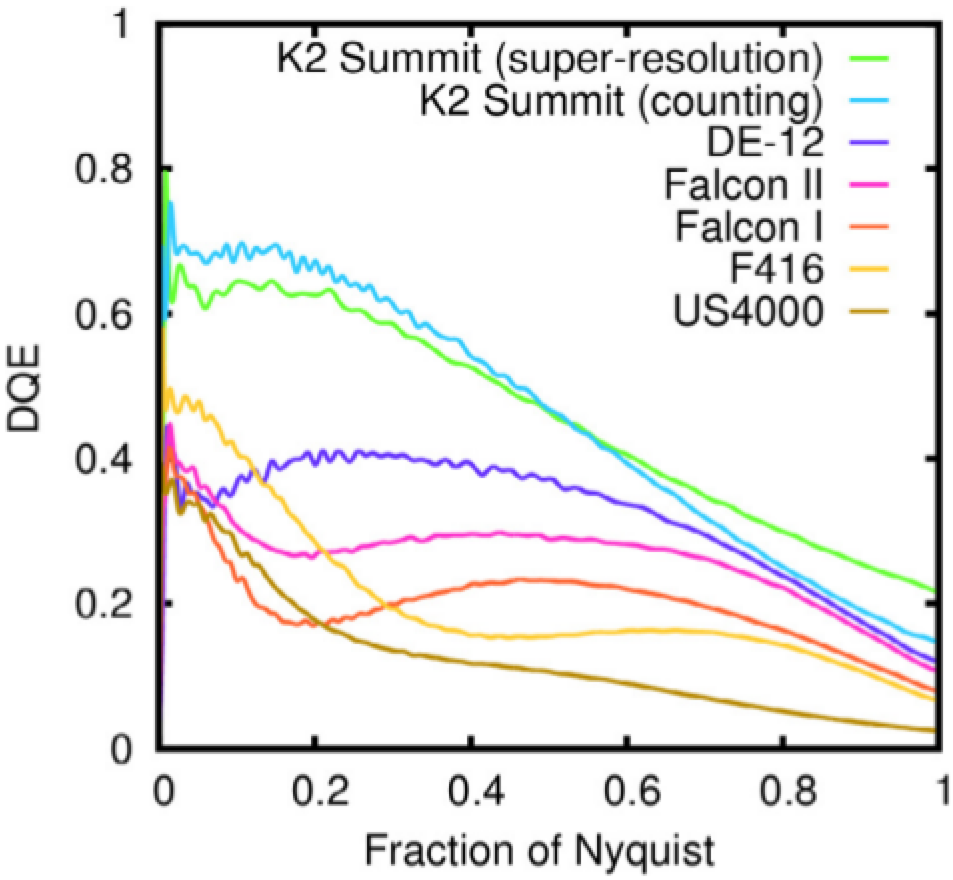
Detectors

DQE – detective quantum efficiency



- probability to detect an electron

- DQE ~ sin(x)/x

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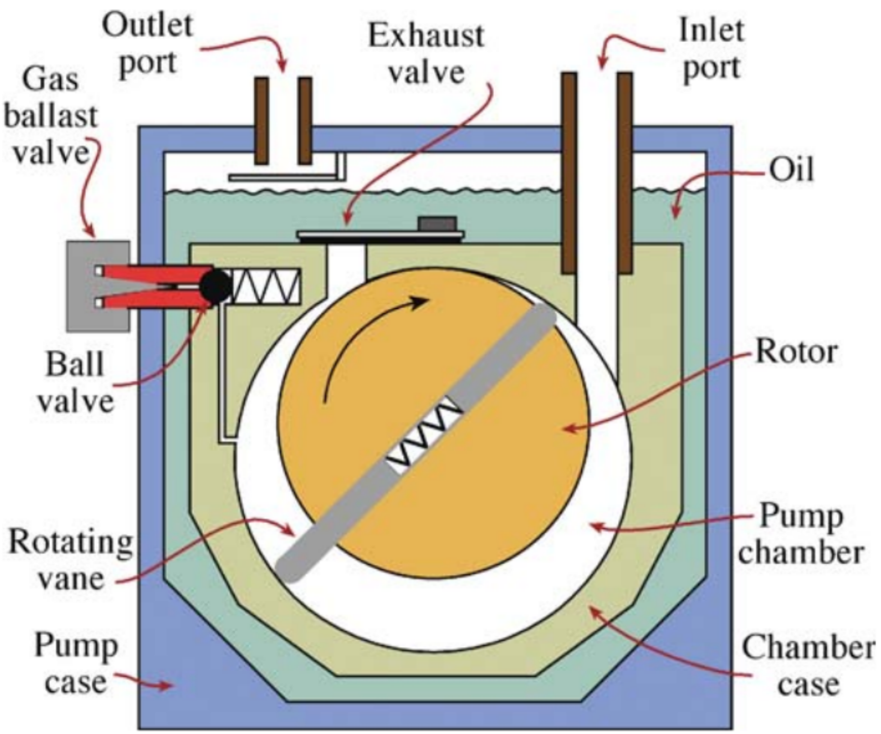
Vacuum system

- roughing pump (10^5 – 10^{-4} Pa)

- turbo molecular pump (10^{-2} – 10^{-8}Pa)

- ion getter pump (up to 10^{-9}Pa)



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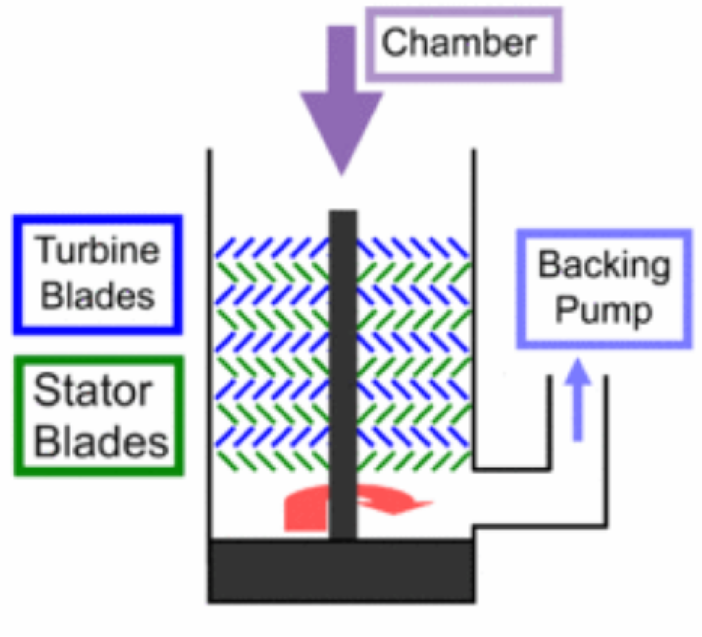

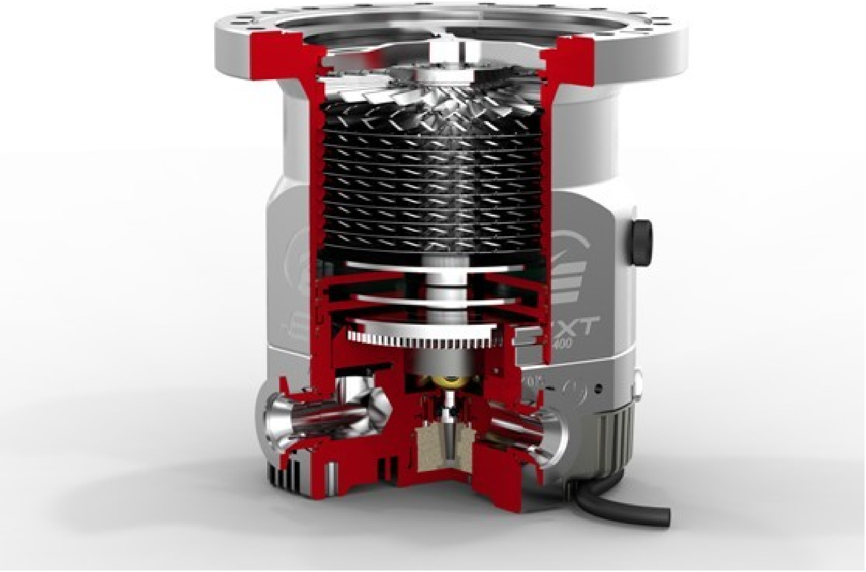

90.000 rpm

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Vacuum system

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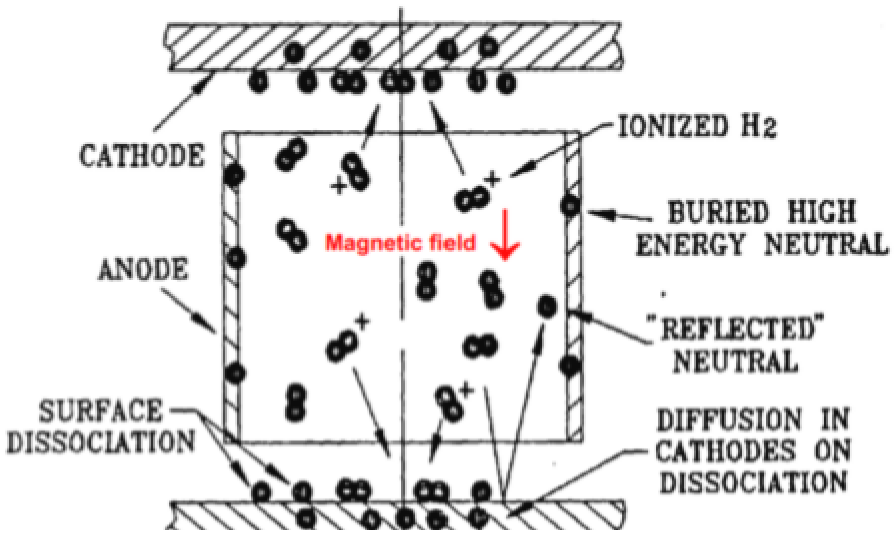
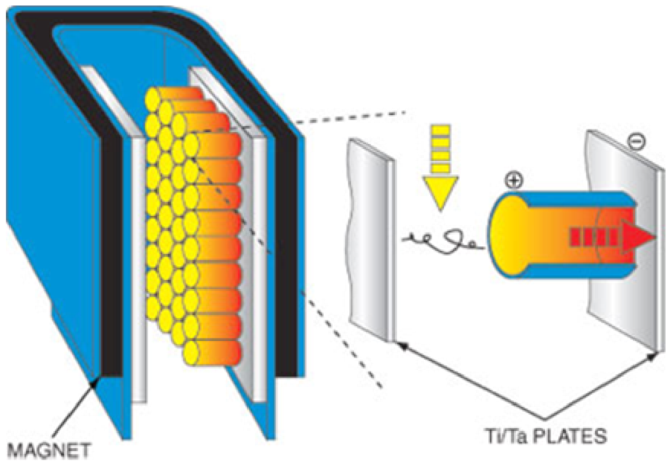
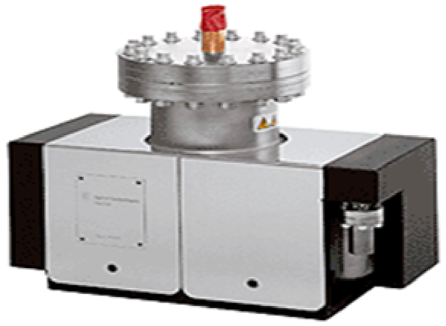


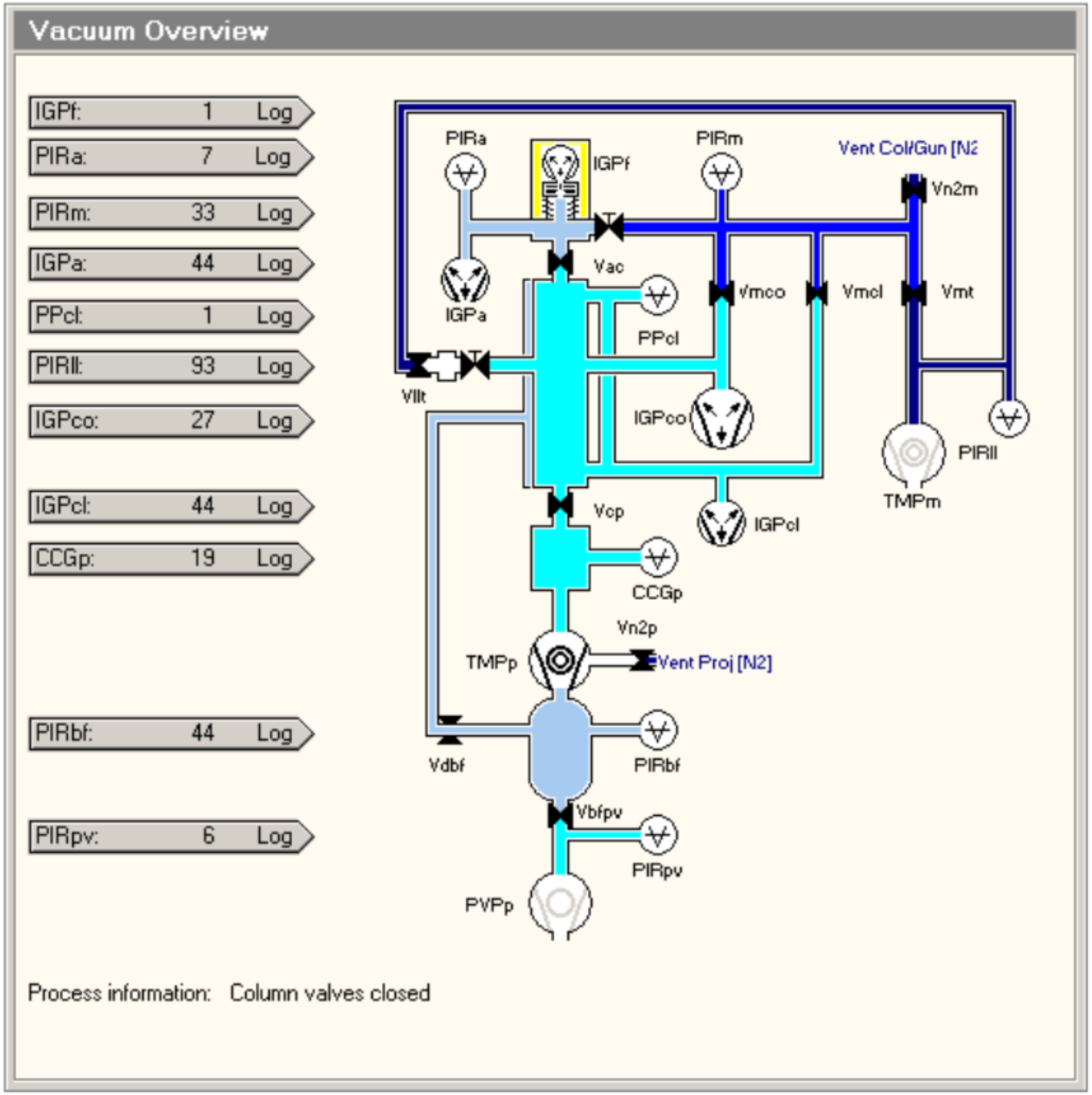


Principle of Operation

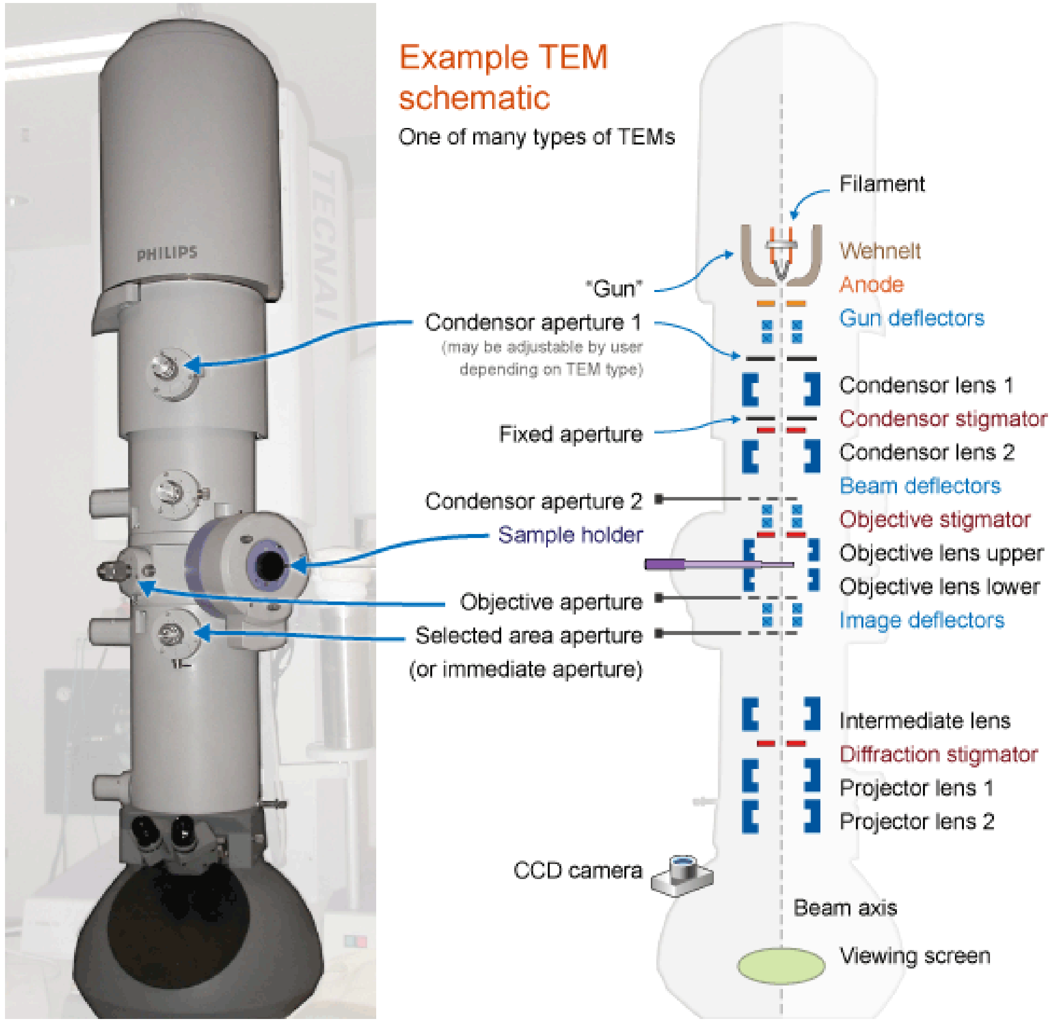


External View

Vacuum system

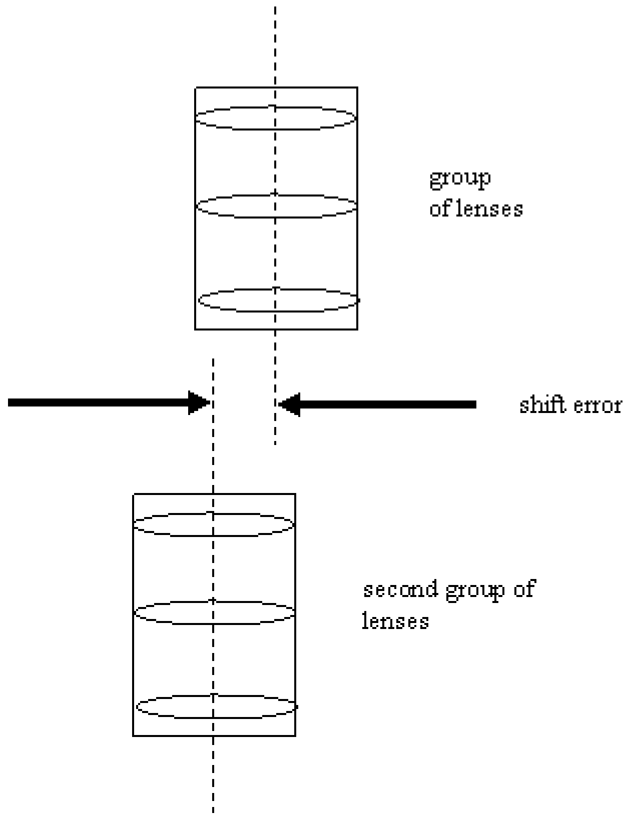


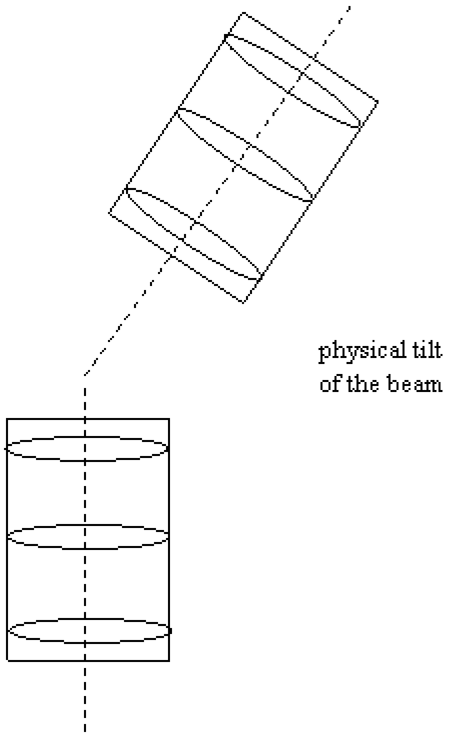
TEM



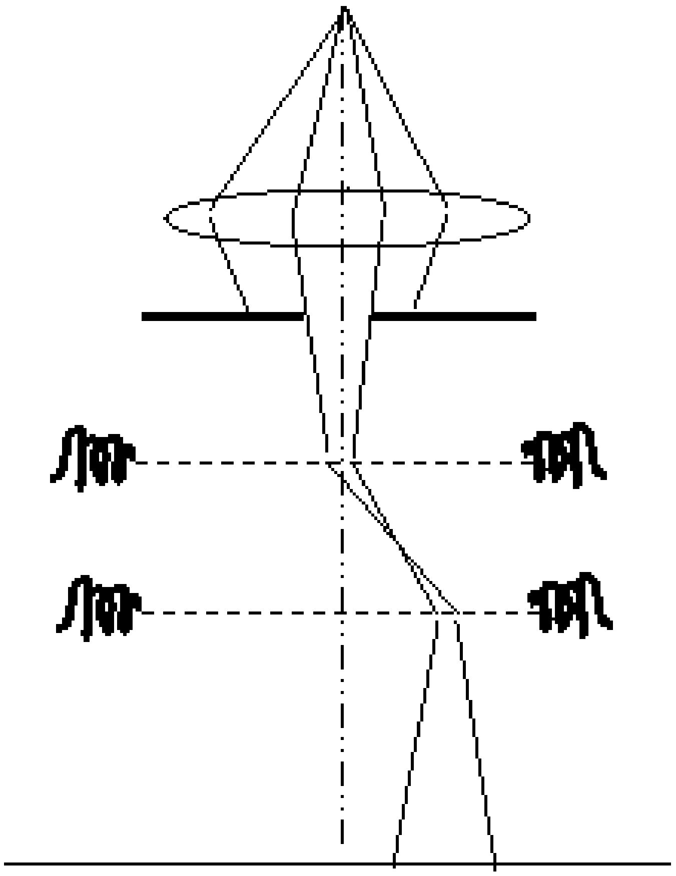
PHILIPS
TECNAI
Example TEM schematic
One of many types of TEMs
Filament
Wehnelt
Anode
Gun deflectors
"Gun"
Condensor aperture 1
(may be adjustable by user depending on TEM type)
Condensor lens 1
Condensor stigmator
Fixed aperture
Condensor lens 2
Beam deflectors
Condensor aperture 2
Objective stigmator
Sample holder
Objective lens upper
Objective lens lower
Objective aperture
Image deflectors
Selected area aperture
(or immediate aperture)
Intermediate lens
Diffraction stigmator
Projector lens 1
Projector lens 2
CCD camera
Beam axis
Viewing screen

TEM


group
of lenses
shift error
second group of
lenses

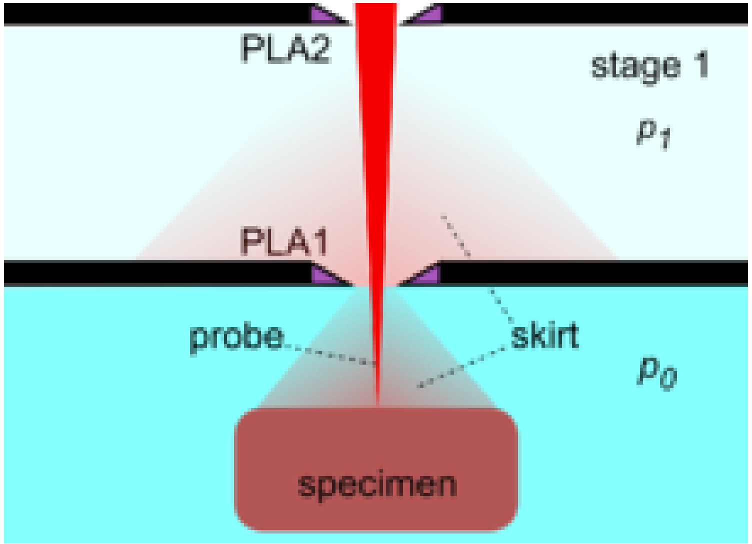

physical tilt
of the beam

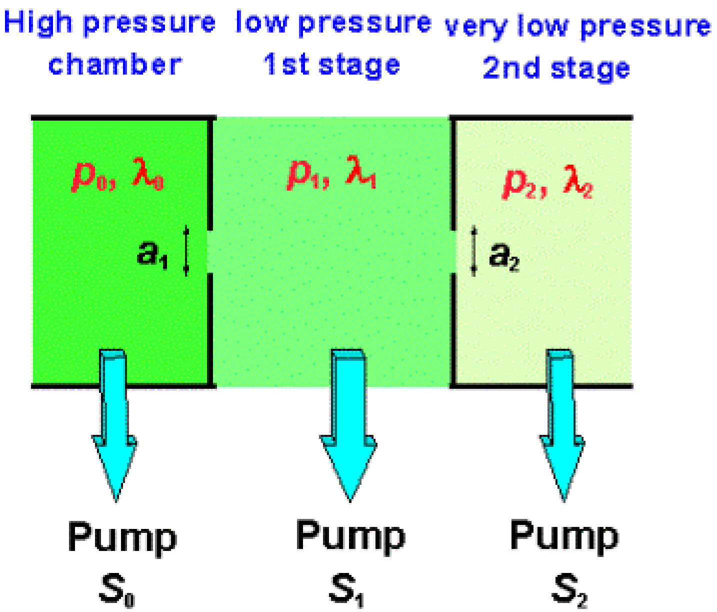
TEM



TEM

Differential pumping apperture





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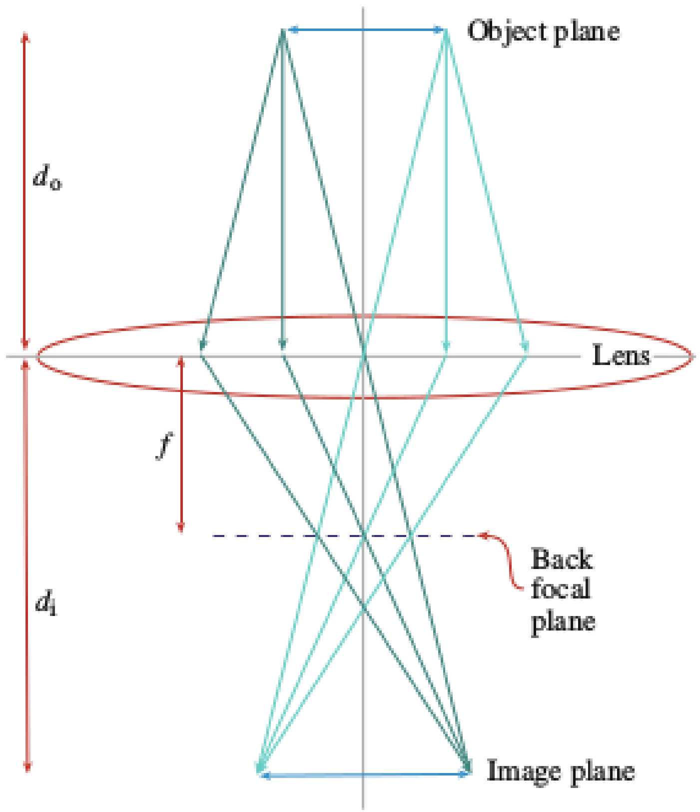
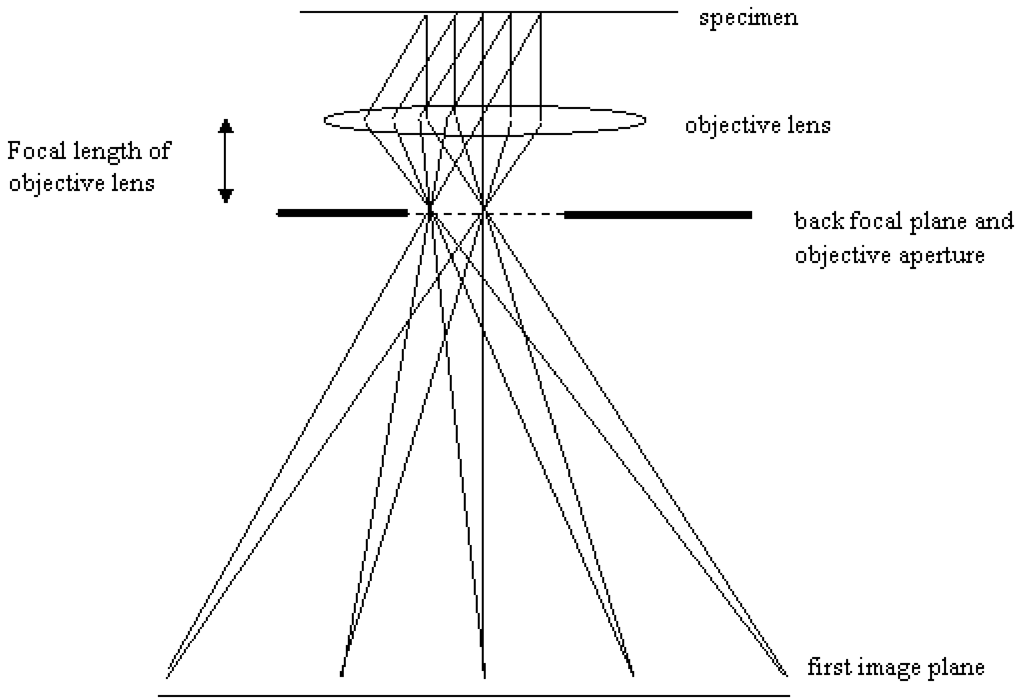
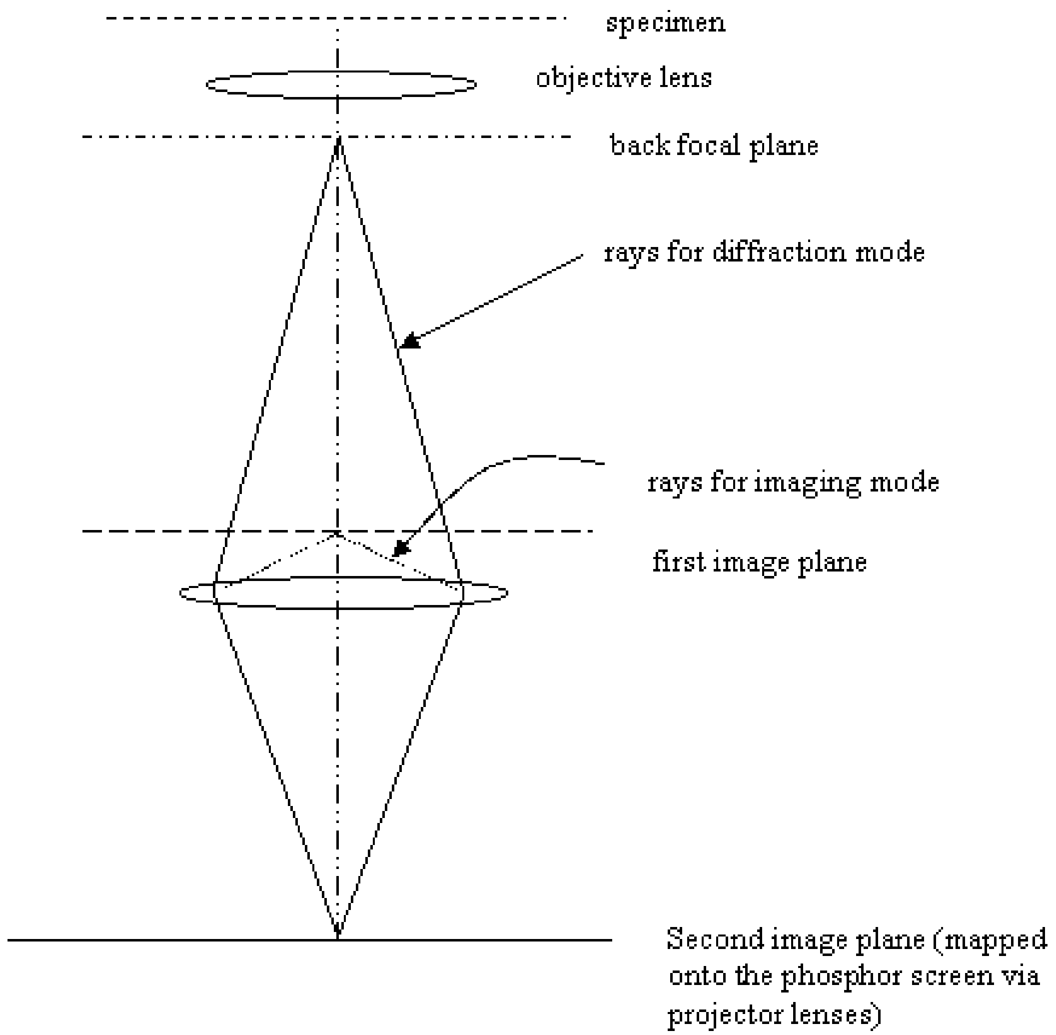
TEM


Object plane
d_o
Lens
f
Back
focal
plane
d_i
Image plane

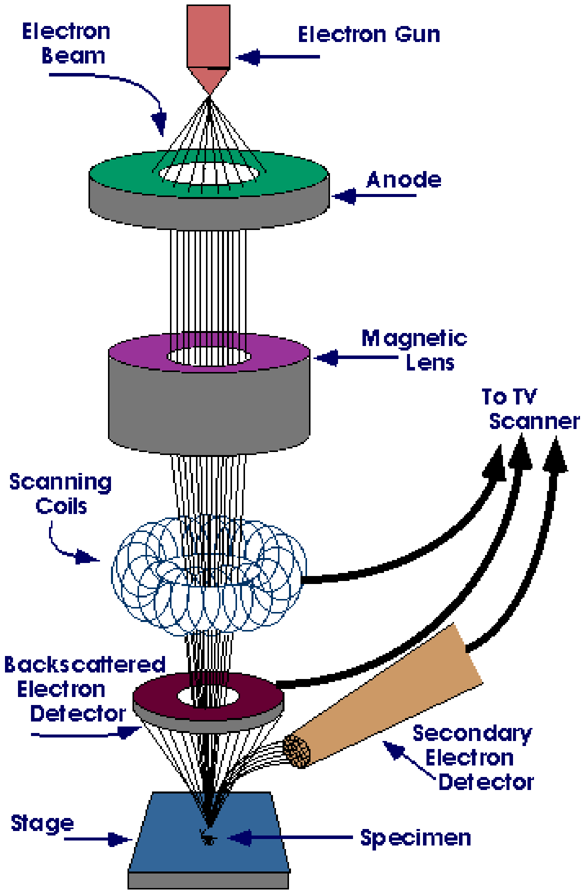

specimen
objective lens
Focal length of
objective lens
back focal plane and
objective aperture
first image plane

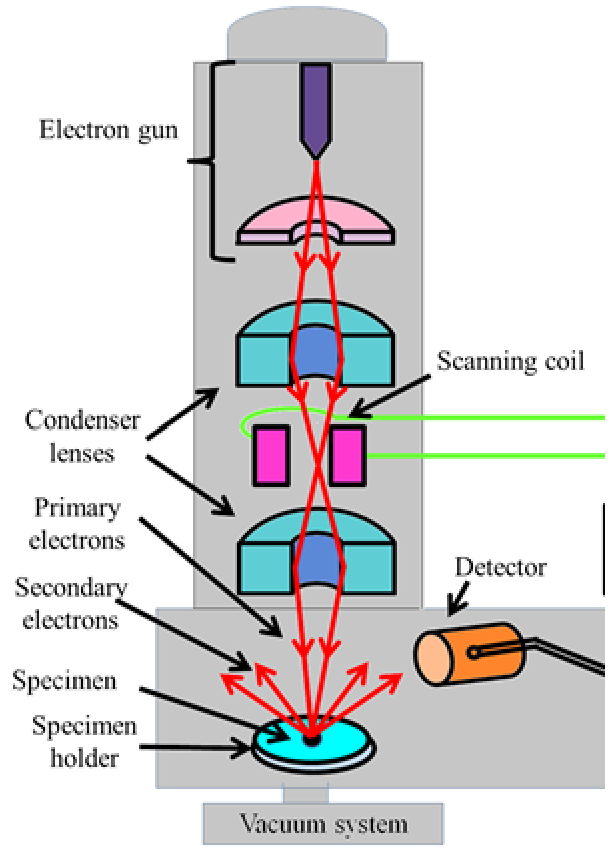
TEM



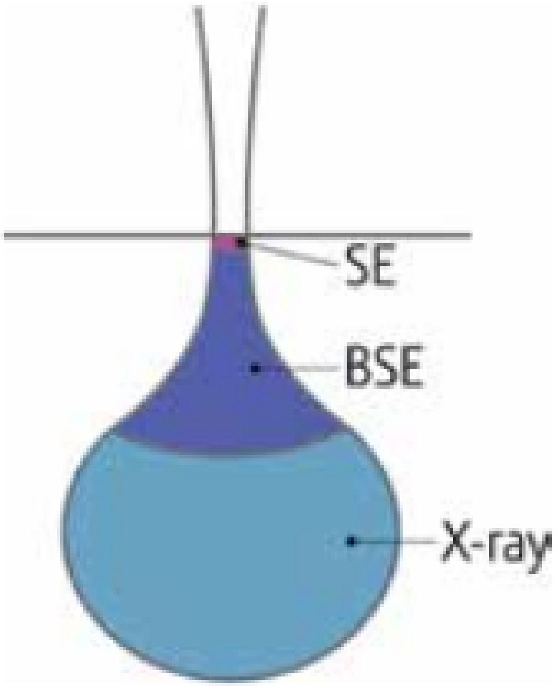
specimen
objective lens
back focal plane
rays for diffraction mode
rays for imaging mode
first image plane
Second image plane (mapped onto the phosphor screen via projector lenses)

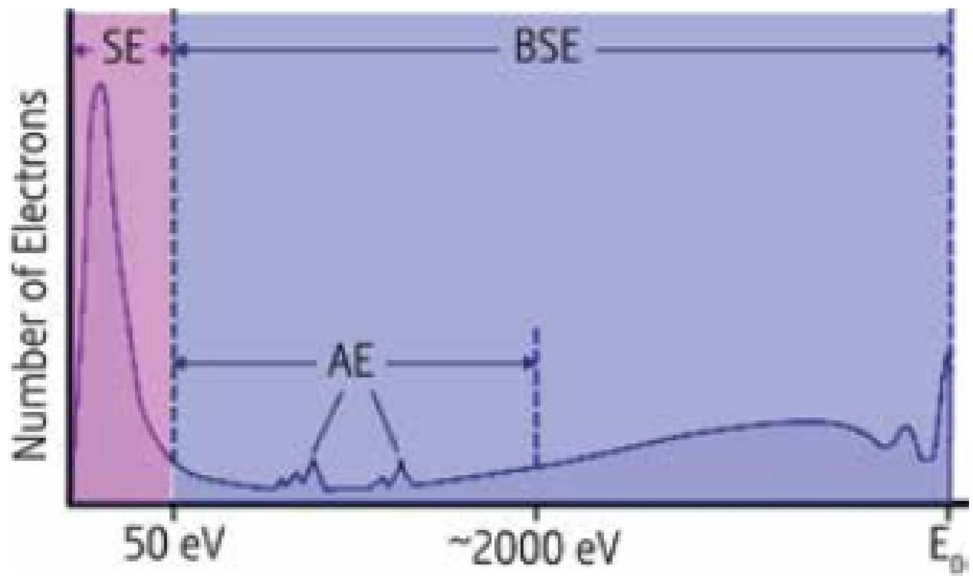
SEM


Electron Beam
Electron Gun
Anode
Magnetic Lens
To TV Scanner
Scanning Coils
Backscattered Electron Detector
Secondary Electron Detector
Stage
Specimen

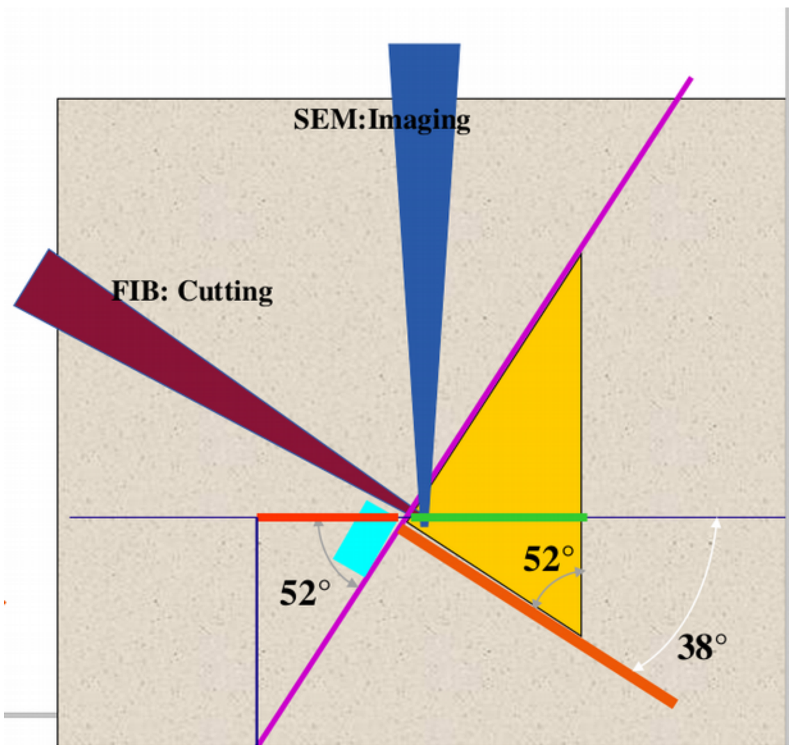

Electron gun
Scanning coil
Condenser lenses
Primary electrons
Secondary electrons
Detector
Specimen
Specimen holder
Vacuum system

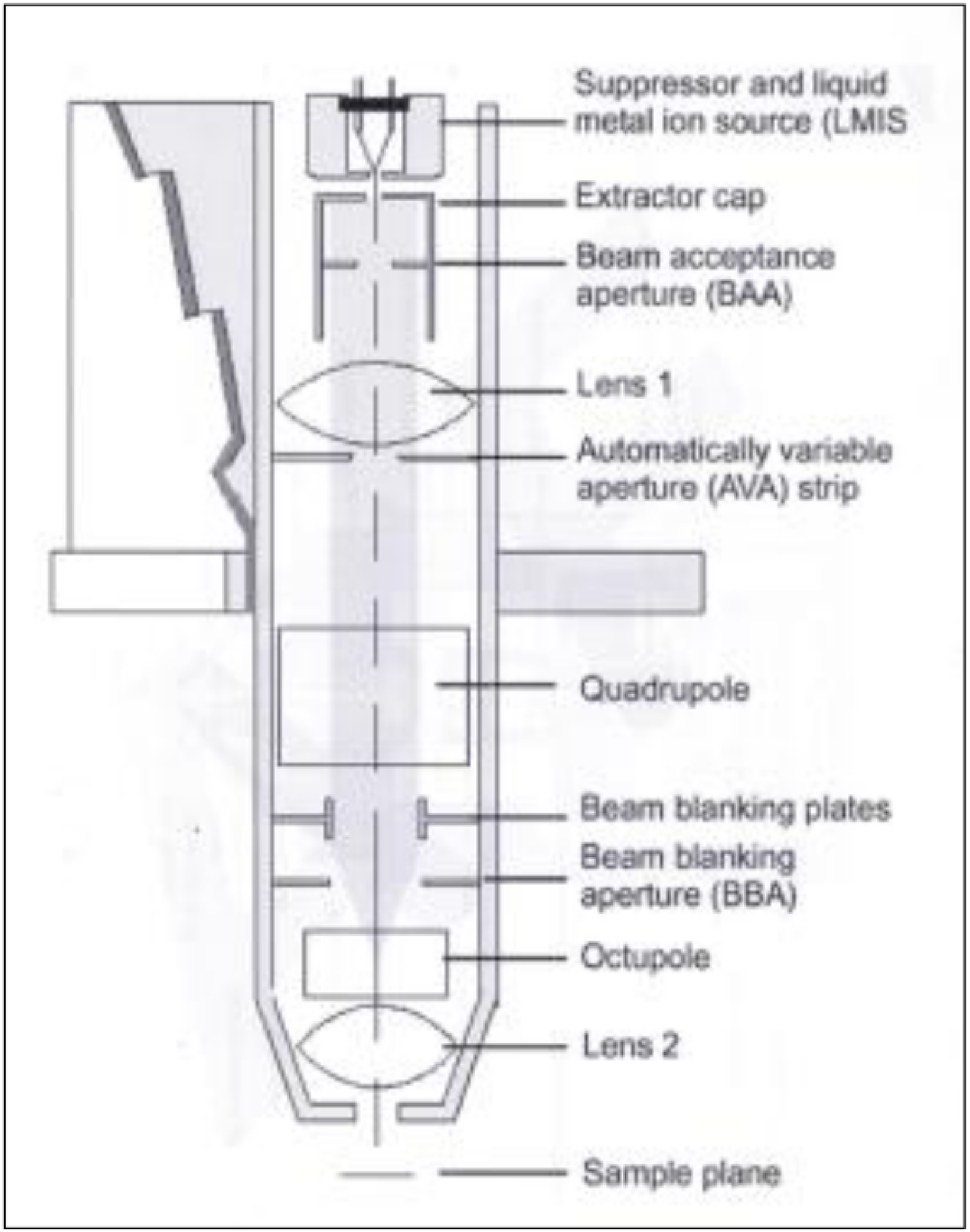
SEM





Dual beam FIB/SEM

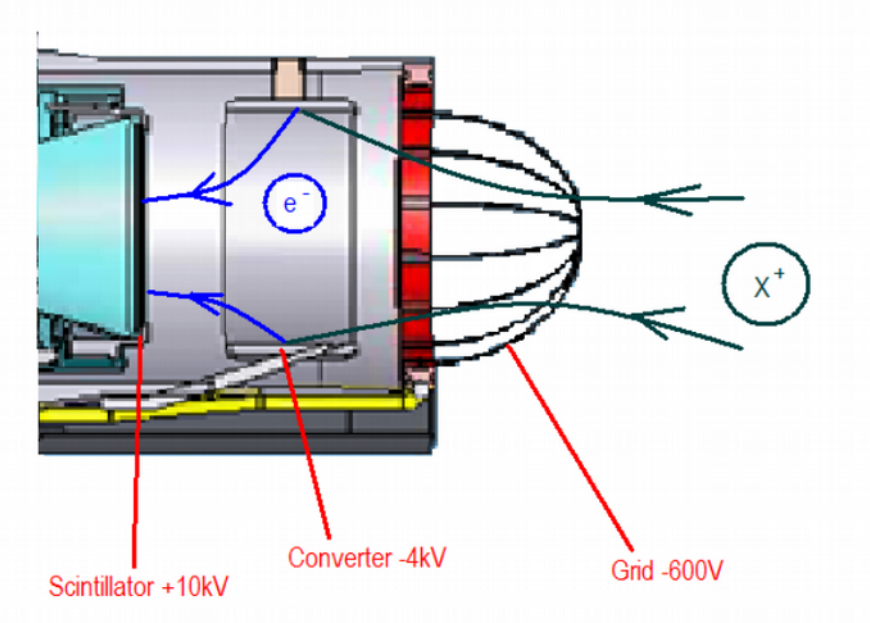


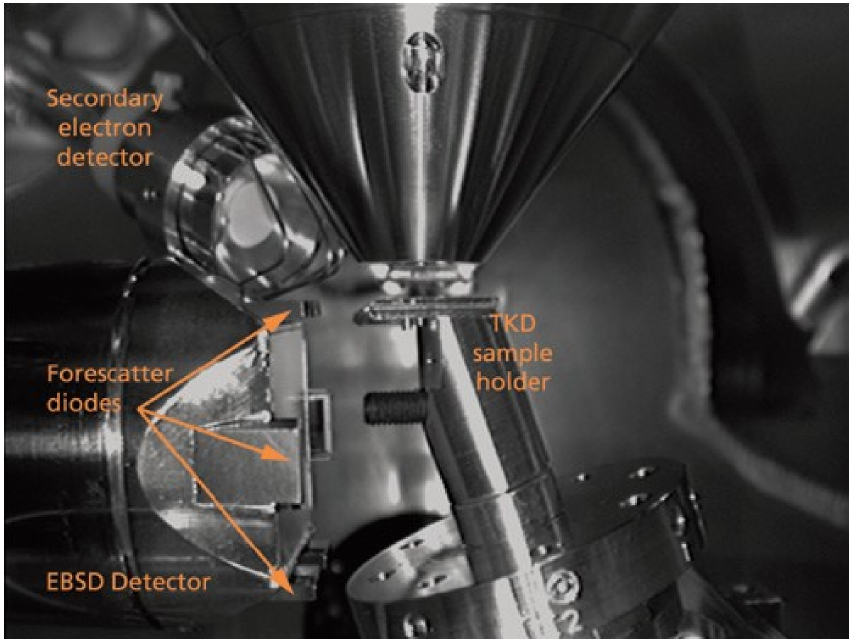


SEM - detection

- Everhart-Thornley Detector (ETD)

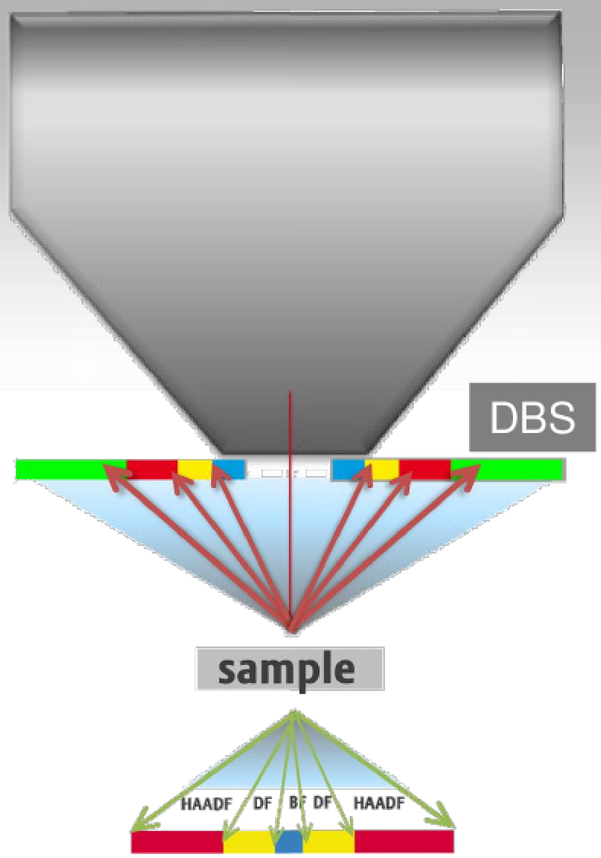
- Ion Convertion to Electron Detector (ICE)





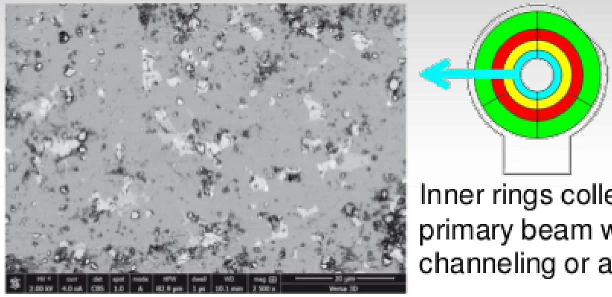
SEM - detection

- Concentric Backscatter detector



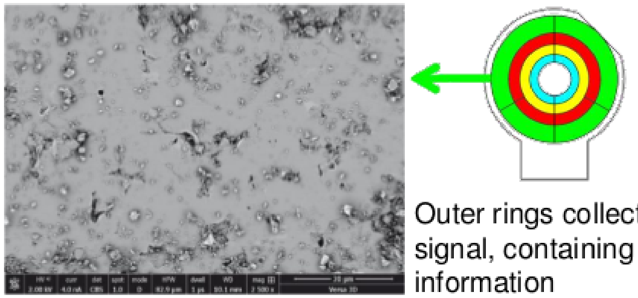
The Directional Backscatter Electron detector* (DBS) allows collection of surface or compositional information through a Concentric Backscatter mode (CBS) to filter signal from various angles (which can be selected by segment, working distance and/or Beam Deceleration*). A range of angles can be precisely selected based on imaging conditions to reveal unique information.

Composition and material contrast



Inner rings collect signal on-axis with the primary beam which contains most channeling or atomic contrast information.

Surface information and topographic contrast



Outer rings collect large angle BSE signal, containing mostly topographic information