CEITEC

Středoevropský technologický institut

BRNO | ČESKÁ REPUBLIKA

Electron microscopy

InnoCore project

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EVROPSKÁ UNIE
EVROPSKÝ FOND PRO REGIONÁLNÍ ROZVOJ
INVESTICE DO VAŠÍ BUDOUCNOSTI

2007–13
OP Výzkum a vývoj pro inovace

Sylabus

- **Lecture 1: Applications of electron microscopy in life-science research**
- **Lecture 2: Transmission electron microscope, cryo-electron microscopy, principles of image formation**
- **Lecture 3: Data alignment in 2D, techniques for 3D model determination in cryo-EM**

Sylabus

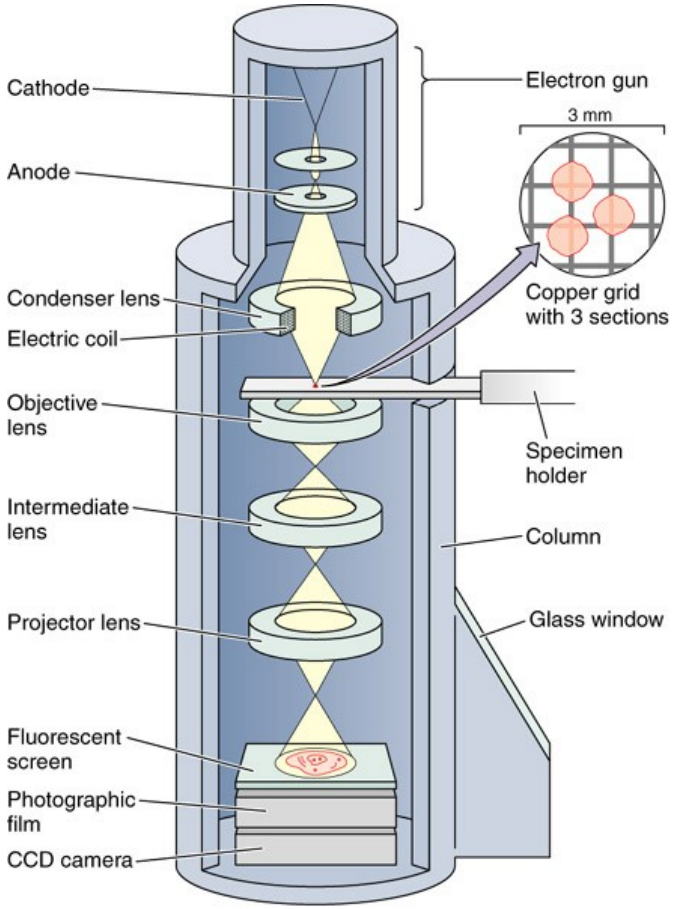
- Lecture 1: Applications of electron microscopy in life-science research
- **Lecture 2: Transmission electron microscope, cryo-electron microscopy, principles of image formation**
- Lecture 3: Data alignment in 2D, techniques for 3D model determination in cryo-EM

Content

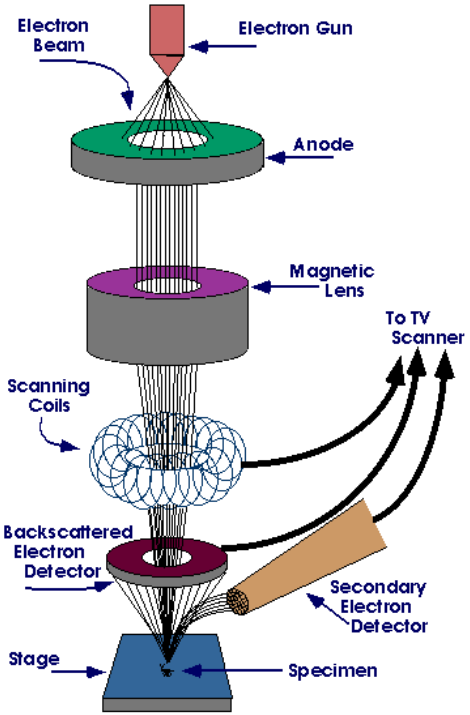
- Electron microscopes
- Transmission electron microscope
- Principles of image formation

Electron microscopes

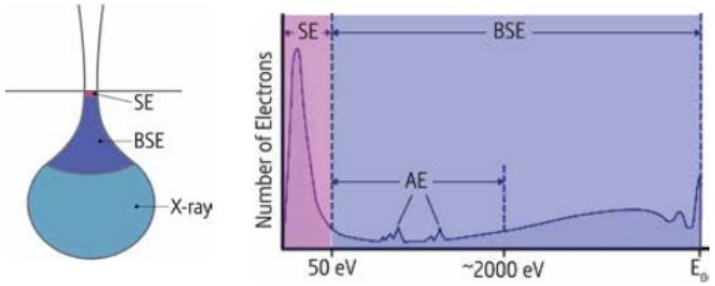
Transmission electron microscope



Scanning electron microscope

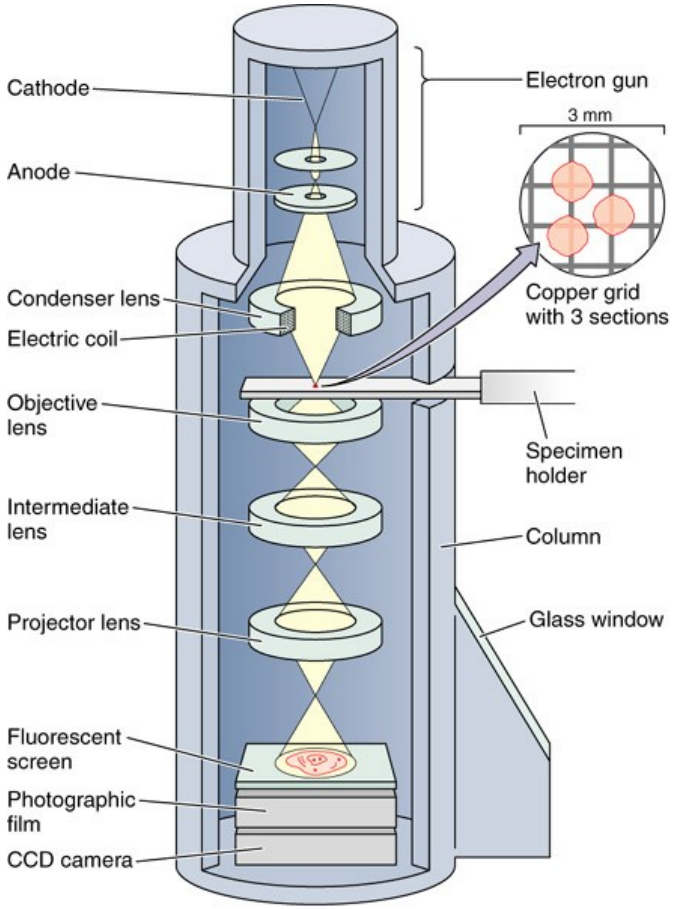


Scanning transmission electron microscope

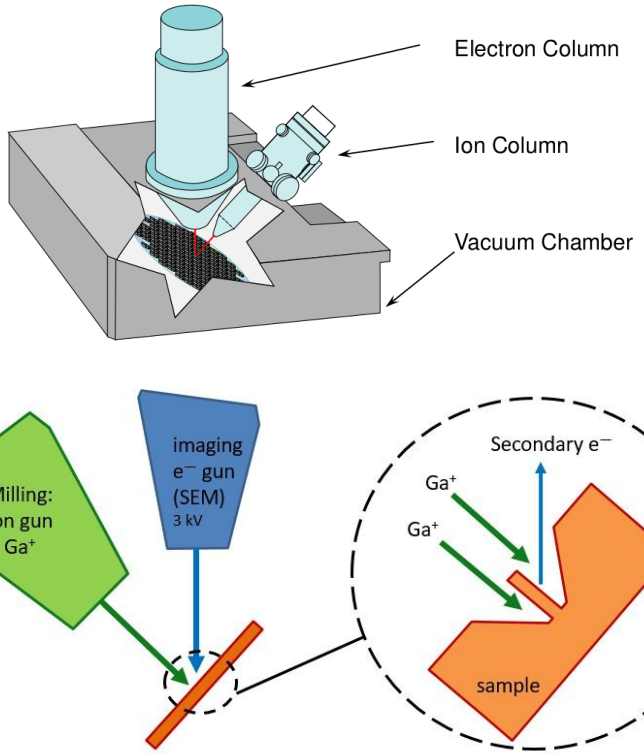


Electron microscopes

Transmission electron microscope

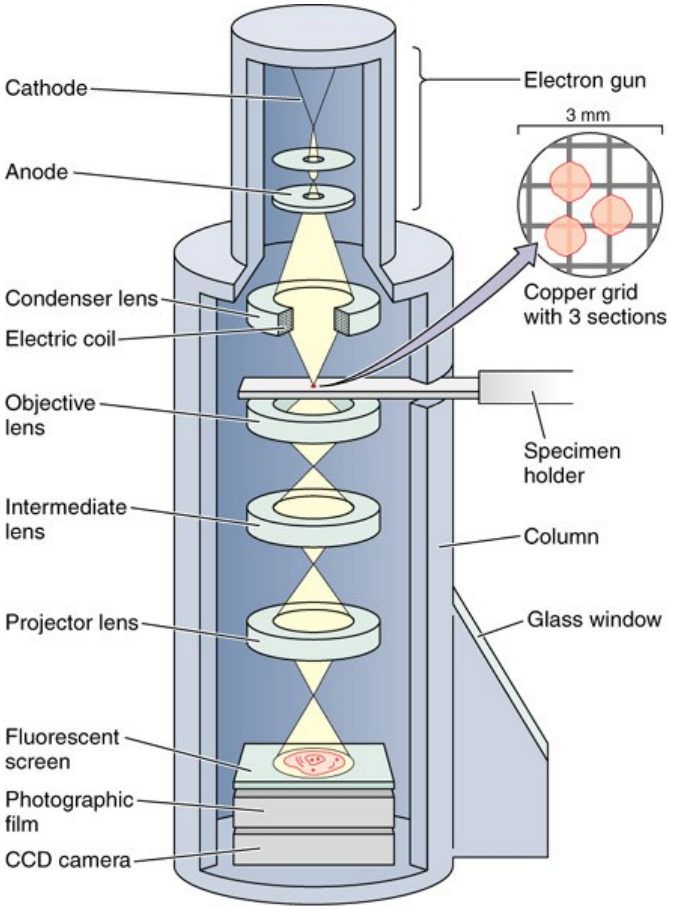


FIB/SEM microscope

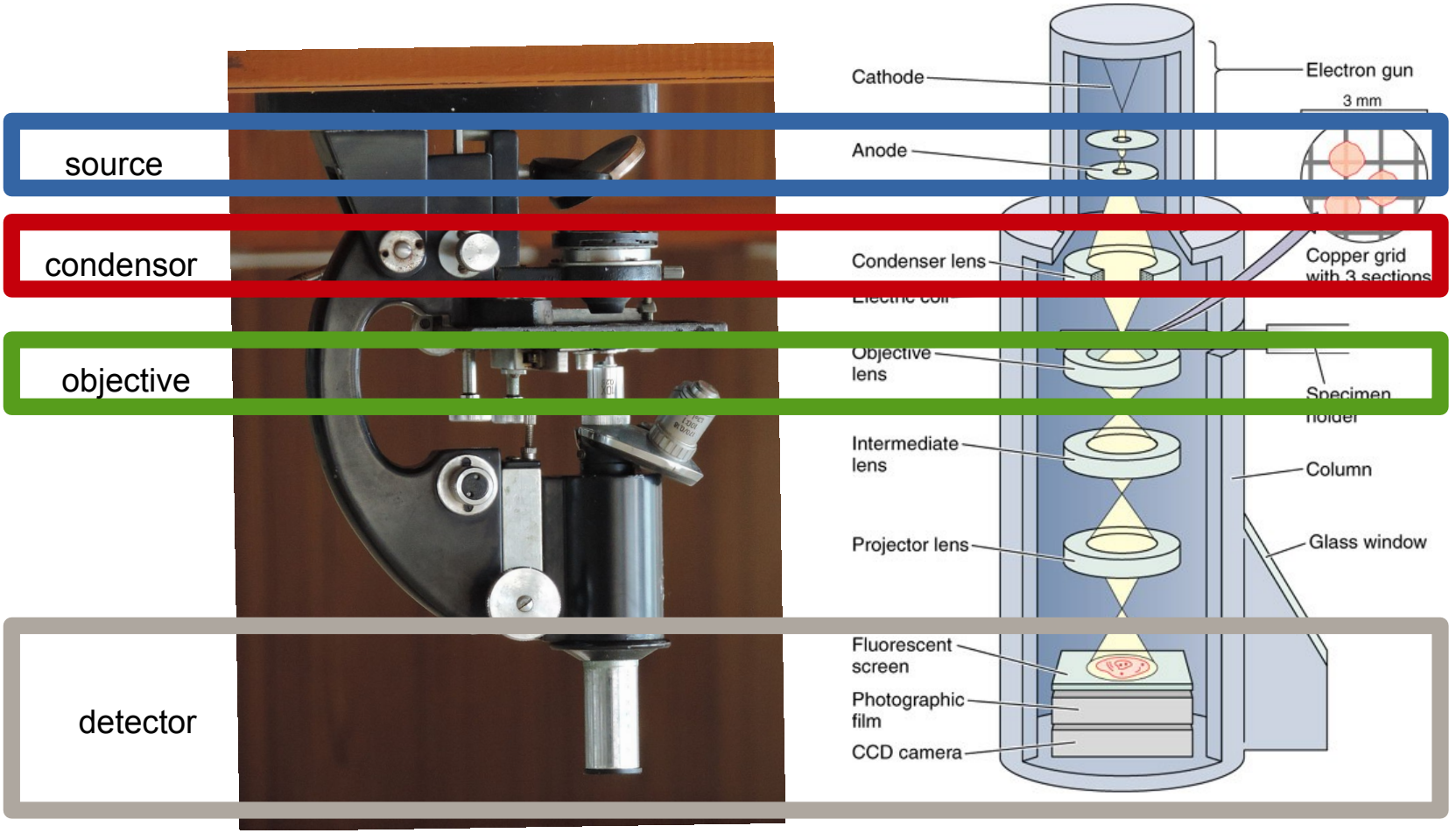


Scanning transmission electron microscope

Optical vs. TEM microscope



Optical vs. TEM microscope



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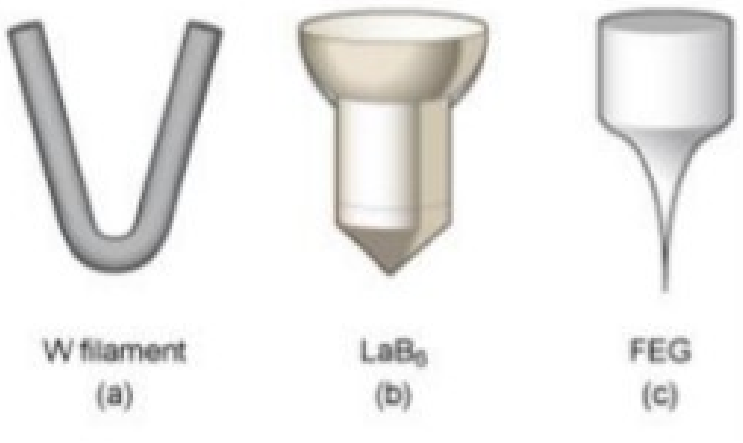
Electron source

- thungsten filament

- LaB6 crystal

- Field Emission Gun

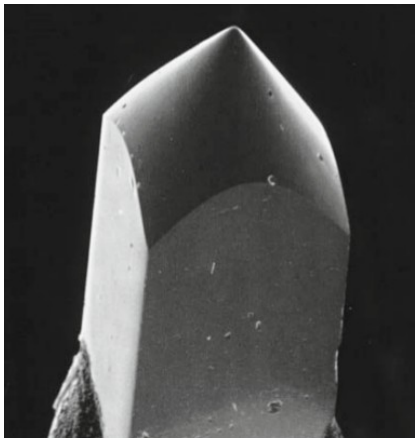


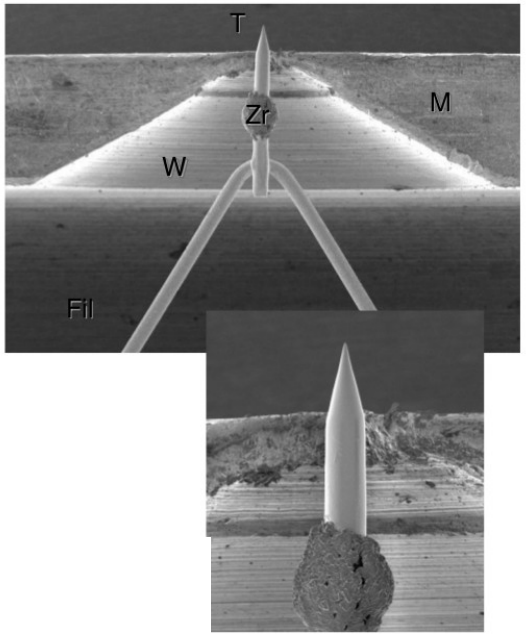
	Units	Tungsten	LaB_6	Schottky FEG	Cold FEG
Work function, Φ	eV	4.5	2.4	3.0	4.5
Richardson's constant	A/m^2K^2	6×10^9	4×10^9		
Operating temperature	K	2700	1700	1700	300
Current density (at 100 kV)	A/m^2	5	10^2	10^5	10^6
Crossover size	nm	$> 10^5$	10^4	15	3
Brightness (at 100 kV)	A/m^2sr	10^{10}	5×10^{11}	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

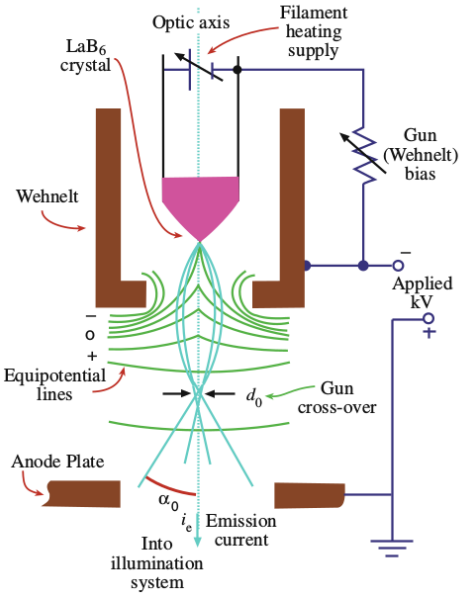
Electron source

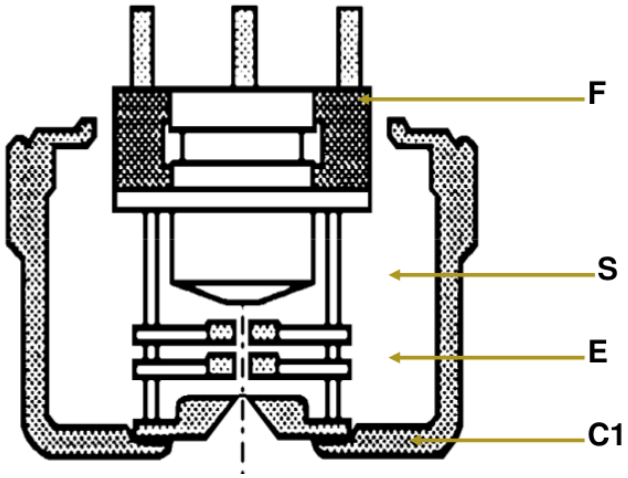
LaB6

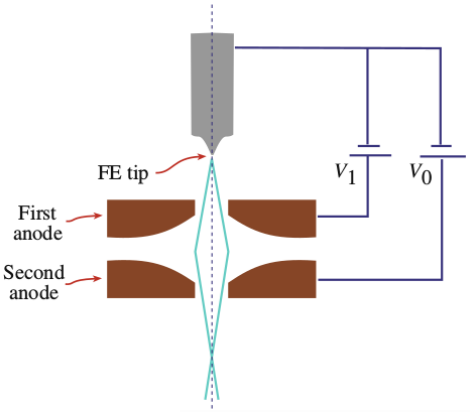
Field emission gun



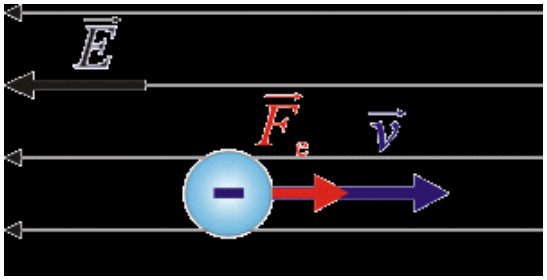








Accelerator

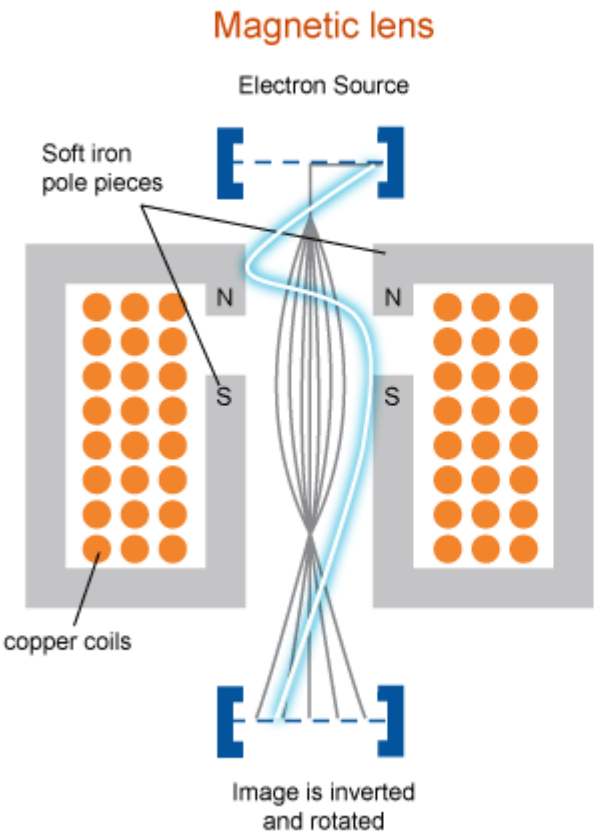


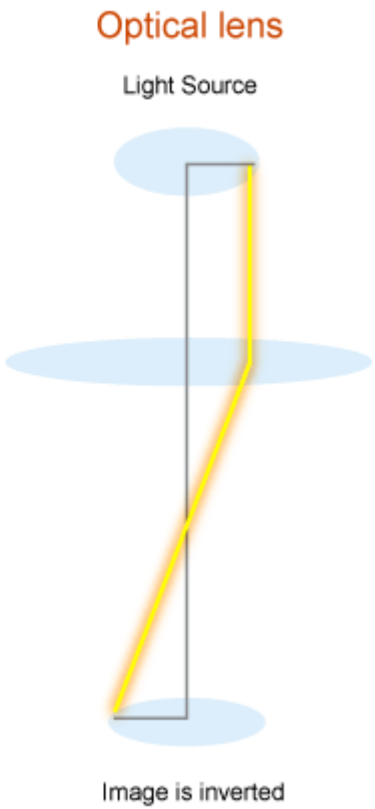
$$\lambda_{\text{de Broglie}} = \frac{h}{p} = \frac{h \cdot c}{\sqrt{(e \cdot V_a)^2 + 2 \cdot e \cdot V_a \cdot m_e \cdot c^2}}$$

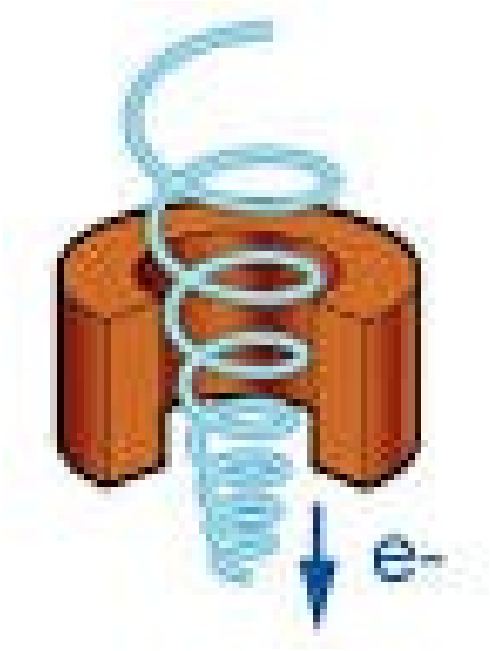
Acceleration Voltage [kV]	Non-relativistic wavelength [pm]	Relativistic wavelength [pm]
2	27.35	27.32
20	8.65	8.57
100	3.87	3.69
200	2.73	2.50
300	2.23	1.96

Electromagnetic lenses

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





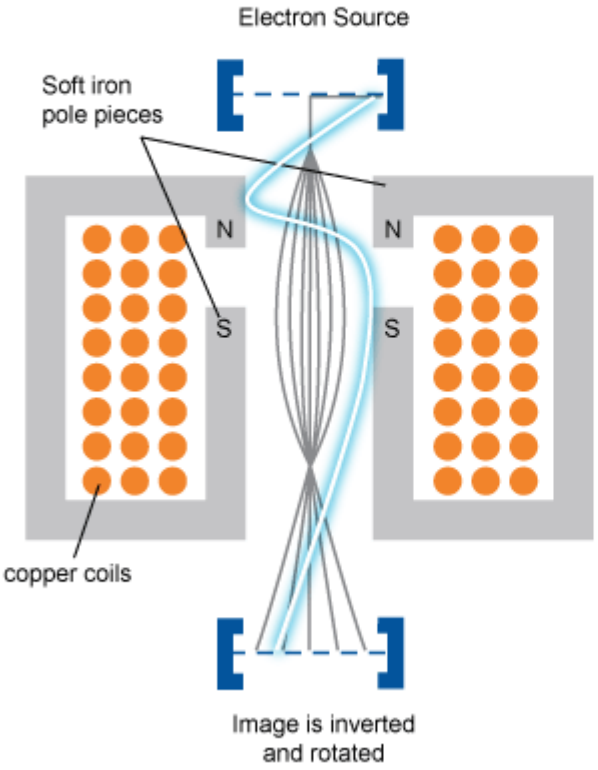


Magnetic lenses rotate image

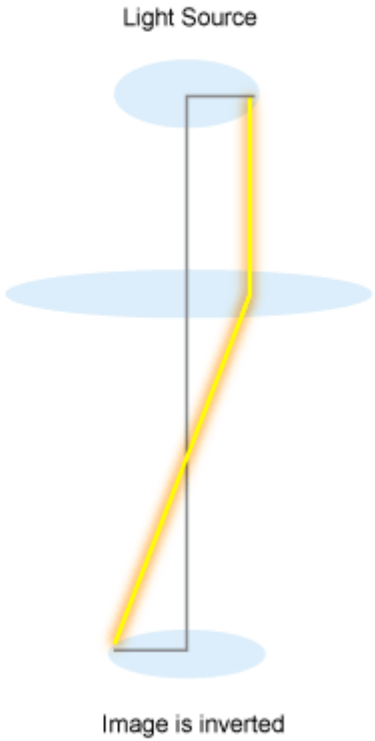
Electromagnetic lenses

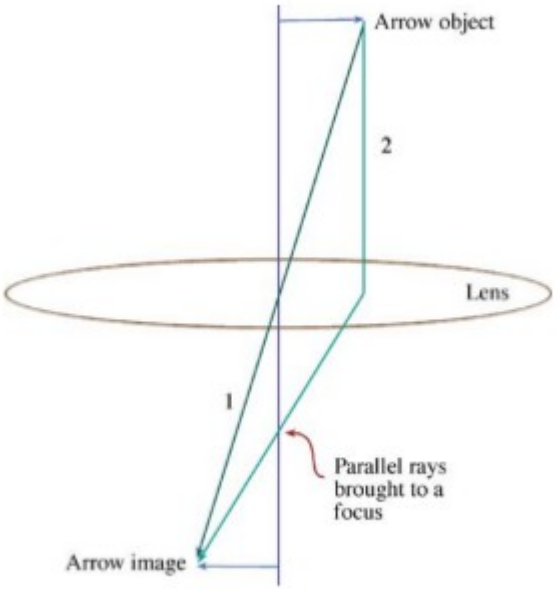
Lorentz force: $\mathbf{F} = q(\mathbf{E} + \mathbf{v} \times \mathbf{B})$

Magnetic lens



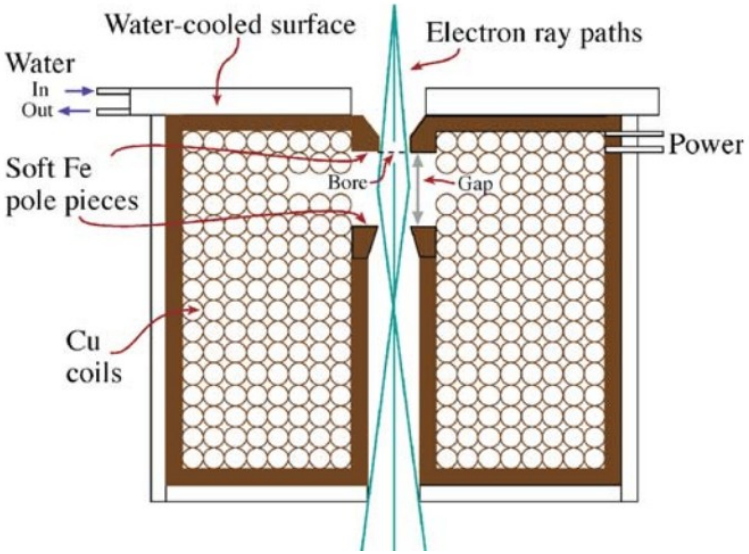
Optical lens

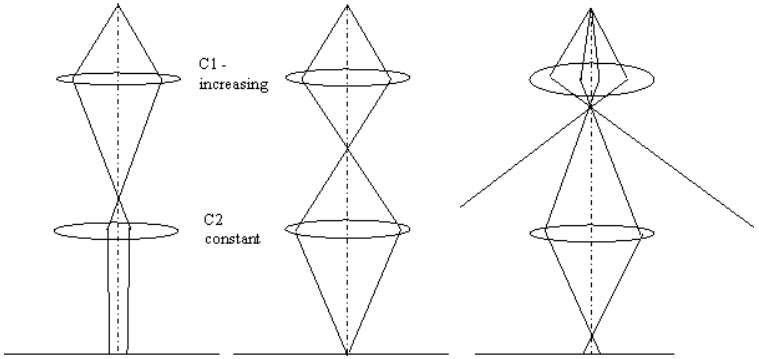




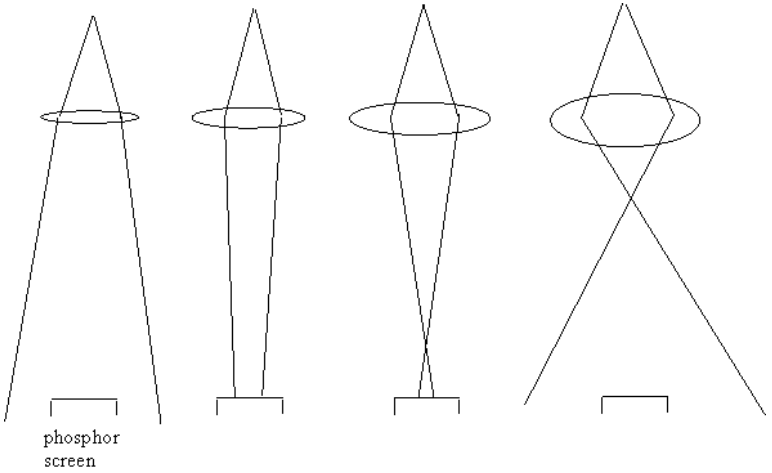
Magnetic lenses rotate image

Electromagnetic lenses





I distance (power) of the magnetic lens can be changed



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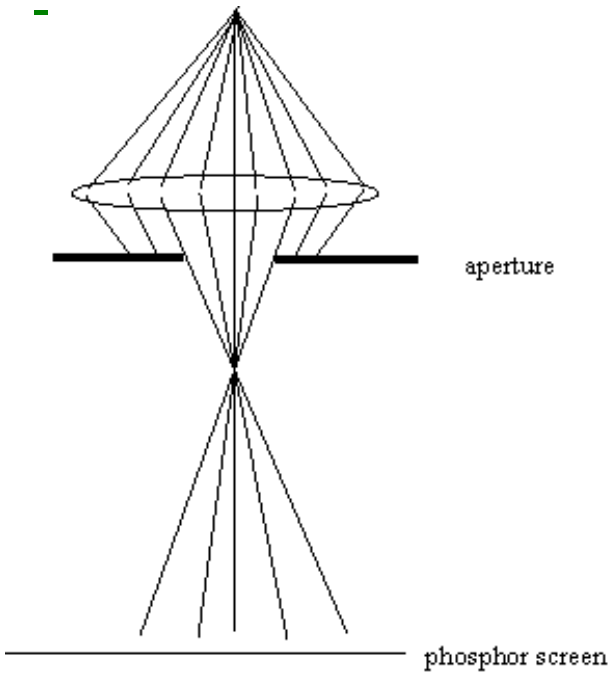
Electromagnetic lens assembly

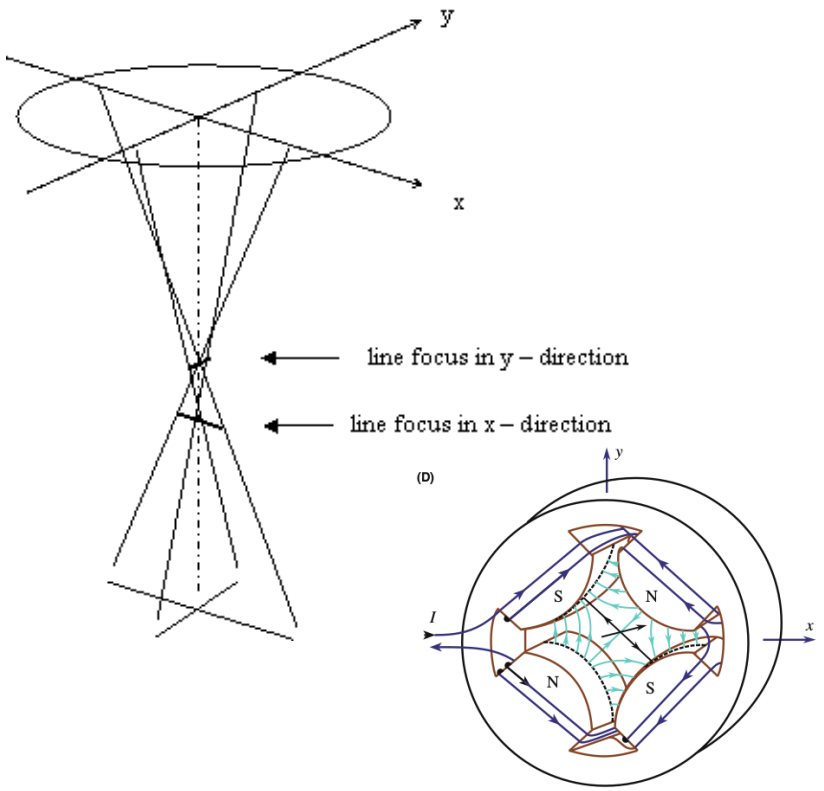
Aperture

-

-

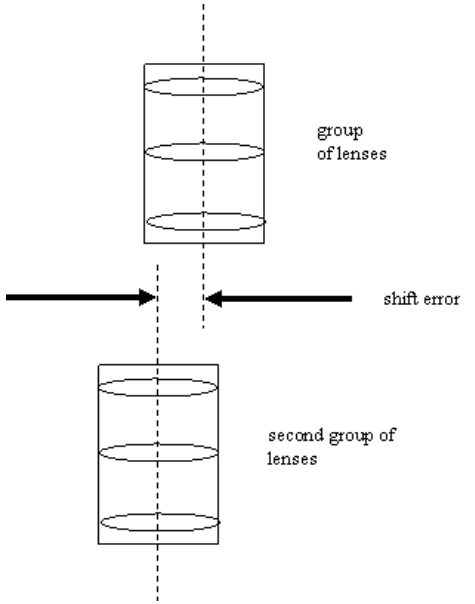


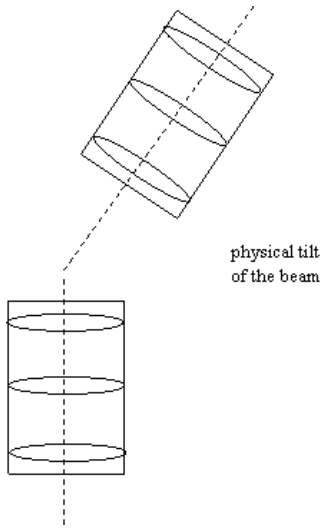
Stigmator



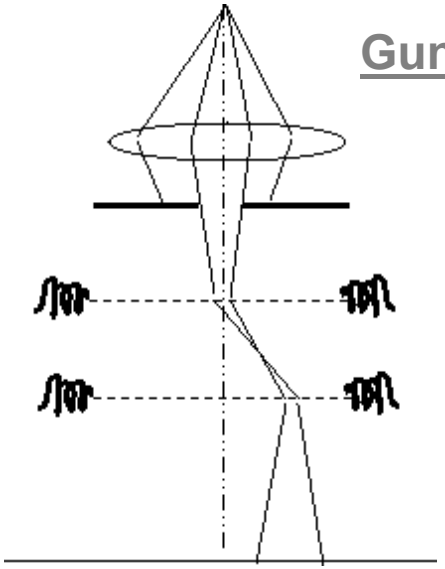
Multiple lens assemblies

Shift **Tilt**



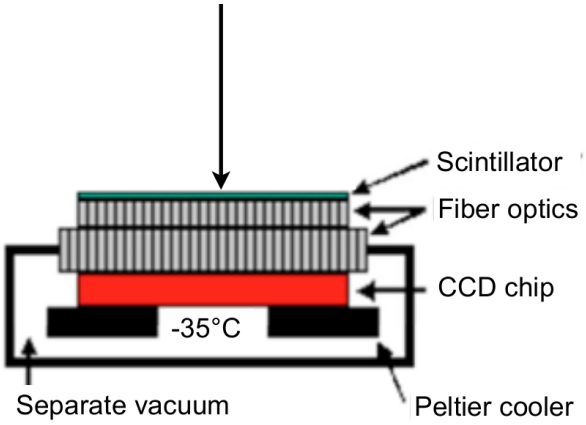


Gun/beam/image tilt and shift coils

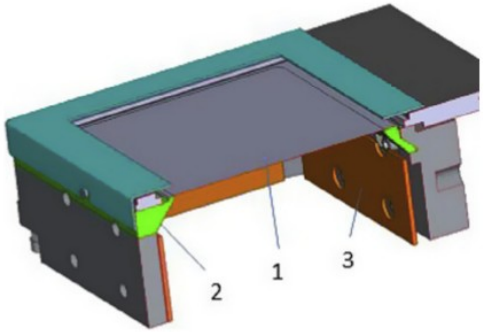


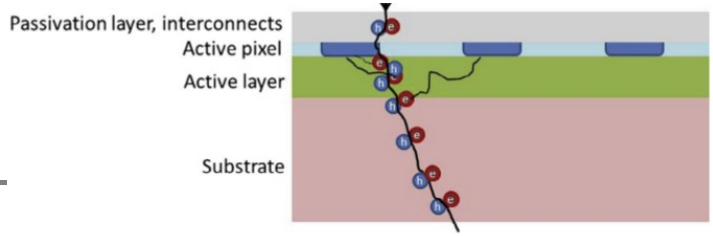
Detectors

CCD – charge coupled device

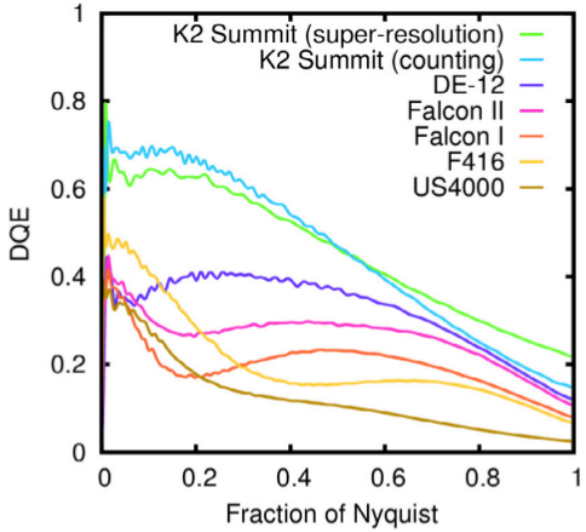


CMOS – complementary metal oxide semiconductor





DQE – detective quantum efficiency

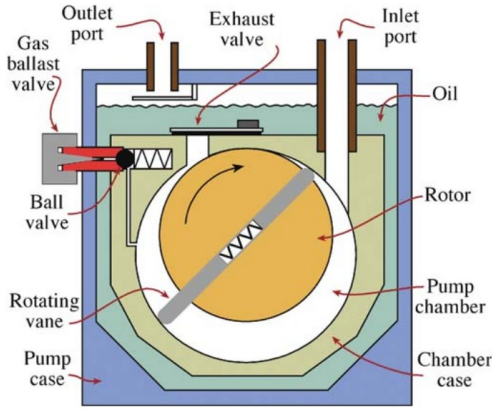


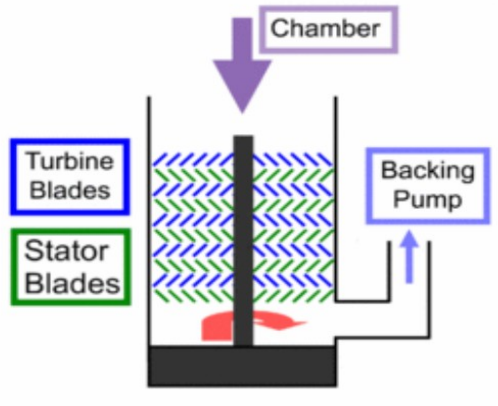
$$\mathrm{DQE}(\omega) = \frac{\mathrm{SNR}(\omega)_{\mathrm{out}}}{\mathrm{SNR}(\omega)_{\mathrm{in}}}$$

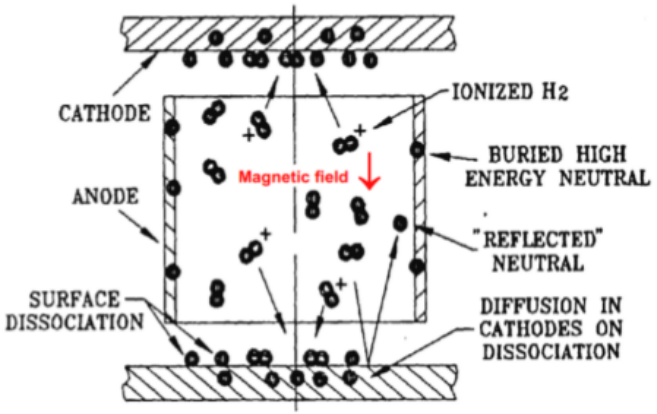
$$\mathrm{DQE}(\omega) = \mathrm{sinc}^2(\pi\omega/2)$$

Vacuum system

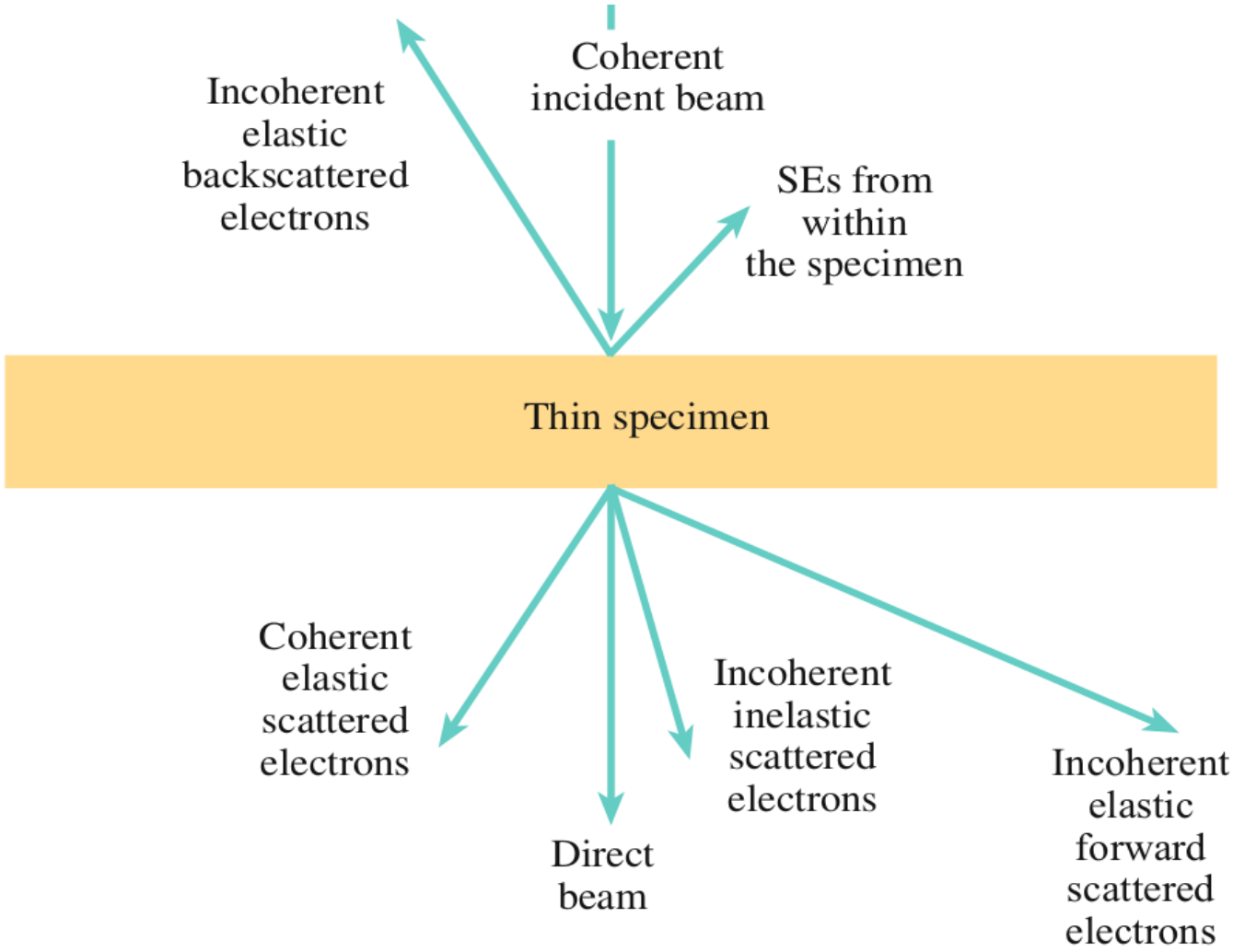
- roughing pump (10^5 – 10^{-4} Pa)
- turbo molecular pump (10^{-2} – 10^{-8}Pa)
- ion getter pump (up to 10^{-9}Pa)



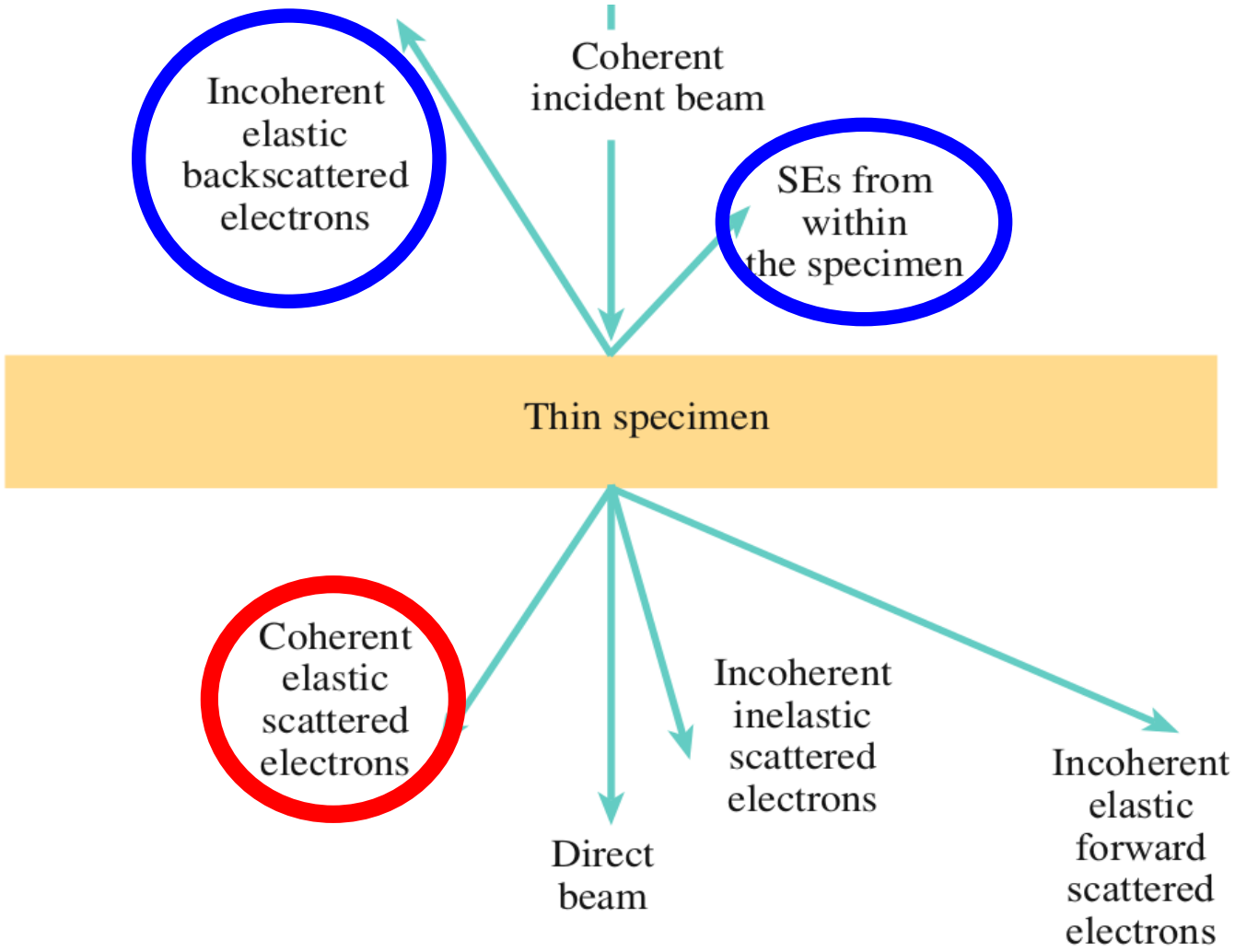




Interaction of electrons with the specimen

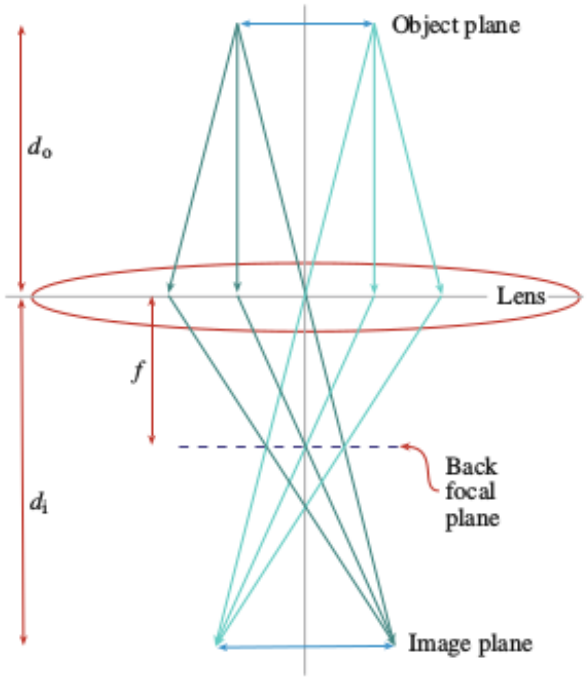


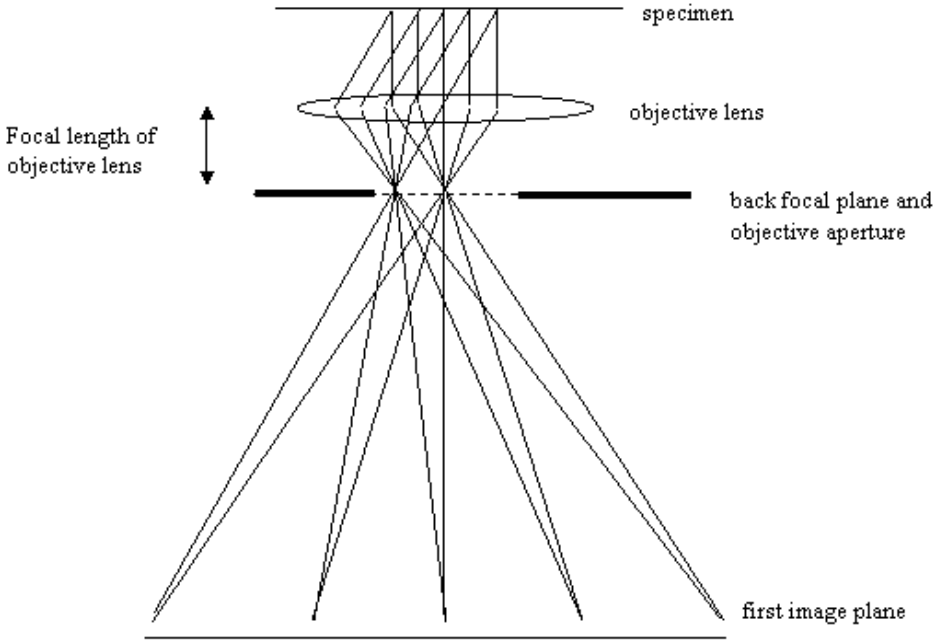
Interaction of electrons with the specimen



Transmission electron microscopy

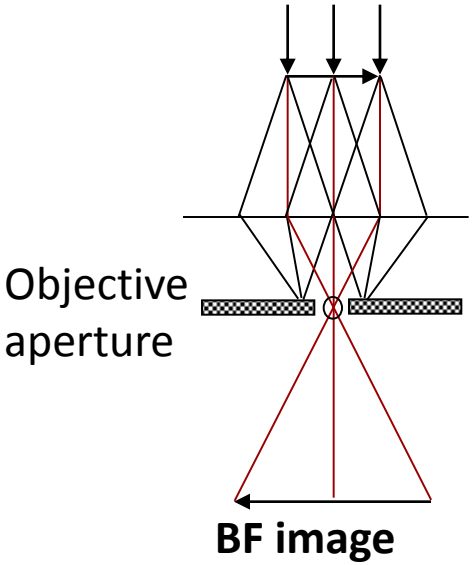
Image formation





Transmission electron microscopy

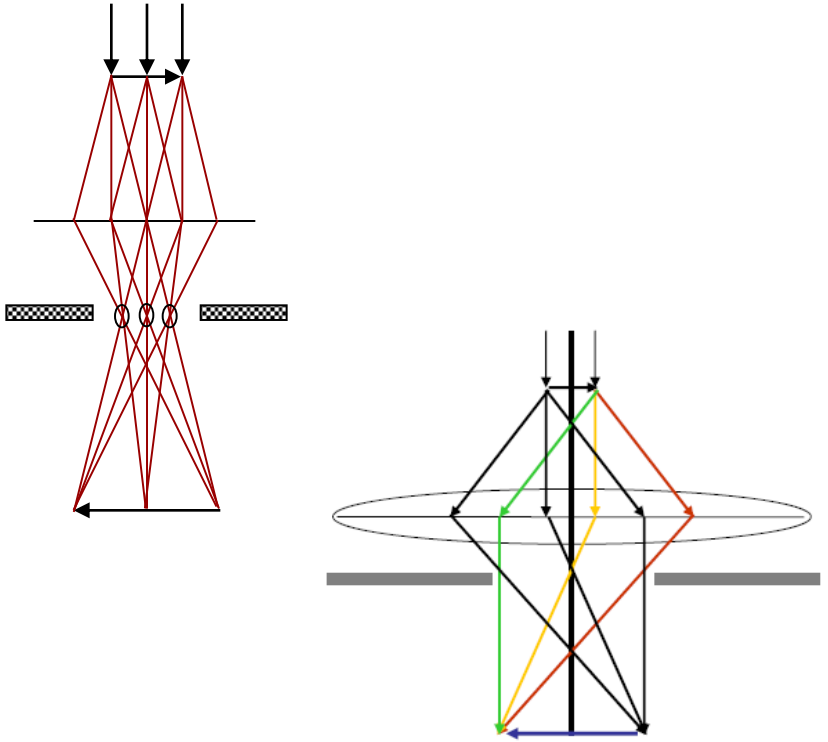
Amplitude contrast



$$C = \frac{(I_2 - I_1)}{I_1} = \frac{\Delta I}{I_1}$$

- difference in intensity in two adjacent areas

Phase contrast



- transmitted and diffracted waves travel through different distances

Thank you for attention

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iNEXT DISCOVERY