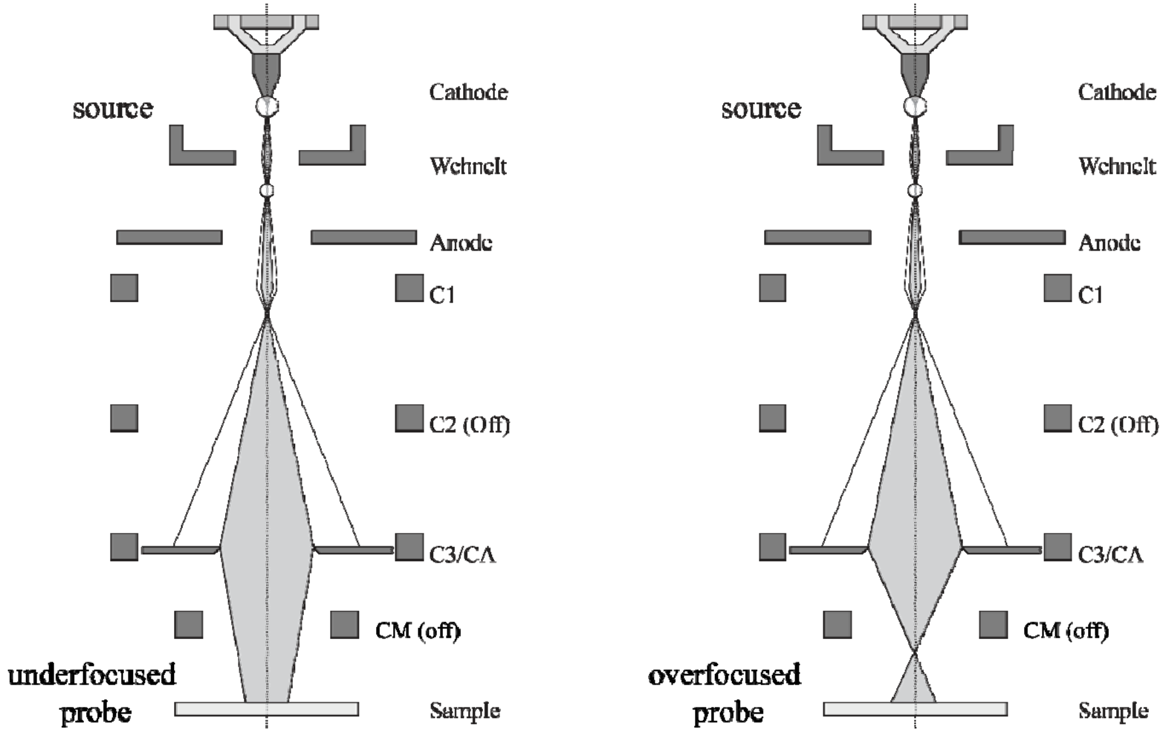
Illumination (Condenser) System

Functions:
1) Demagnify source (C1 - Spot Size)
2) Focus beam on sample with sufficient intensity
3) Vary probe size with magnification
4) Allow control of illuminated area (C3)



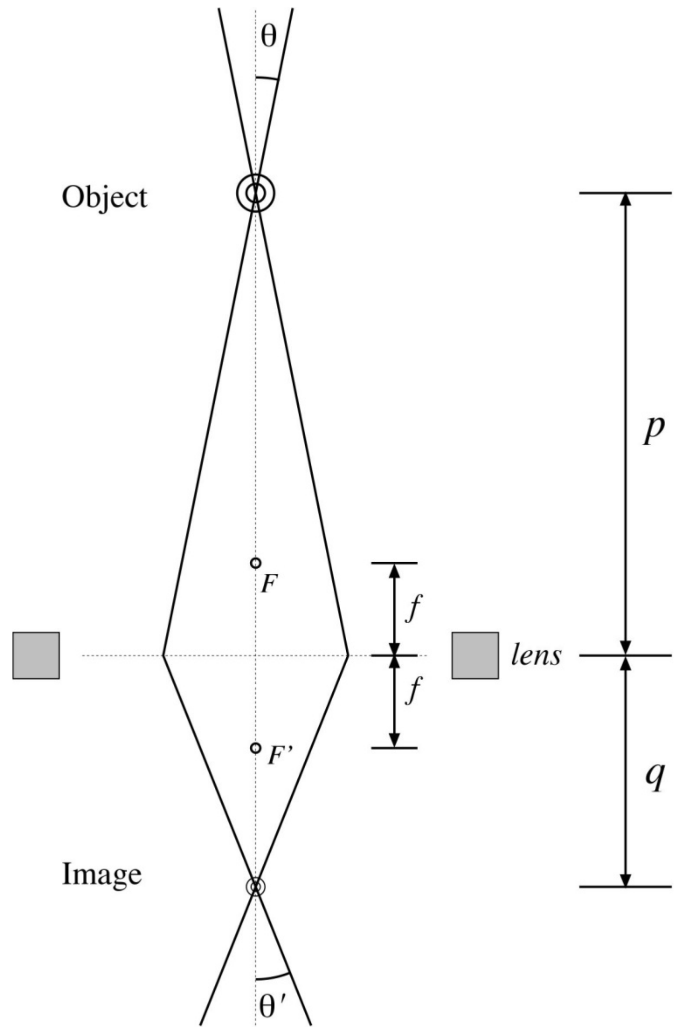
Demagnification of Source

Lateral Magnification

$$M = \frac{q}{p} = \frac{1}{M_\theta} = \frac{\theta}{\theta'}$$

Forming a small probe:

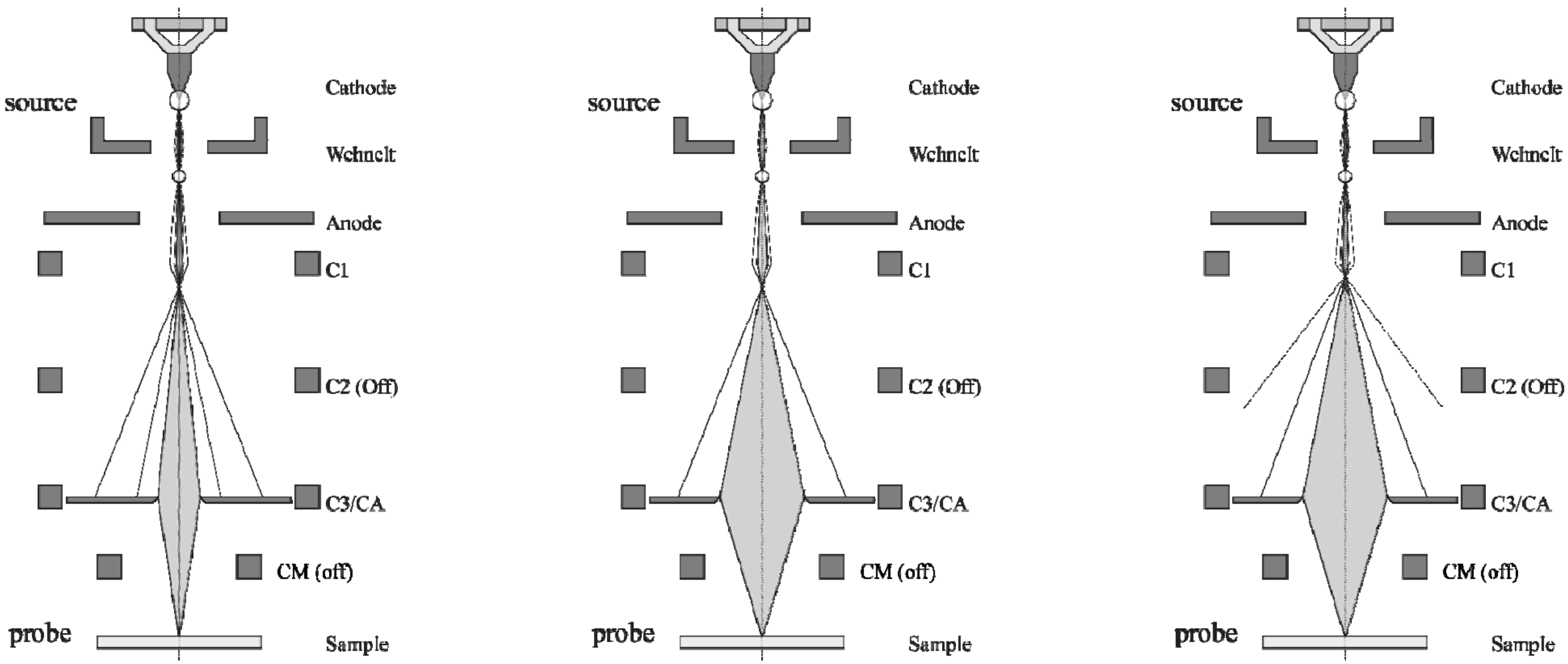
$$\theta' > \theta \Rightarrow q < p \Rightarrow M < 1$$



Demagnification requires increasing angular magnificaiton

Convergence angle and probe size

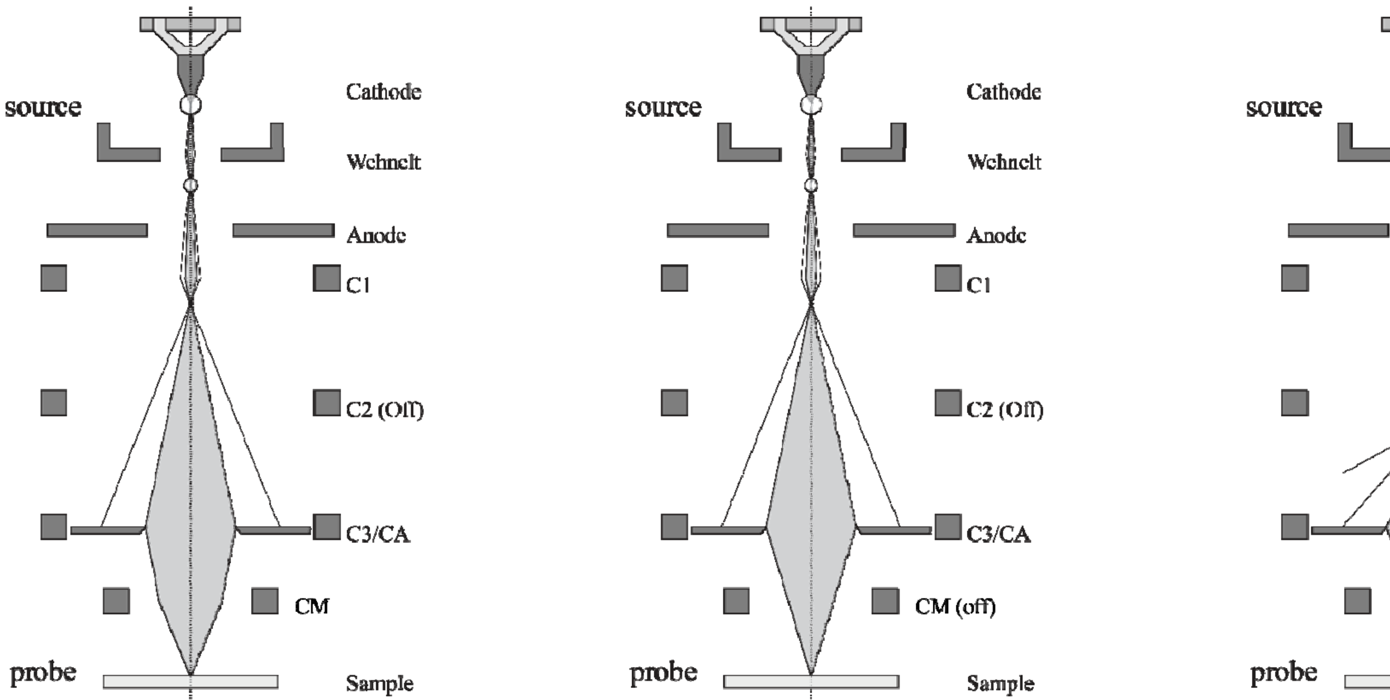
- •Convergence angle decreases with decreasing CA size
- •Probe size decreases with increasing C1 excitation



smaller α | smaller probe

Uses of additional condenser lenses

•Condenser mini-lens (CM) allows larger convergence angles
•C2 lens allows smaller probe sizes



larger α smaller probe

Demagnification with C2 on vs. C2 off

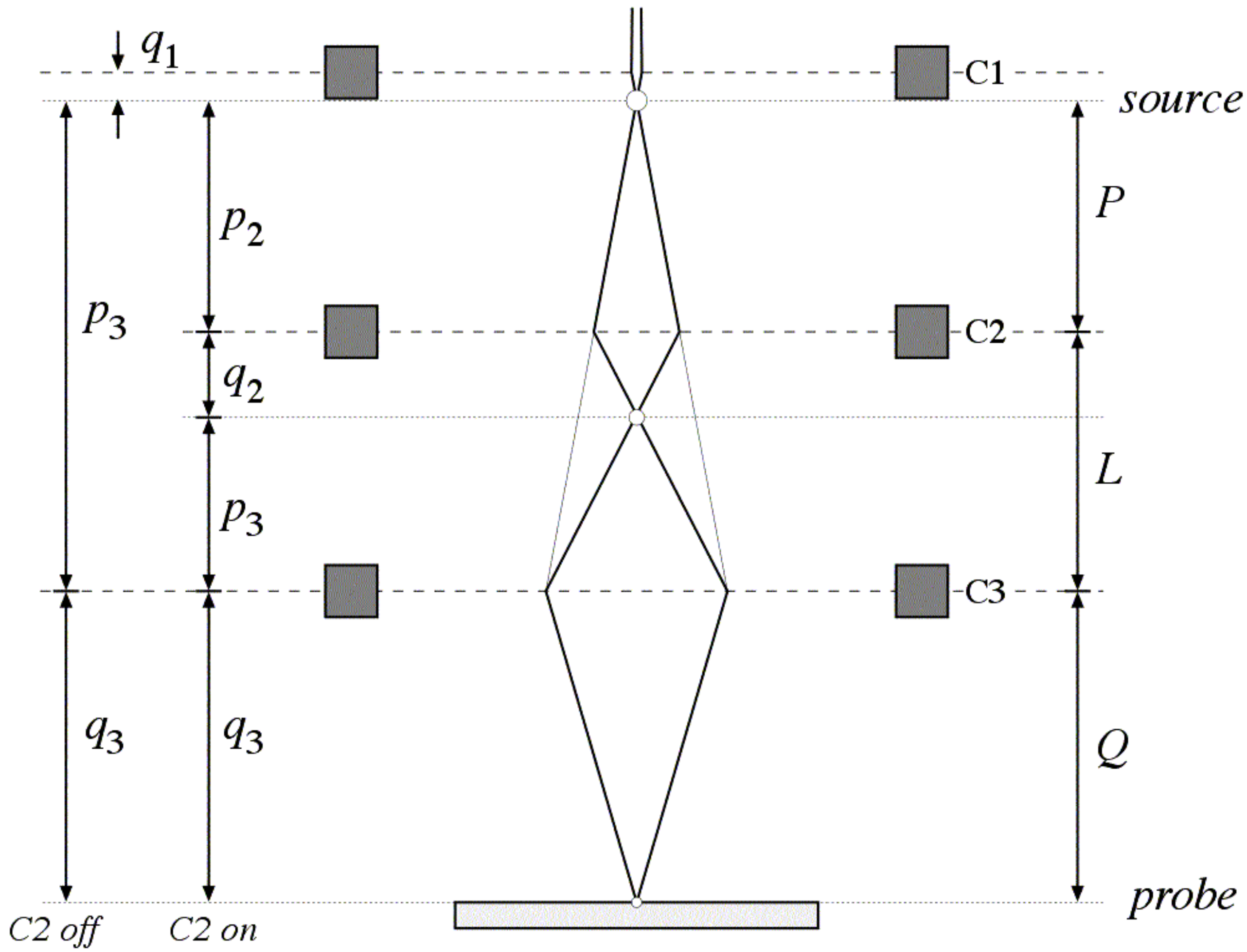


Diagram above shows two lens settings giving the same probe size.

Comparison: C2 off vs. C2 on

C2 On

$$q_2 + p_3 = L$$
$$p_2 = P$$
$$q_3 = Q$$

$$\frac{1}{f_2} = \frac{1}{p_2} + \frac{1}{q_2} = \frac{1}{P} + \frac{1}{q_2}$$

$$M_2 = \frac{q_2}{p_2} = \frac{q_2}{P} = \frac{1}{\frac{P}{f_2} - 1}$$

$$M_3 = \frac{q_3}{p_3} = \frac{Q}{L - q_2} = \frac{Q}{L - \left(\frac{1}{\frac{1}{f_2} - \frac{1}{P}}\right)}$$

$$d' = M_3 \cdot M_2 \cdot d = \frac{Q}{L \cdot P} \cdot \frac{1}{\frac{1}{f_2} - \frac{1}{L} - \frac{1}{P}} \cdot d$$

$$\Rightarrow M_{C2\ on} = \frac{Q}{L \cdot P} \cdot \frac{1}{\frac{1}{f_2} - \frac{1}{L} - \frac{1}{P}}$$

C2 Off

$$p_3 = P + L$$
$$q_3 = Q$$

$$d' = M_3 \cdot d = \frac{q_3}{p_3} \cdot d = \frac{Q}{P + L} \cdot d$$

$$\Rightarrow M_{C2\ \mathrm{off}} = \frac{Q}{P + L}$$

Compare: $M_{C2\ \mathrm{on}} < M_{C2\ \mathrm{off}}$

$$\frac{\not{Q}}{L \cdot P} \cdot \frac{1}{\frac{1}{f_2} - \frac{1}{L} - \frac{1}{P}} < \frac{\not{Q}}{P + L}$$

$$\frac{1}{P} + \frac{1}{L} < \frac{1}{f_2} - \frac{1}{L} - \frac{1}{P}$$

$$f_2 < \frac{1}{2} \cdot \left(\frac{1}{\frac{1}{P} + \frac{1}{L}}\right)$$

(best to have C2 on and strongly excited.)

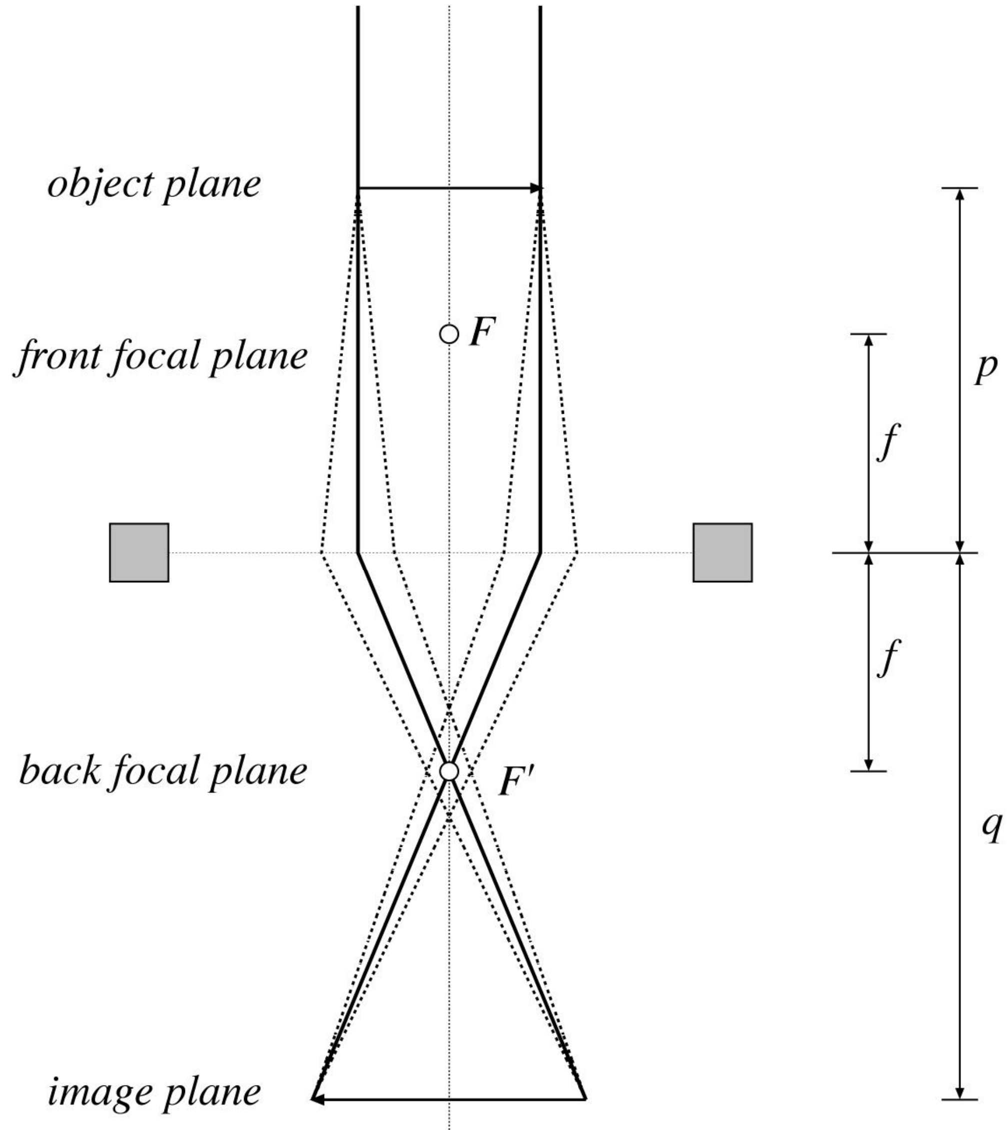
Lens Planes

Parallel Illumination

Diffracted beams deviate from direct beam

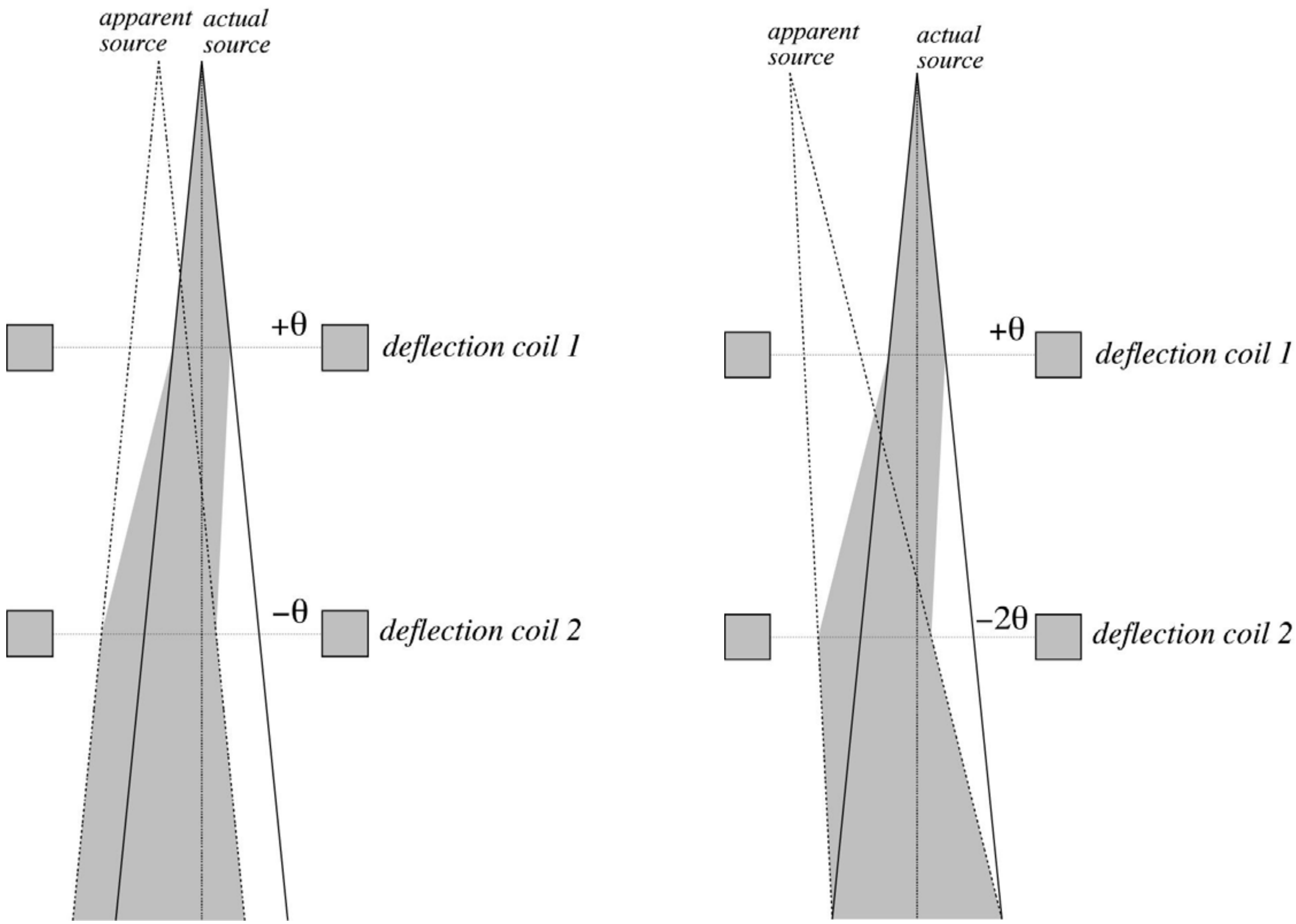
Parallel beams focused to a point in *back focal plane*

→ diffraction pattern



Beam deflection/tilt

Two deflection coils provide deflection/tilt



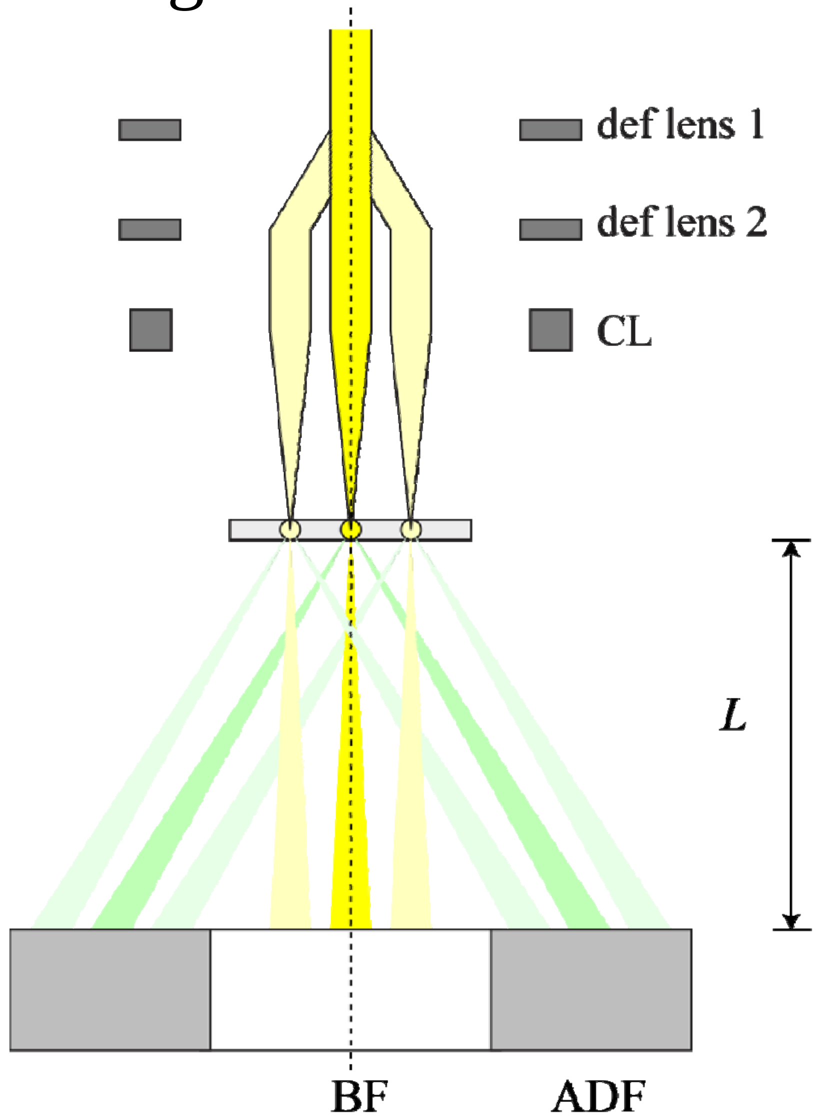
Scanning TEM

Scan beam across sample

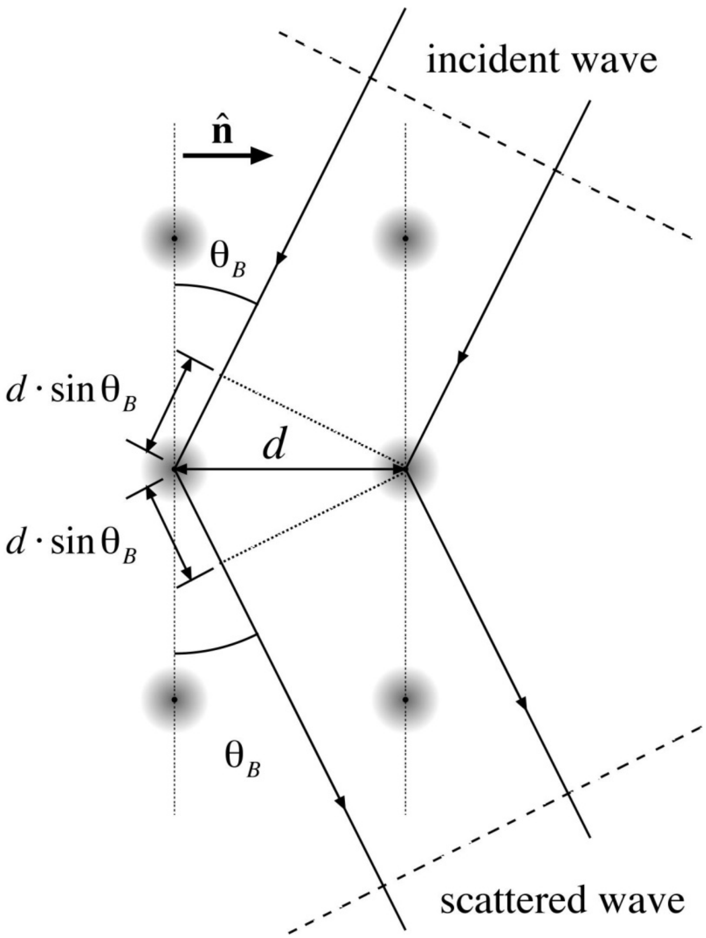
Illumination deflected, not tilted

Axial bright-field detector

Annular dark-field detector



Bragg's law and lattice vectors



Bragg's Law

$$2d\sin\theta_B = n\lambda$$

Reciprocal Lattice Vector

$$\vec{\mathbf{g}} = \left(\frac{1}{d}\right)\hat{\mathbf{n}}$$

Objective aperture placement

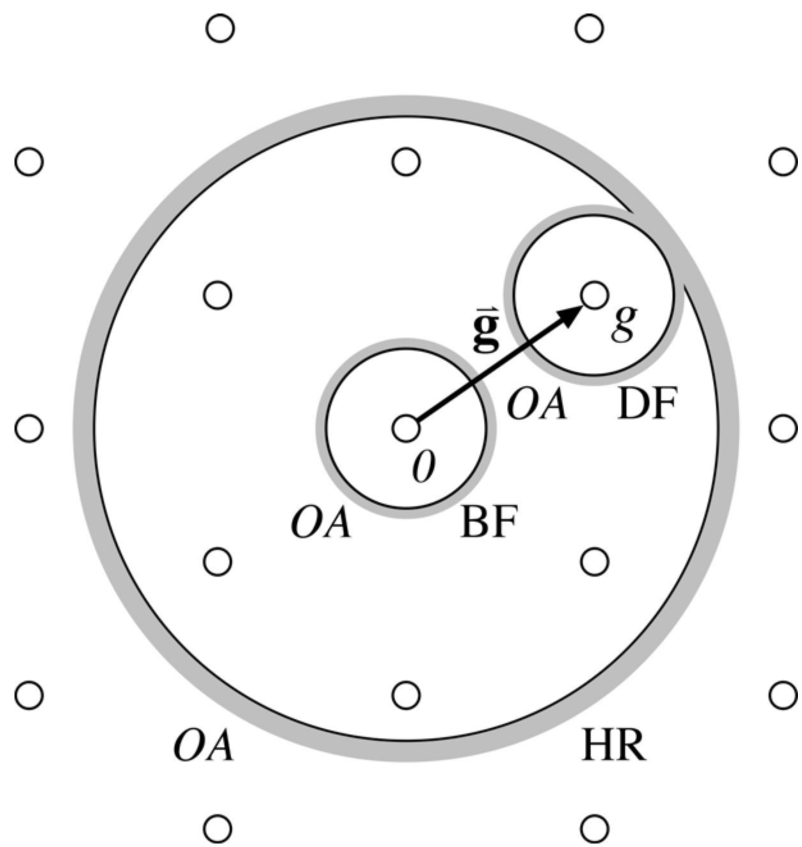
Position of objective aperture in back focal plane

Imaging Modes:

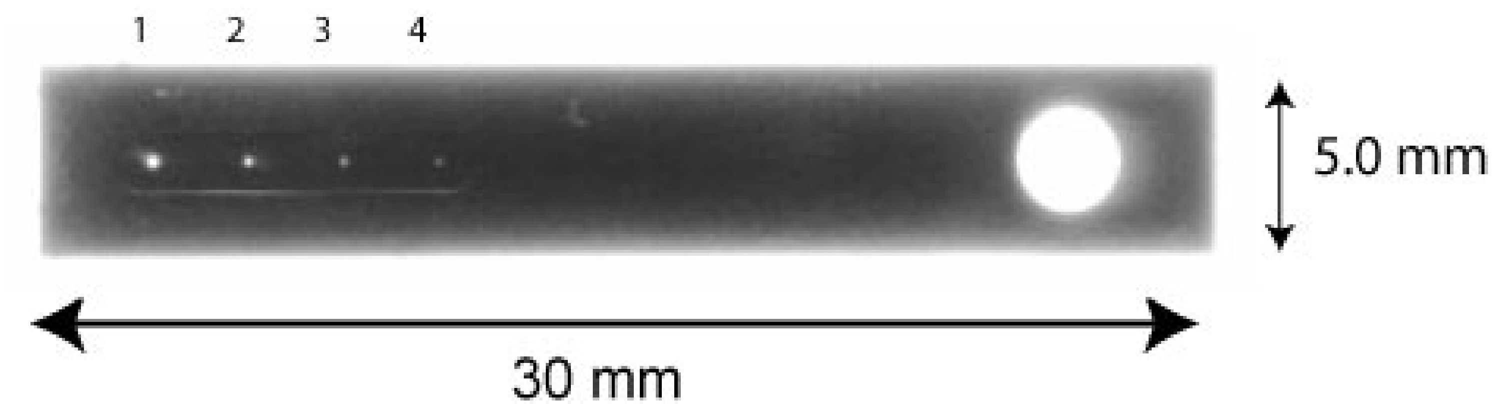
Bright Field: *OA* includes *0*

Dark Field: *OA* excludes *0*

High-Resolution Lattice Image:
OA includes *0* and several beams



Objective aperture strip for Hitachi TEM



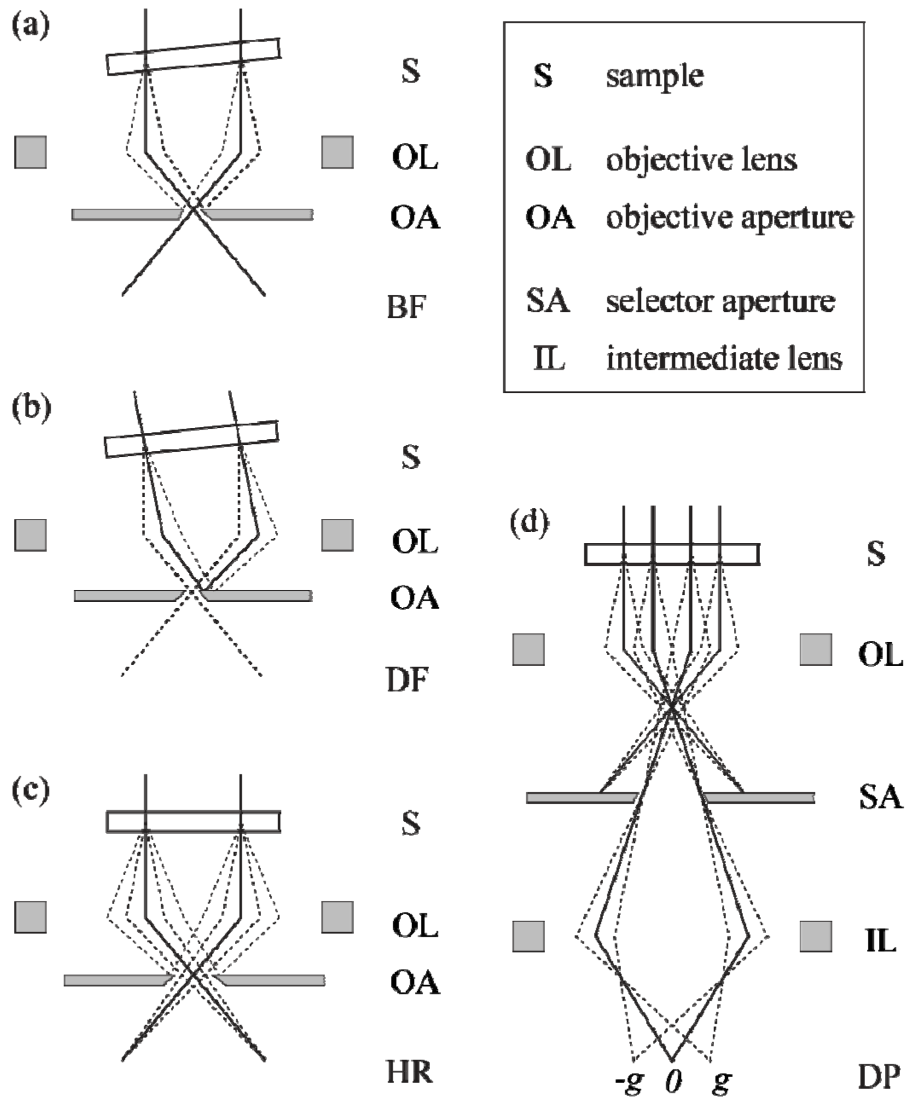
TEM Operational Modes

Bright Field (BF):
OA includes *0*
Two-beam condition

Dark Field (DF):
OA excludes *0*
Two-beam condition

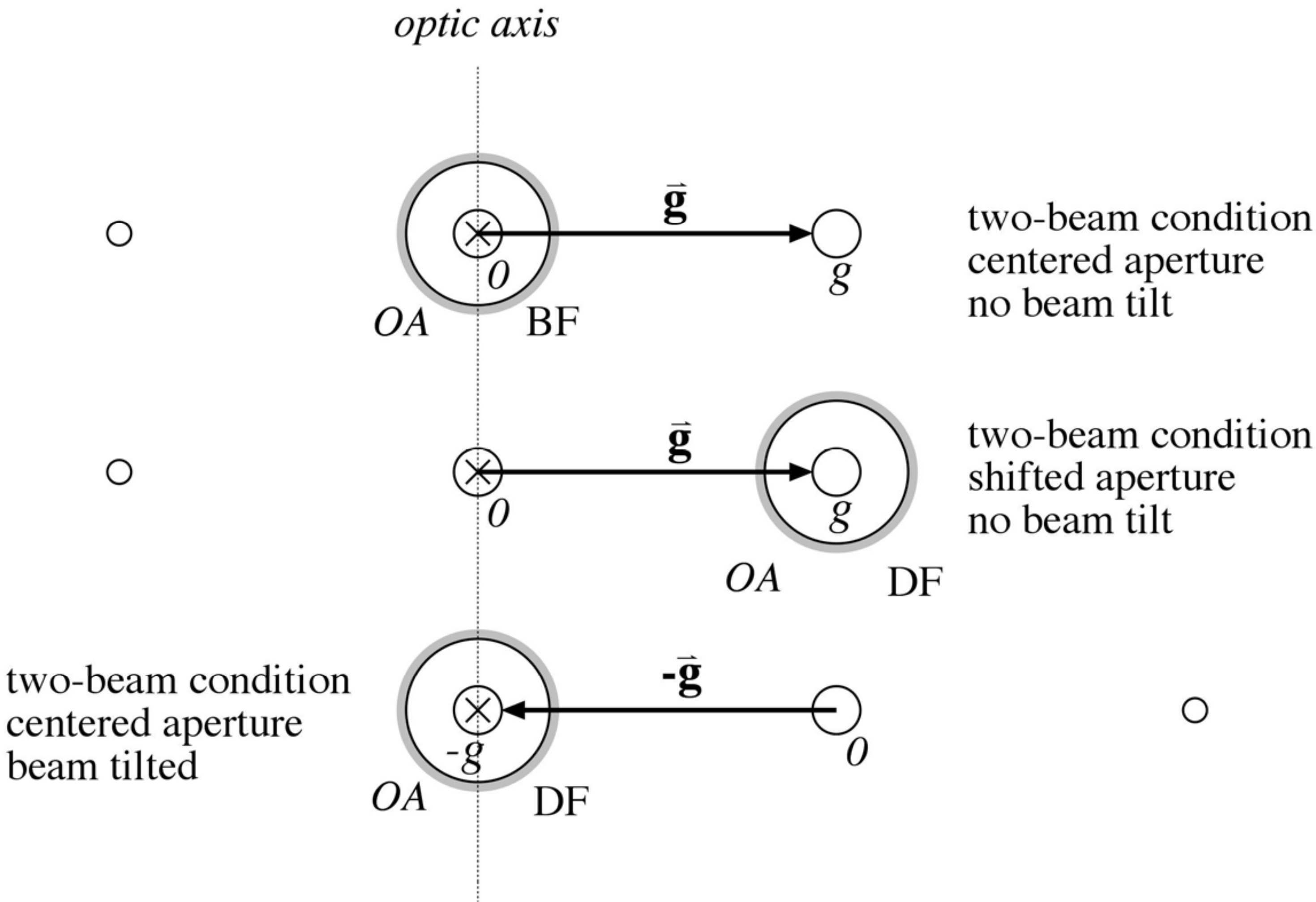
High-Resolution Lattice Image (HR):
OA includes *0*
Orient on low-index zone axis

Selected-Area Diffraction Pattern (DP):
SA in image plane



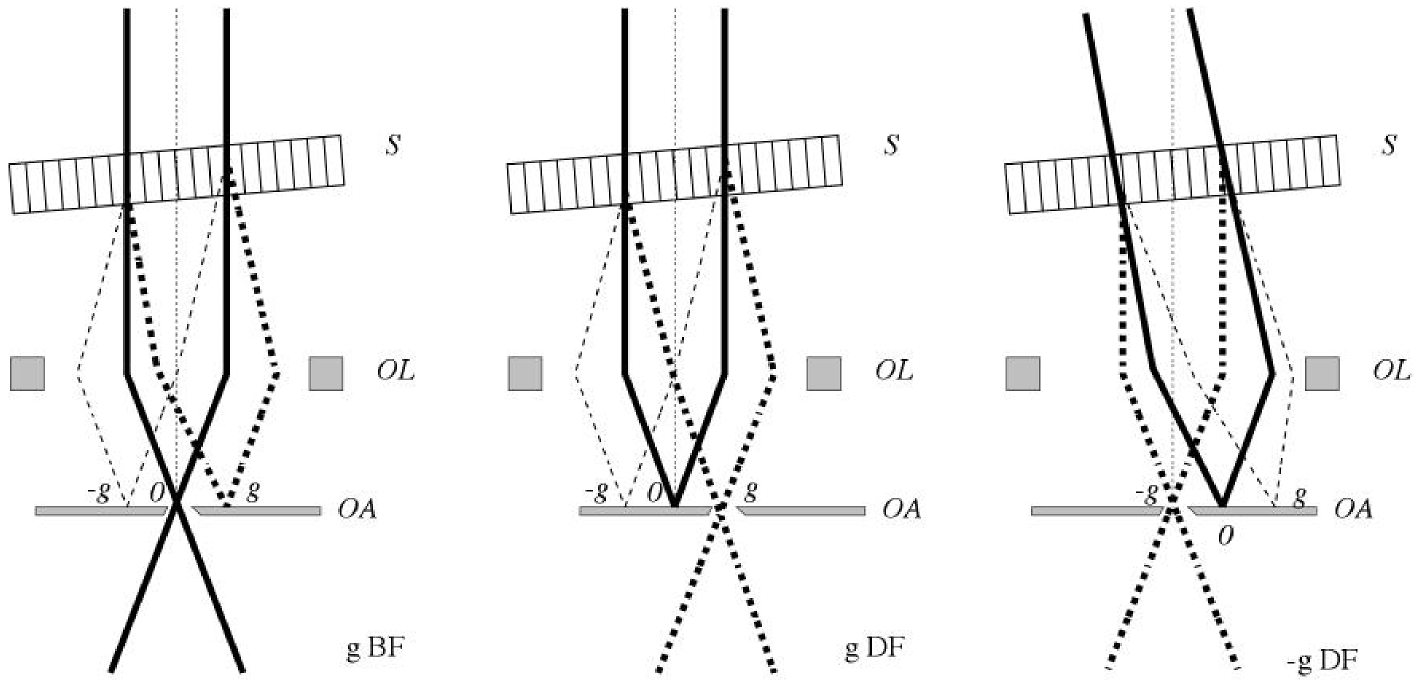
Bright-/dark-field methods

Objective aperture placement in back focal plane



Centered dark-field imaging

Two-beam condition
Tilt the beam to generate dark-field with the scattered beam on-axis
Set up diffraction condition for *g*, then bring -*g* parallel to the optic axis.



bright-field   off-axis dark field   centered dark field