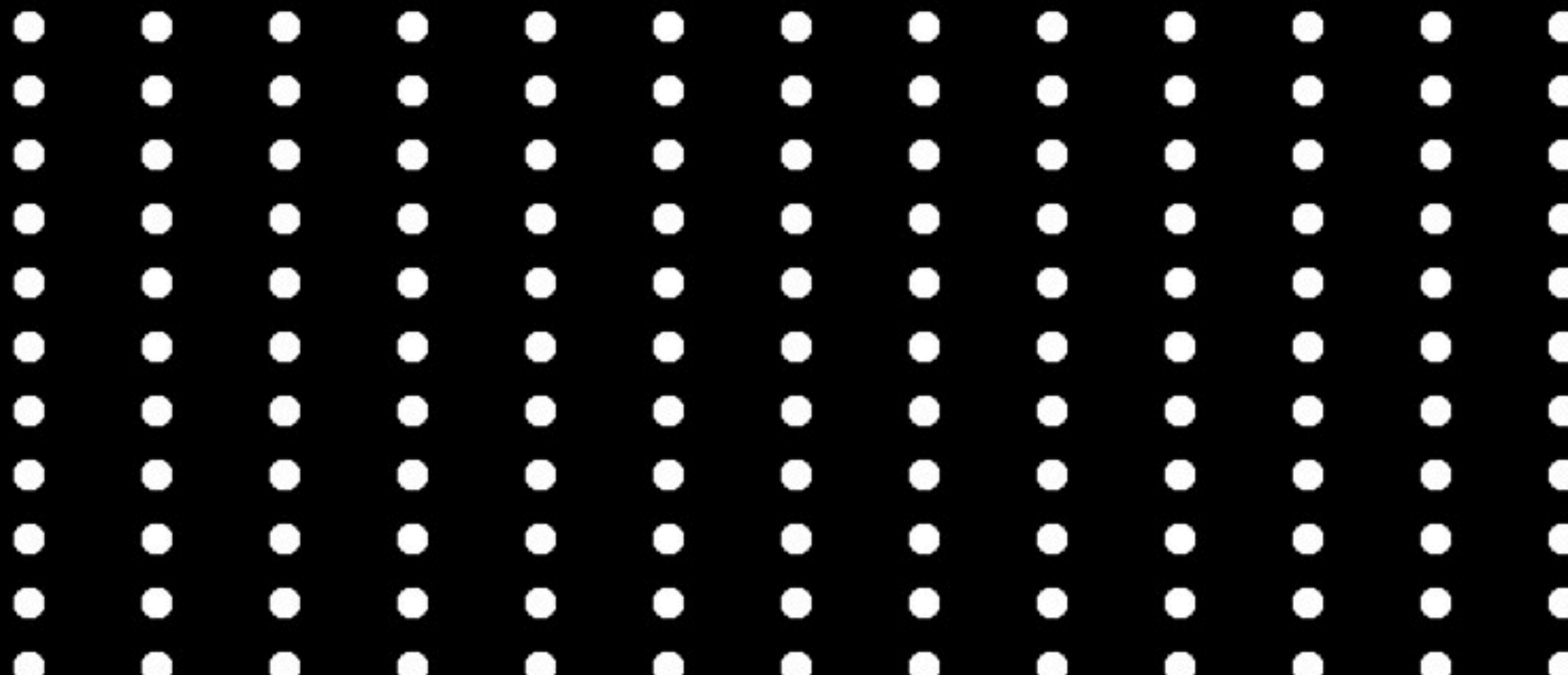
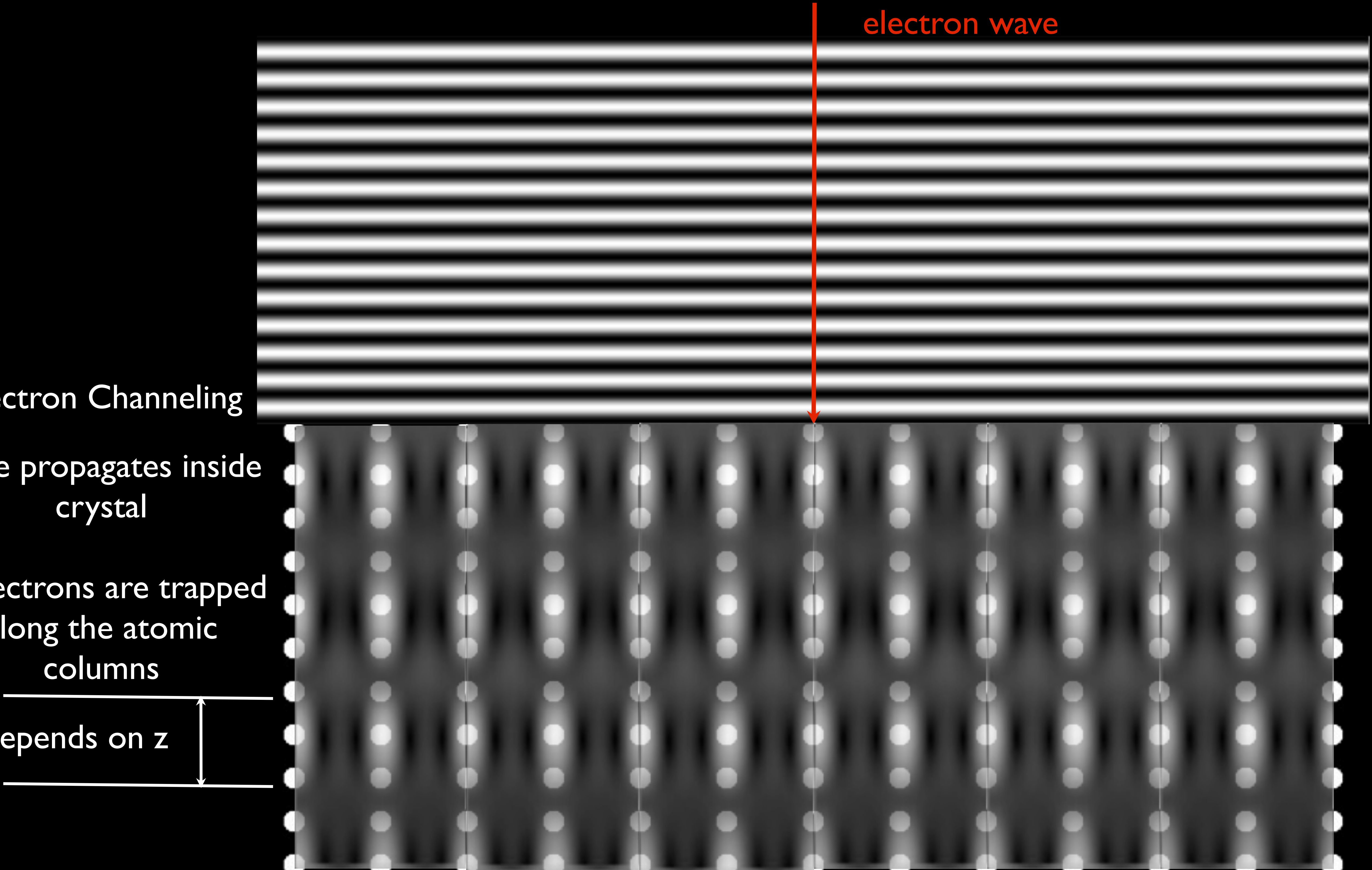
Chapter 3

Imaging Modes



Electron Channeling



wave propagates inside crystal

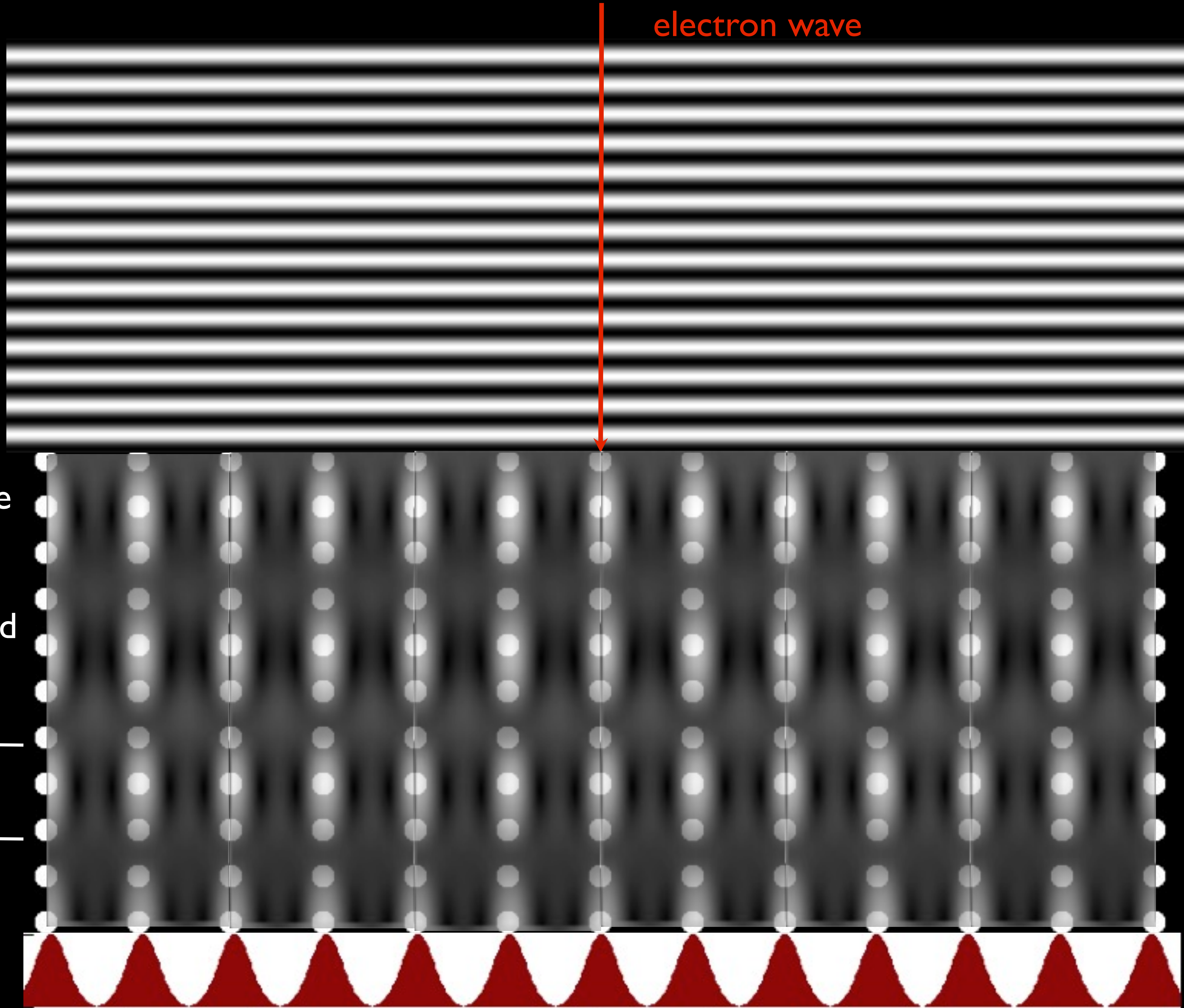
~ electrons are trapped along the atomic columns

Electron Channeling

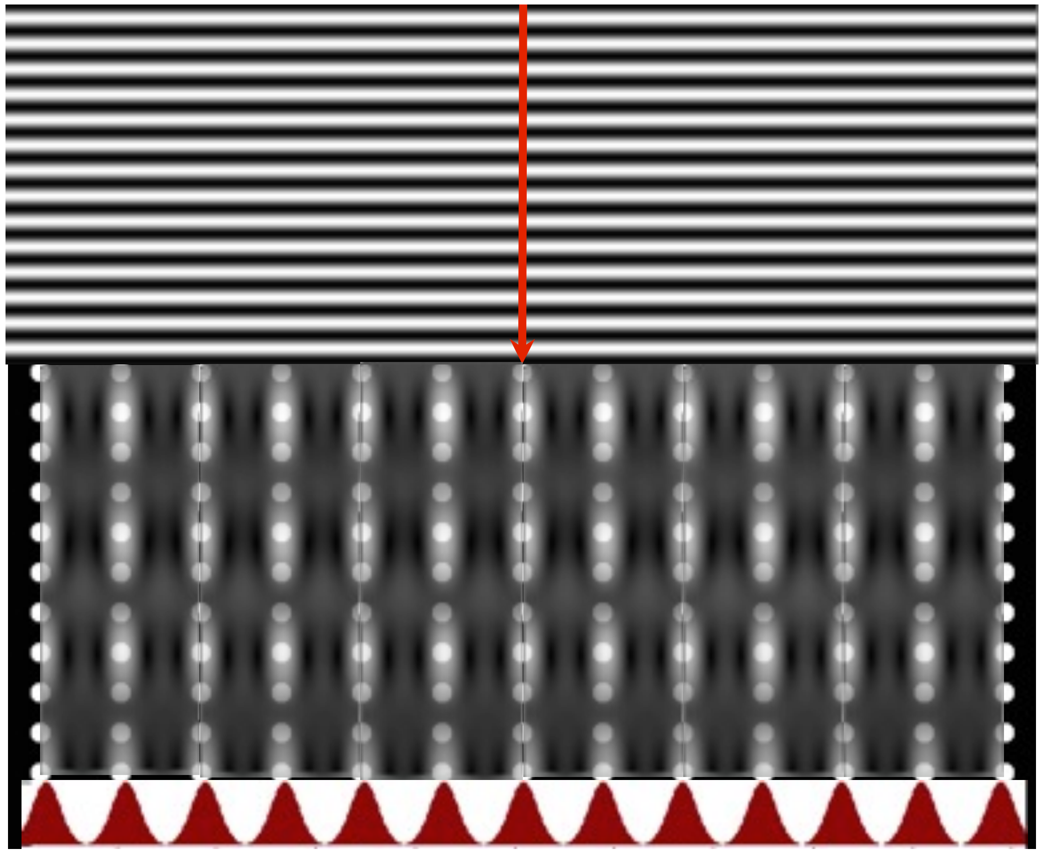
wave propagates inside crystal

~ electrons are trapped along the atomic columns

depends on z



Exit Wave



exit wave

$\psi_e(r)=A(r)\exp(i\varphi(r))$

exit wave

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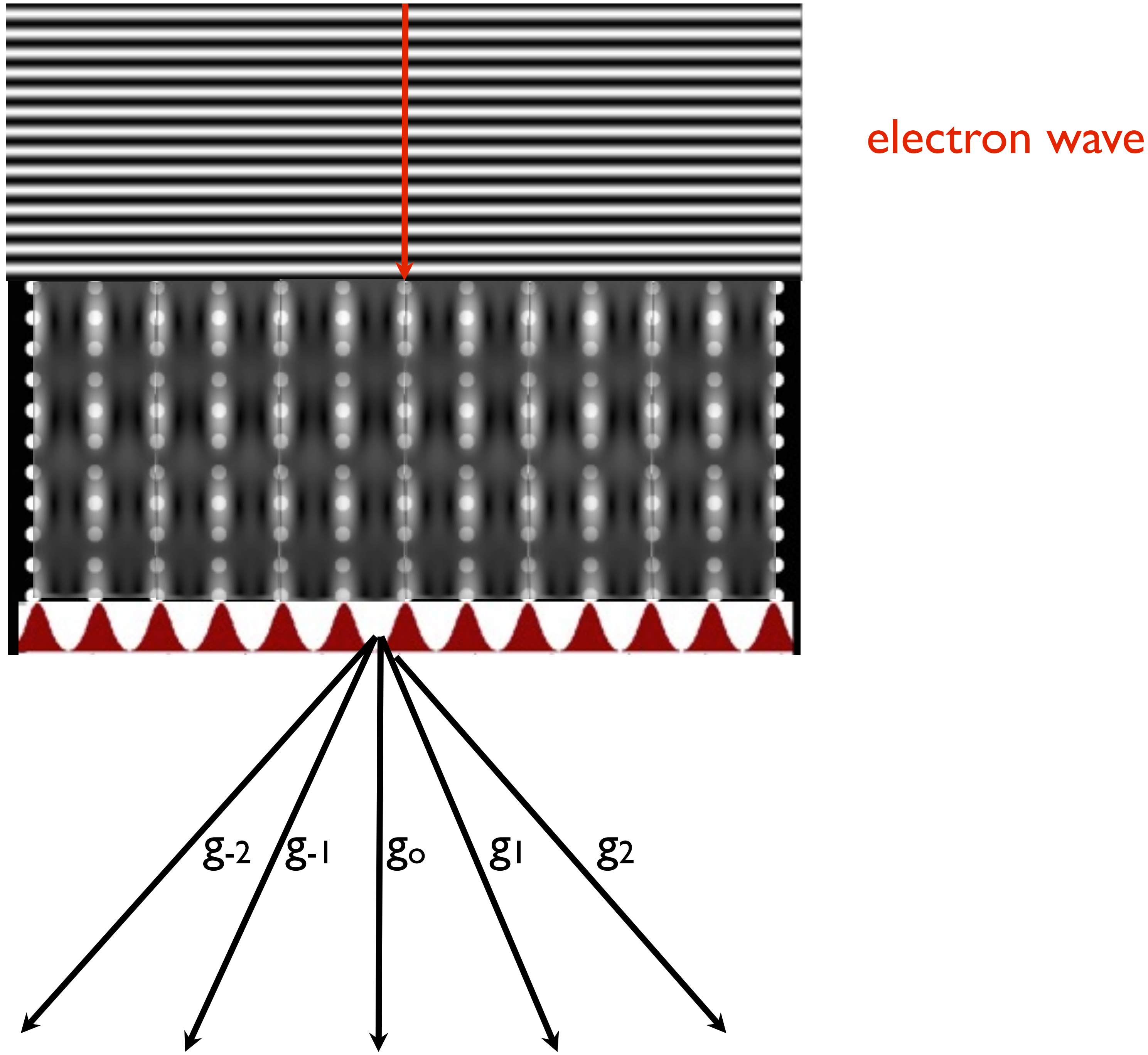
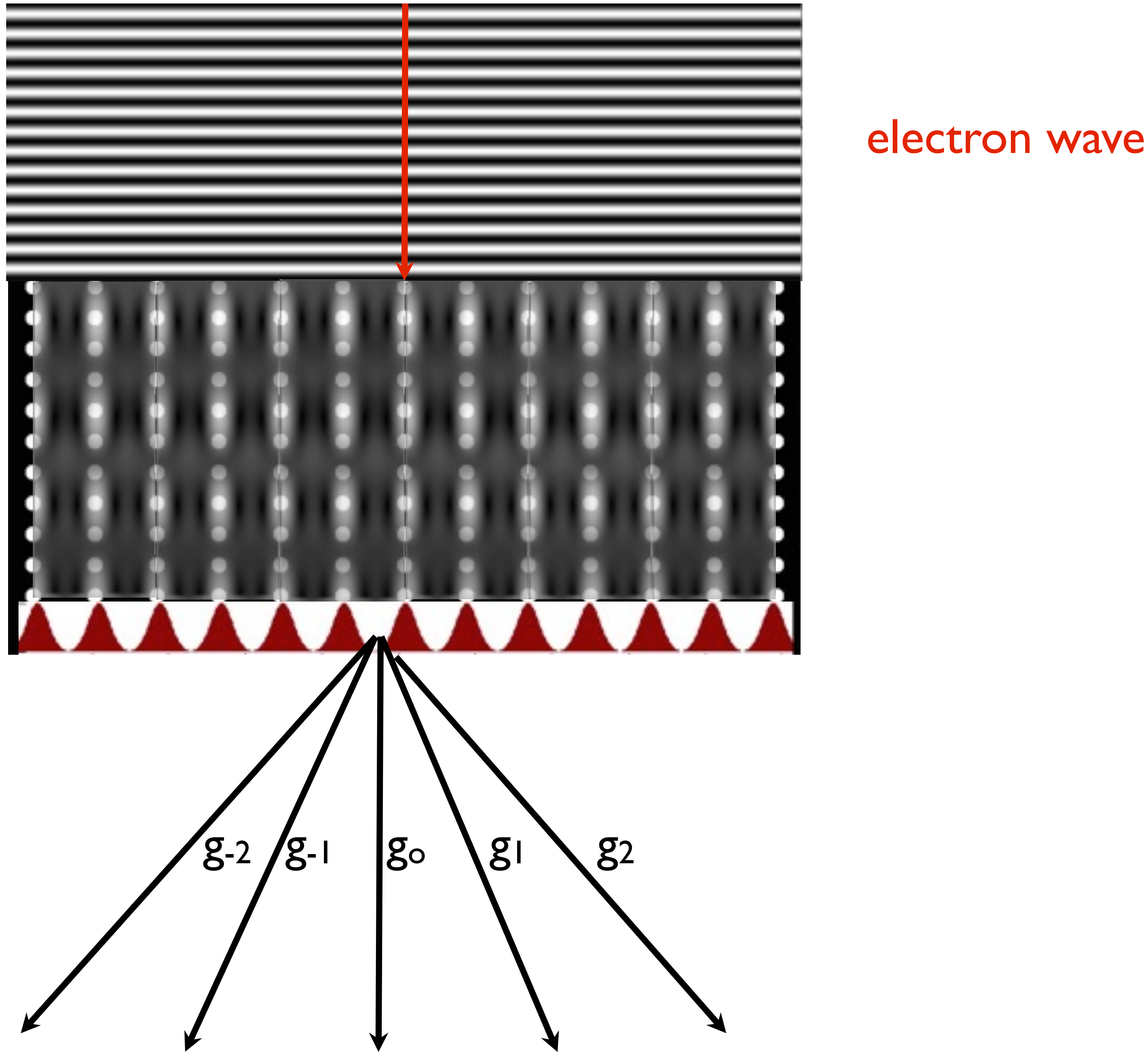


Fourier Theory

$\psi_e(x,y)=\Sigma F(g)\exp(2\pi gr)$



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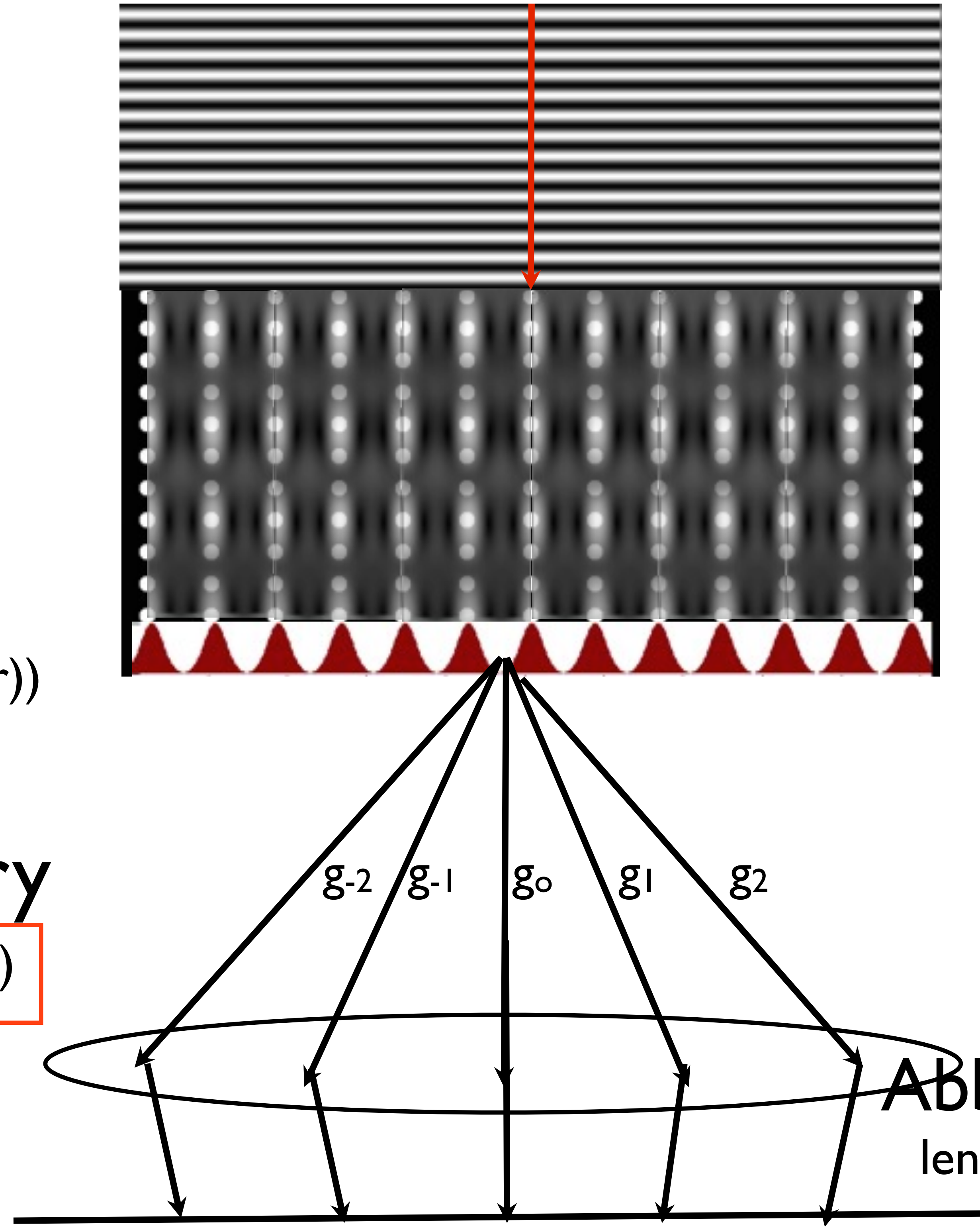
Physics

each Fourier component is called diffracted wave

electron wave



exit wave

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Fourier Theory

$\psi_e(x,y)=\Sigma F(g)\exp(2\pi gr)$

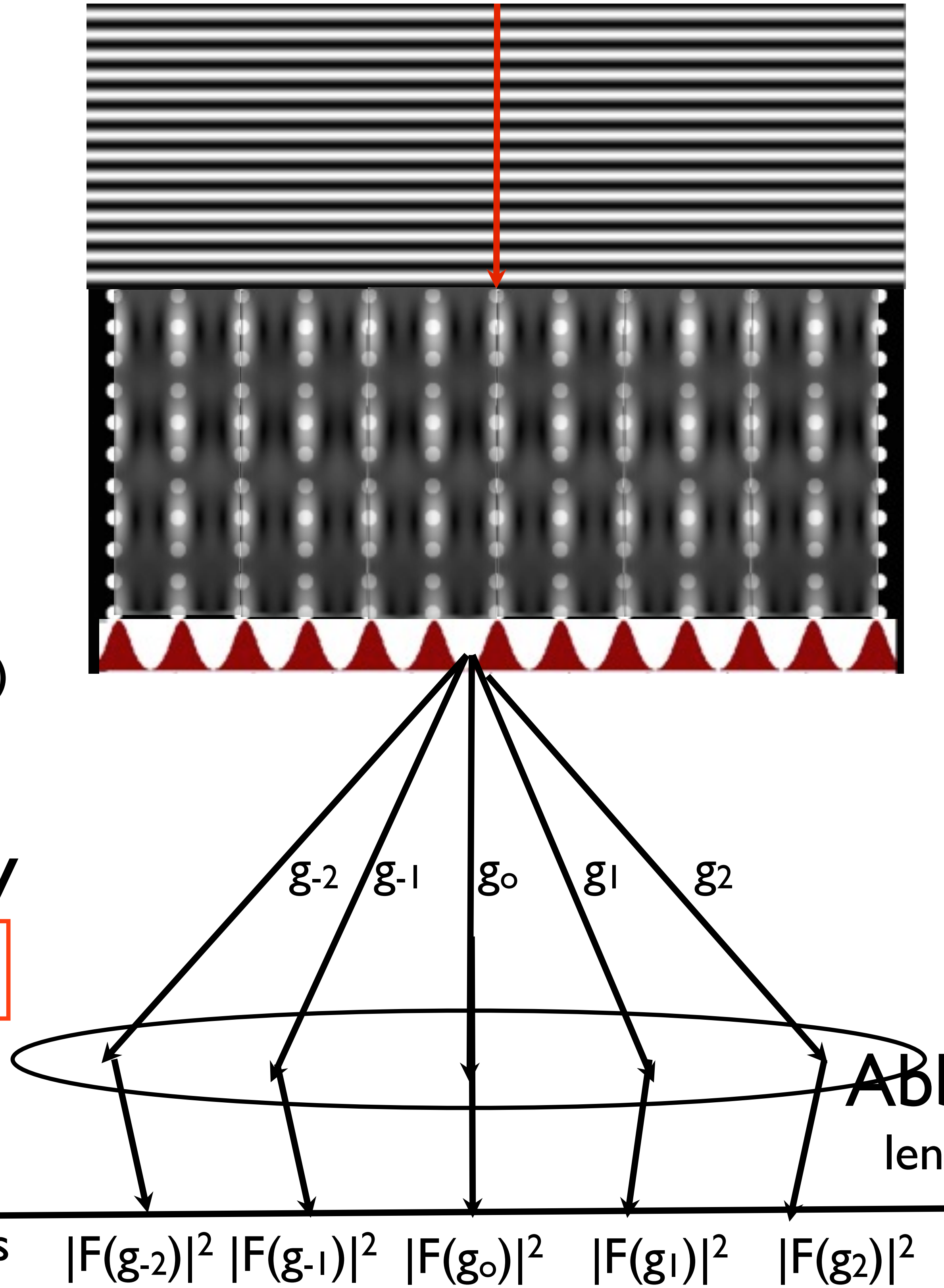
Abbe Microscopy Theory

lens does two Fourier transforms

Physics

each Fourier component is called diffracted wave

electron wave



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Physics

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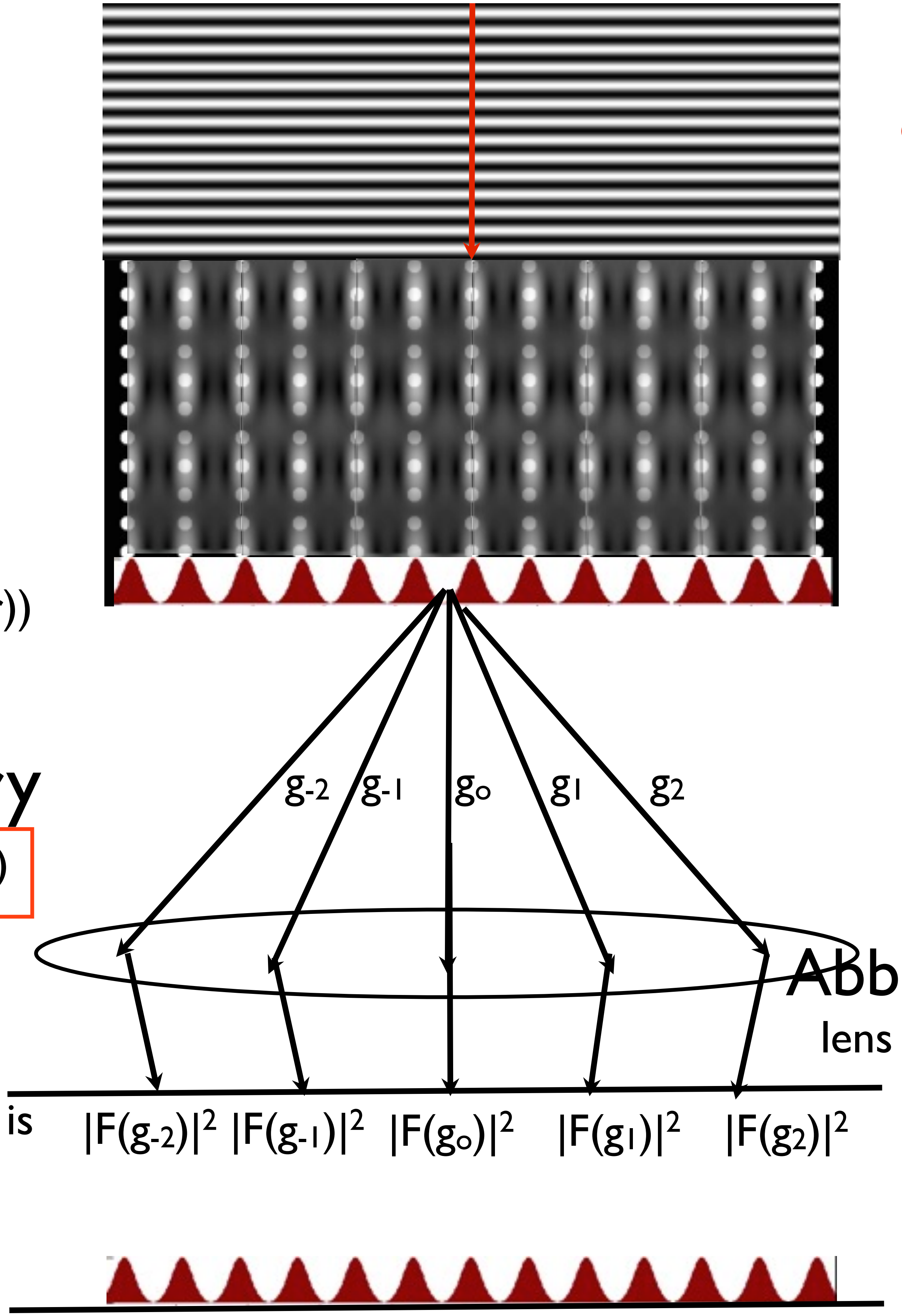
Abbe Microscopy Theory

lens does two Fourier transforms

Focal plane



electron wave

exit wave

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Fourier Theory

$\psi_e(x,y)=\Sigma F(g)\exp(2\pi gr)$

Physics

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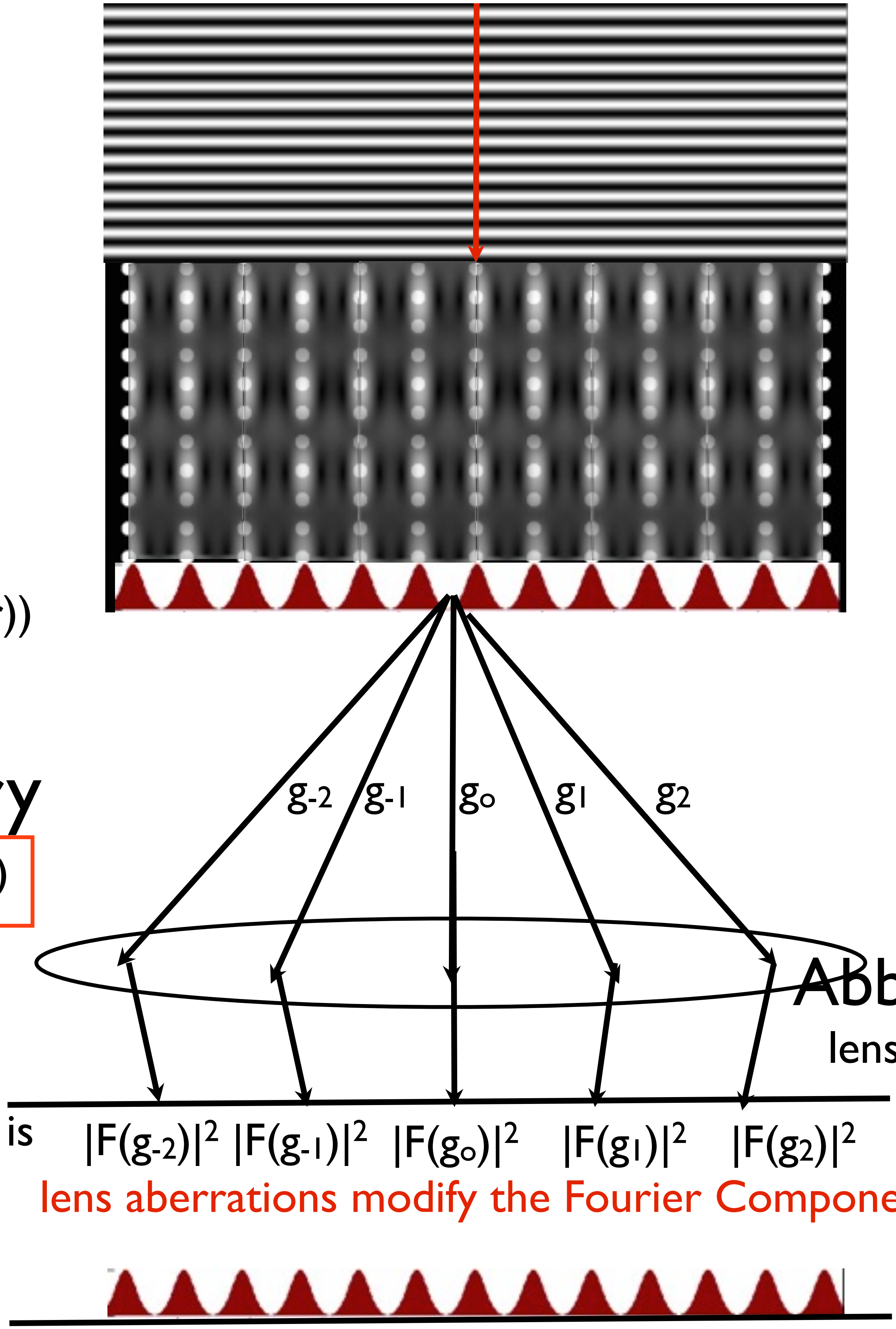
Abbe Microscopy Theory

lens does two Fourier transforms

Focal plane

image plane

electron wave



exit wave

$\psi_e(r)=A(r)\exp(i\varphi(r))$

Fourier Theory

$\psi_e(x,y)=\Sigma \boxed{F(g)\exp(2\pi gr)}$

Physics

each Fourier component is called diffracted wave

Abbe Microscopy Theory

lens does two Fourier transforms

Focal plane

$|F(g_{-2})|^2$ $|F(g_{-1})|^2$ $|F(g_o)|^2$ $|F(g_1)|^2$ $|F(g_2)|^2$

lens aberrations modify the Fourier Components

image plane

electron wave

exit wave

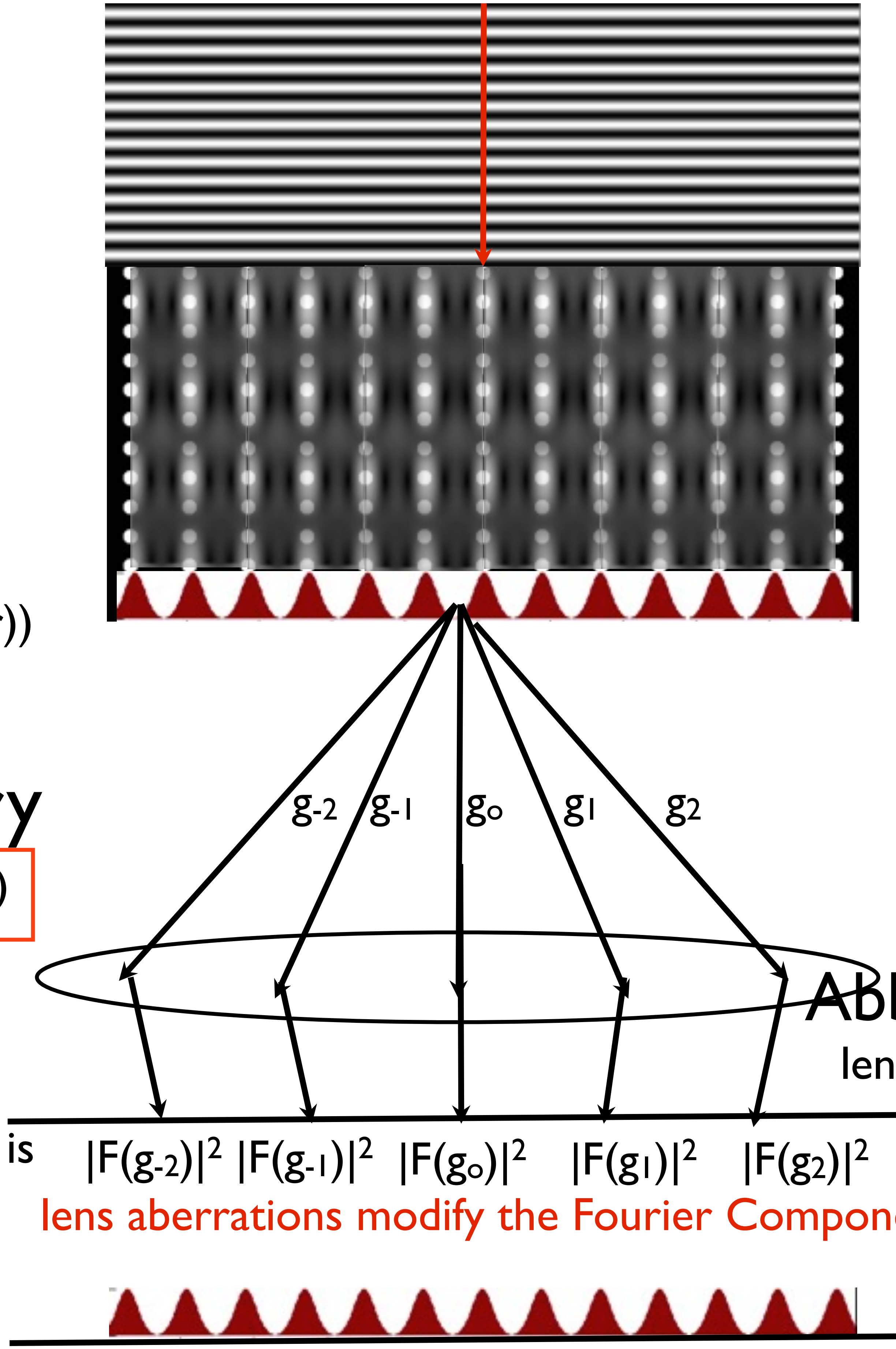
$\psi_e(r)=A(r)\exp(i\varphi(r))$

Fourier Theory

$\psi_e(x,y)=\Sigma F(g)\exp(2\pi gr)$

Physics

each Fourier component is called diffracted wave



Abbe Microscopy Theory

lens does two Fourier transforms

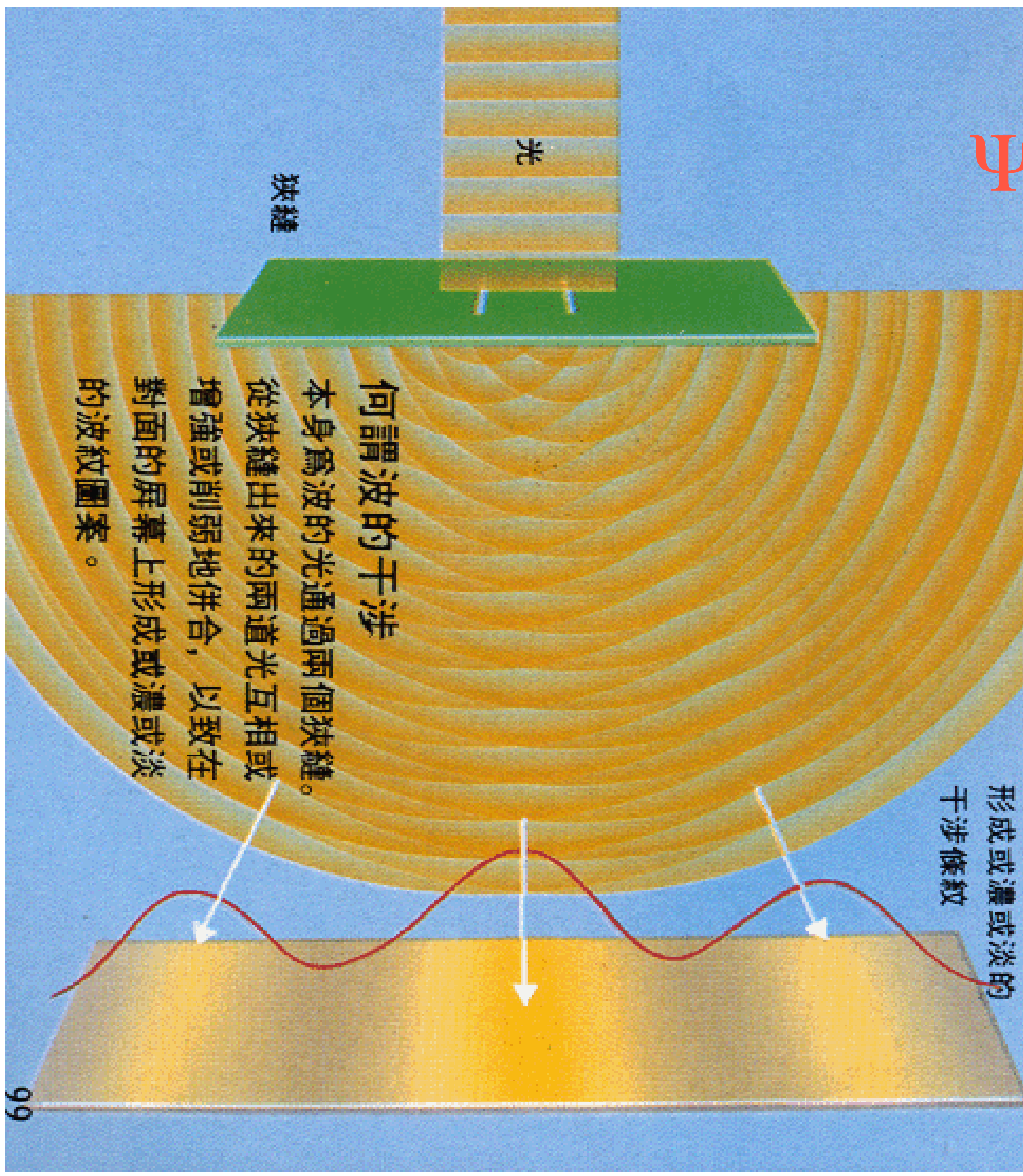
Focal plane

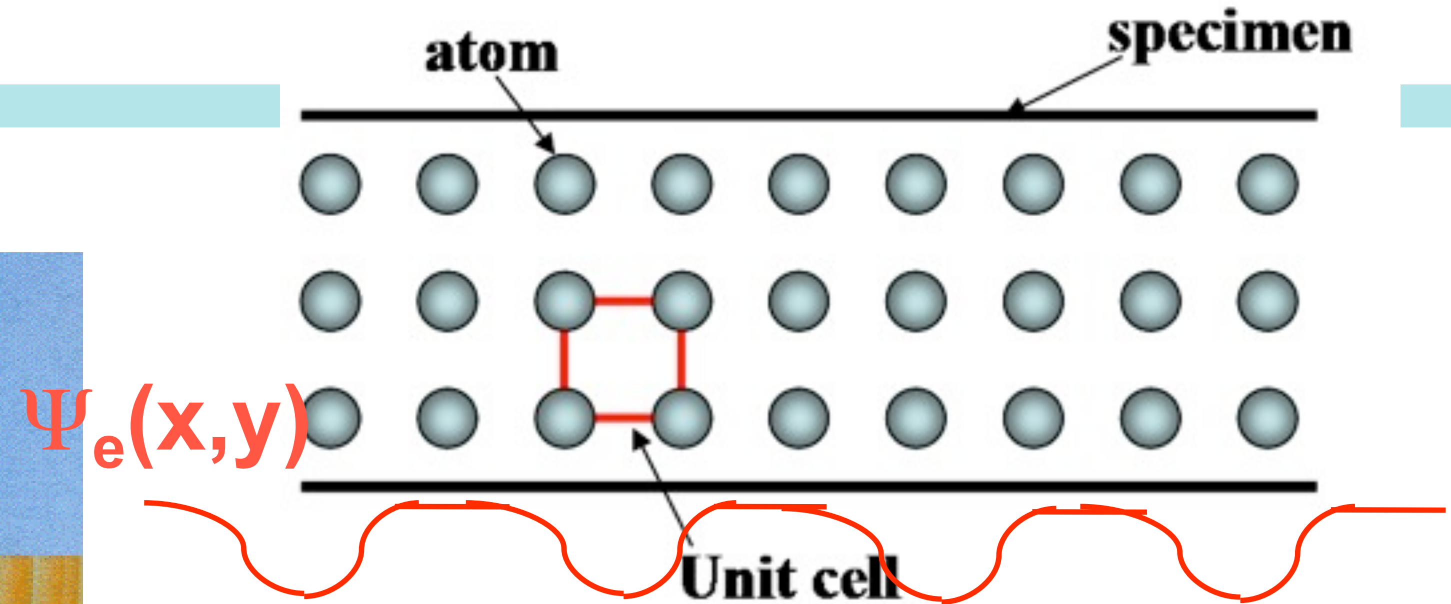
lens aberrations modify the Fourier Components

image plane

$I=|A(r)|^2$, Phase lost

Interaction of Electron Wave with Crystal





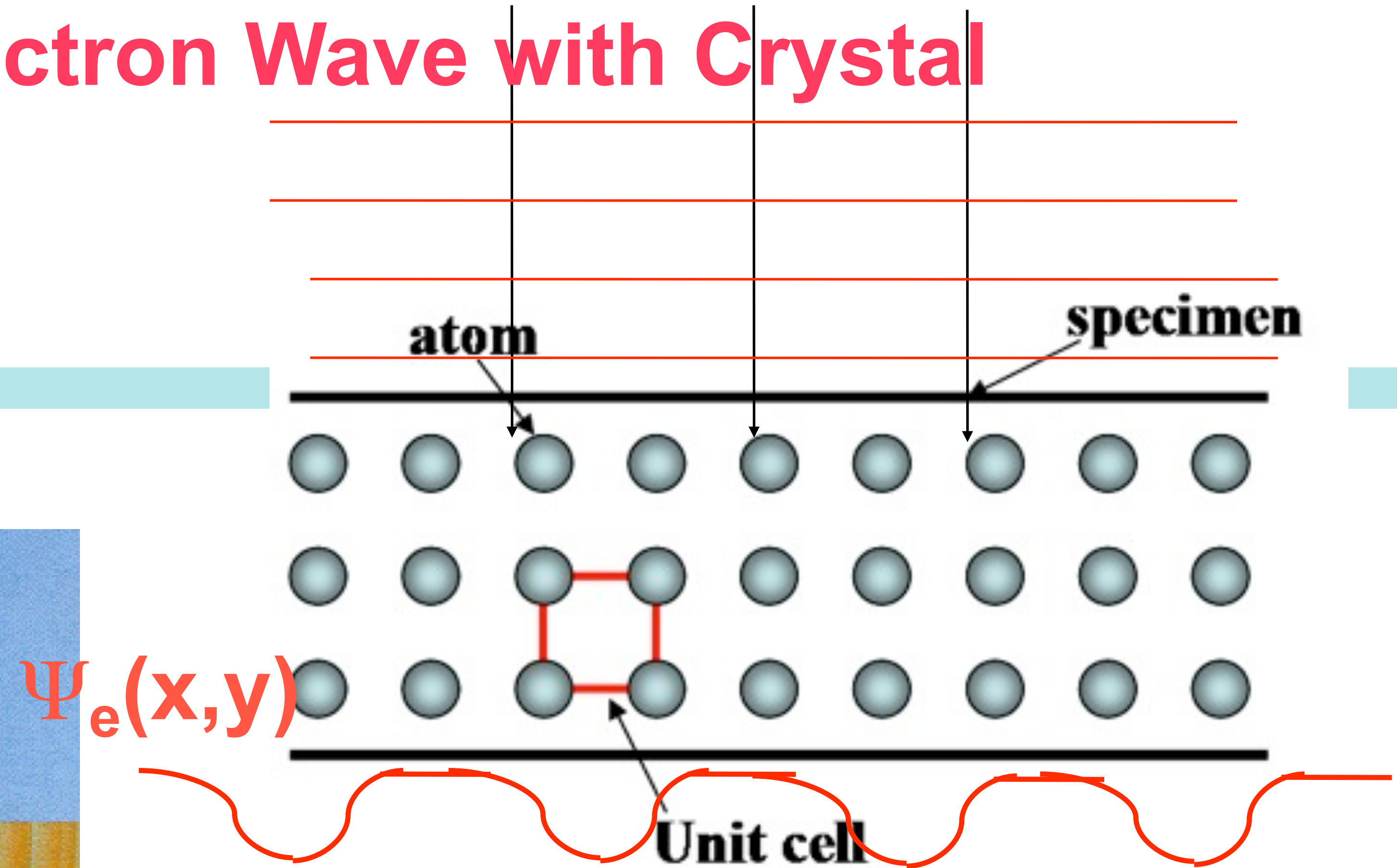
g_{-1} g_o g_1

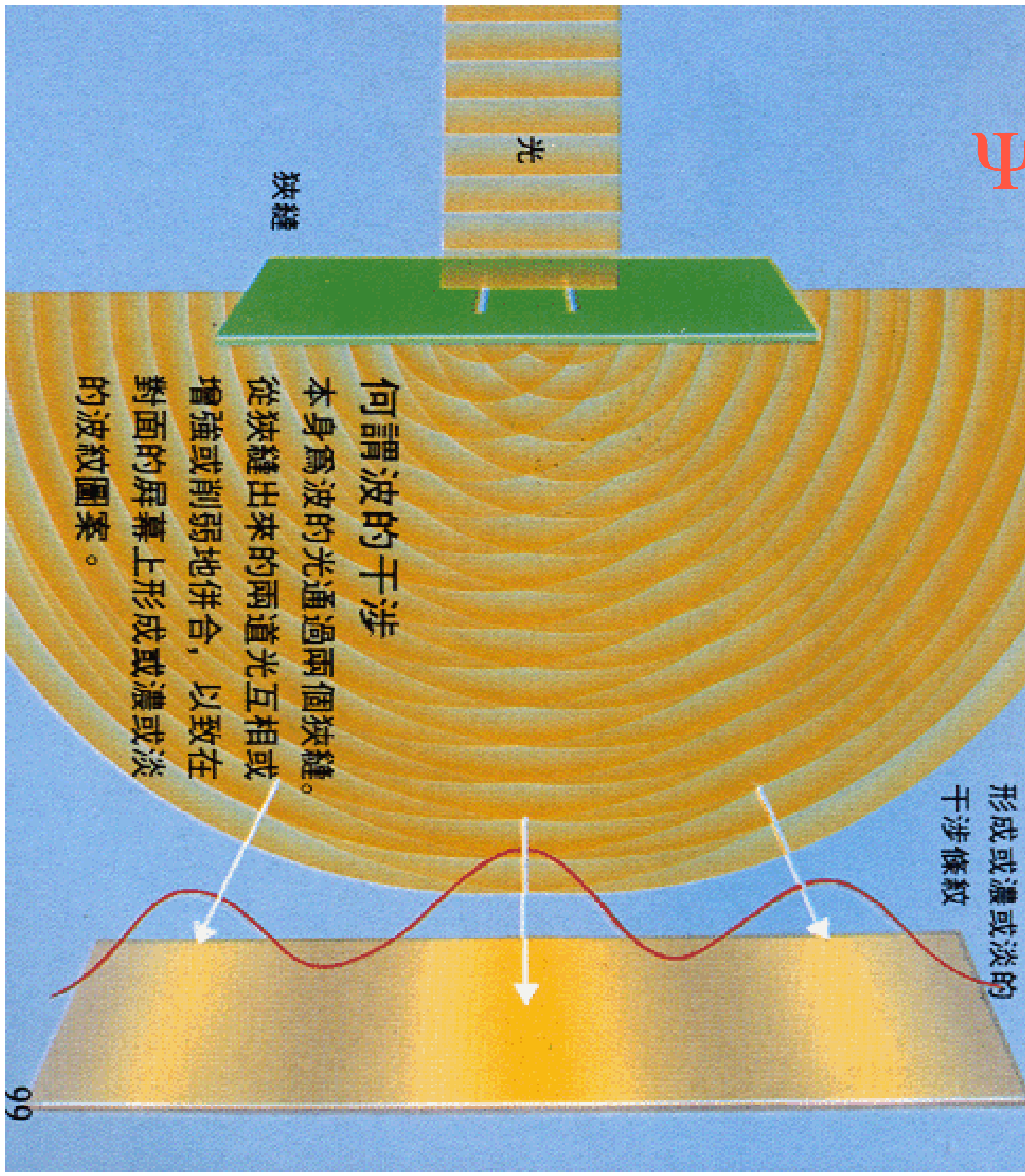
Ψ_e is composed of many Fourier components

$$\Psi_e(x,y) = \sum_{H=-g}^{g} F(H)\exp(-2\pi H \bullet r)$$

亮線位置不一定與原子柱位置重疊

Interaction of Electron Wave with Crystal





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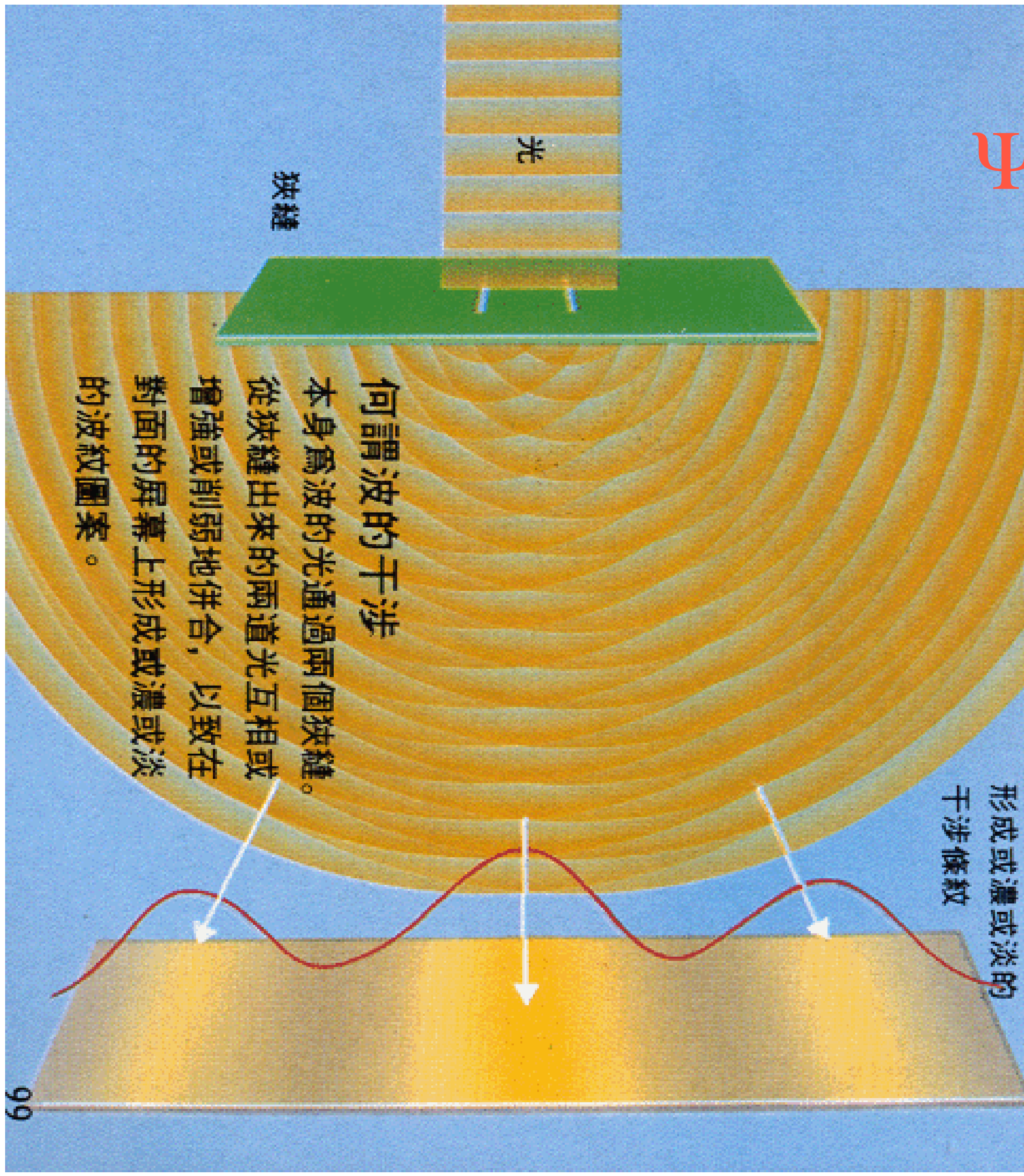

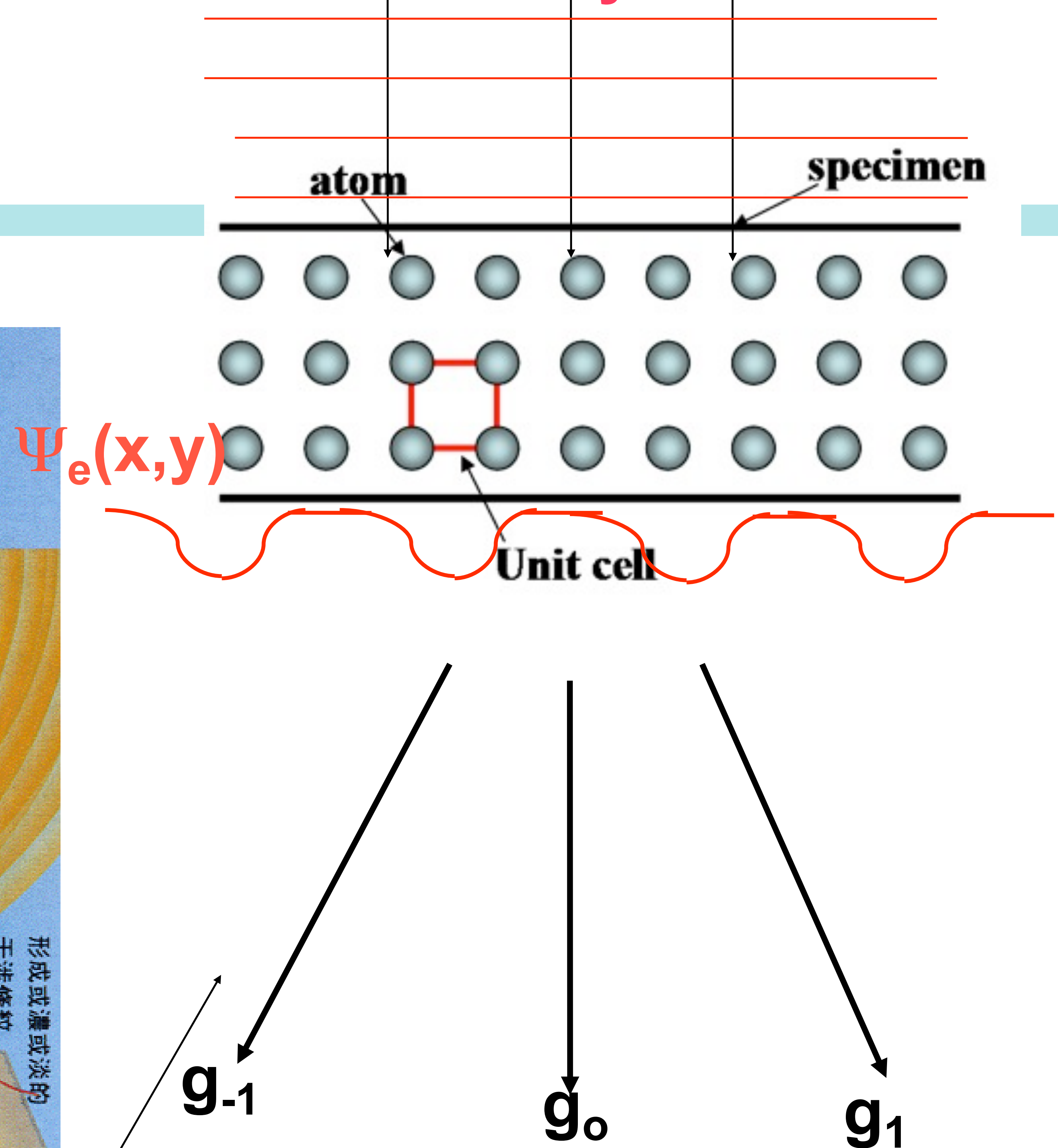

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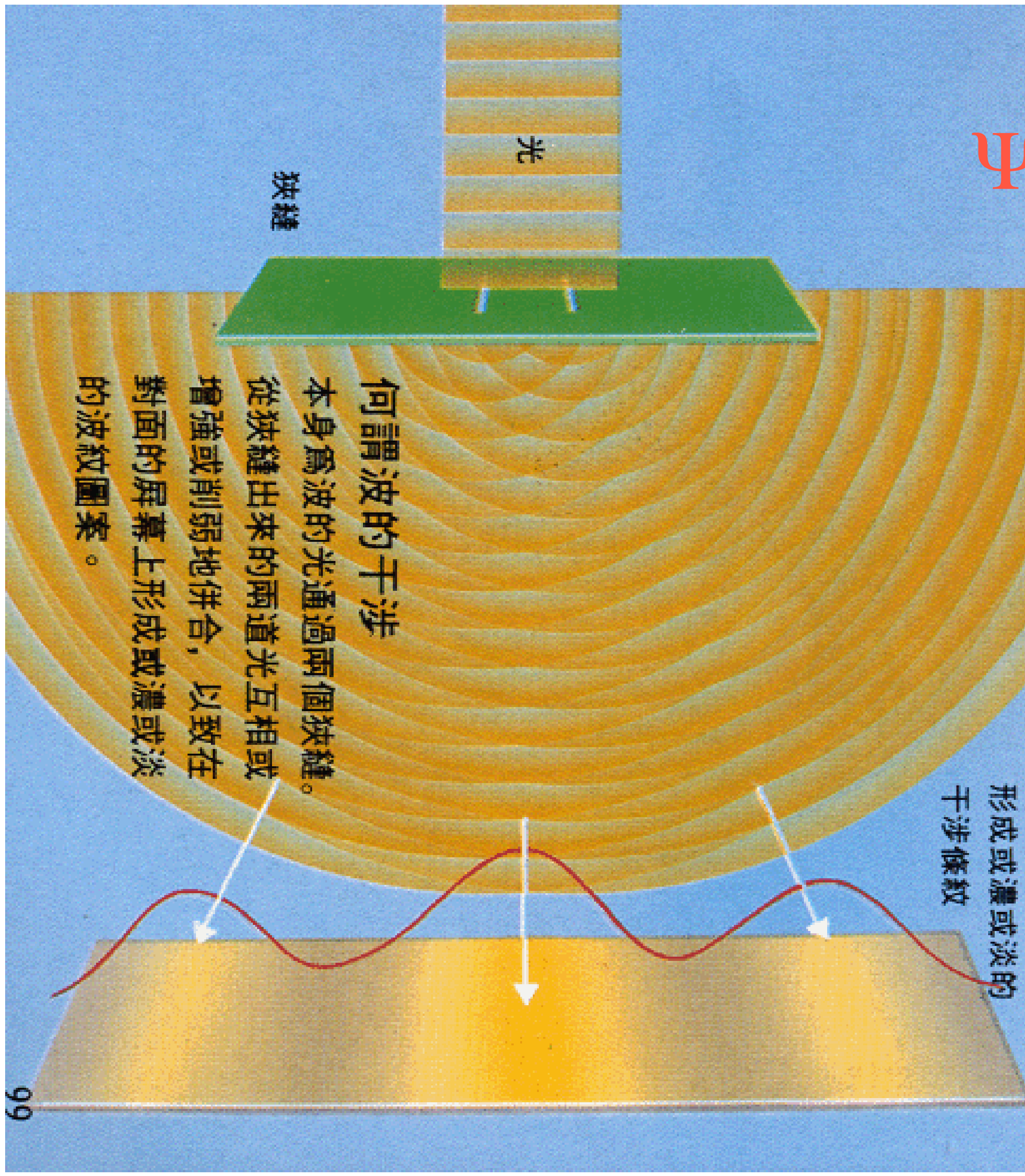

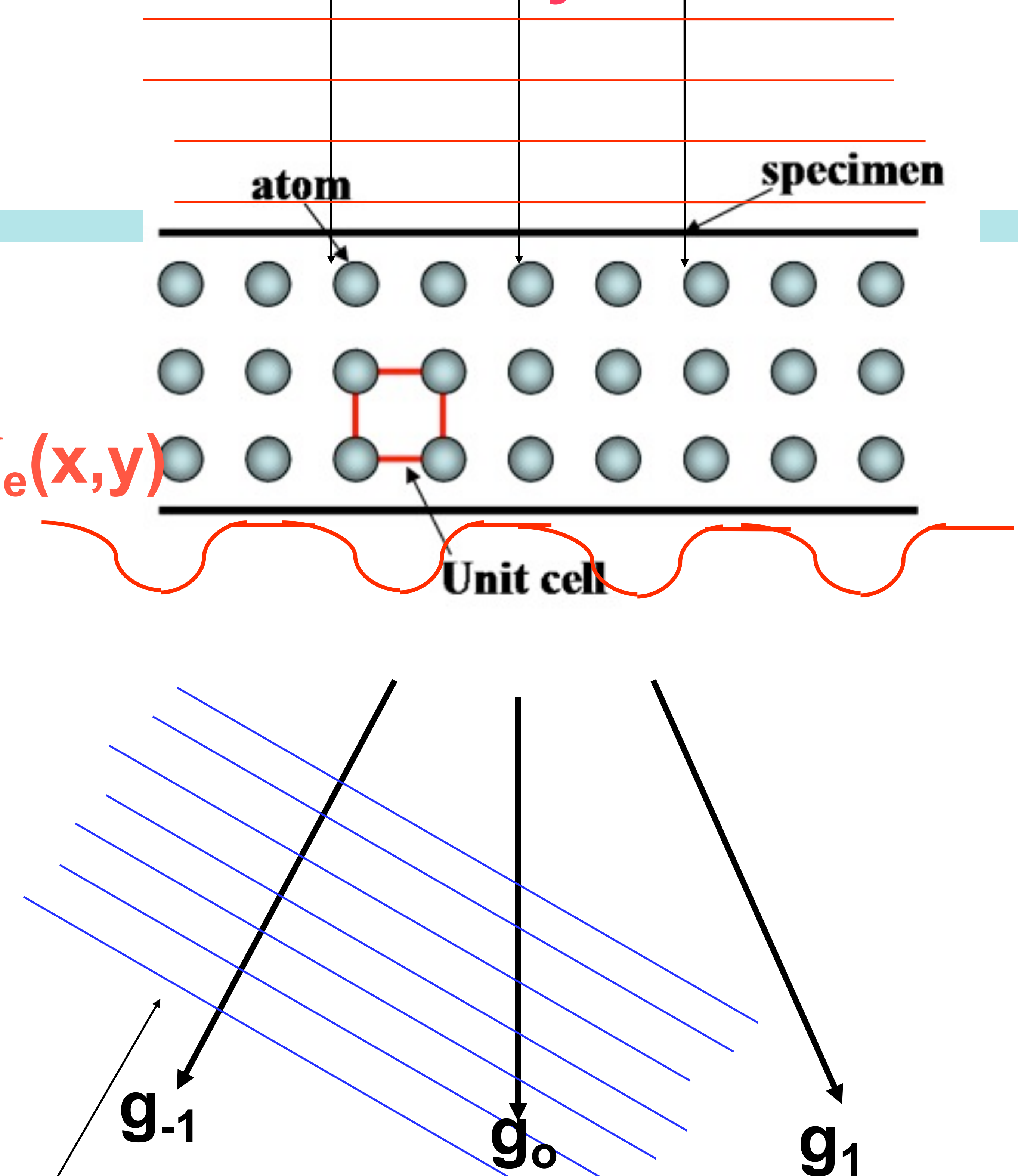

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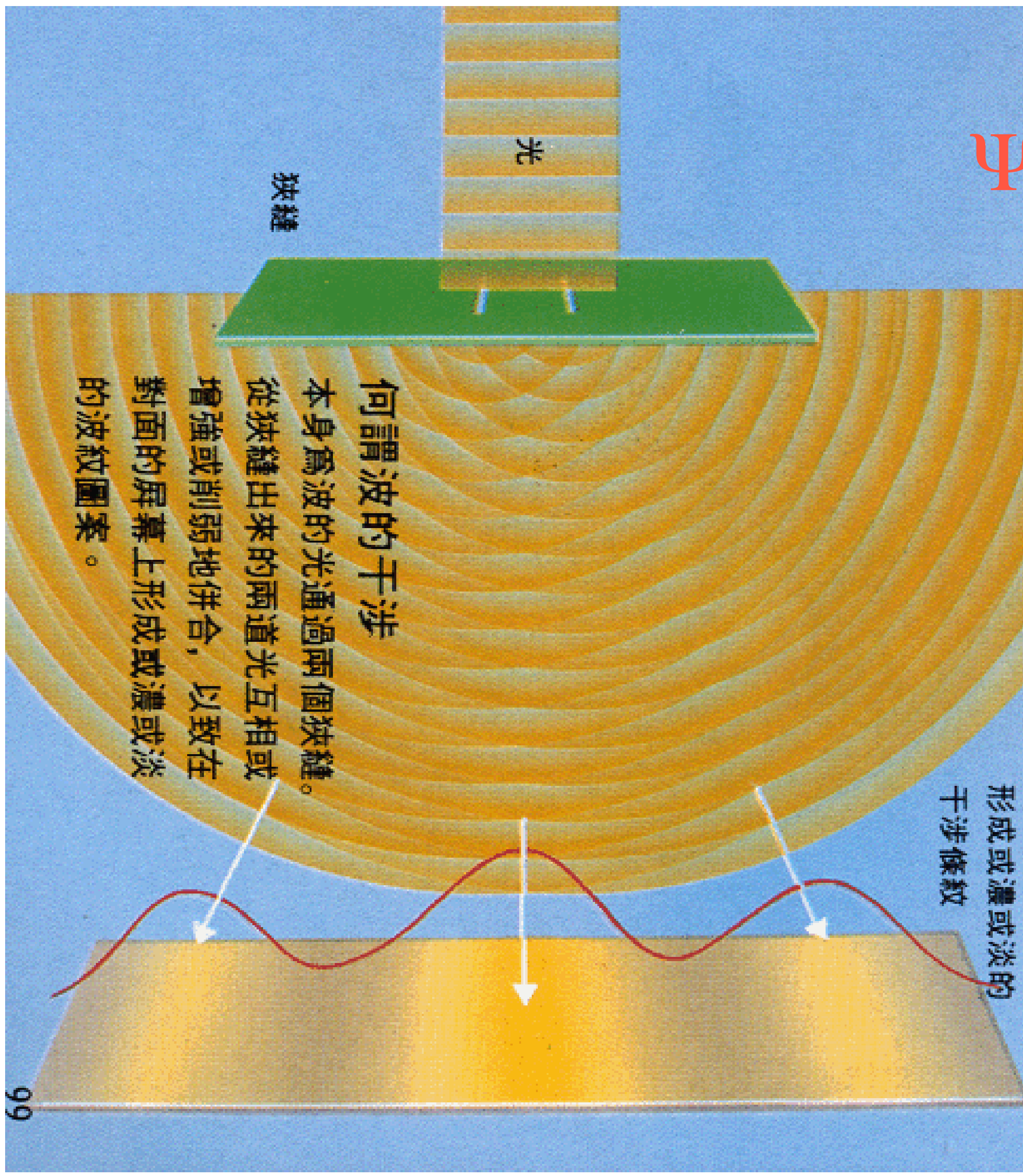

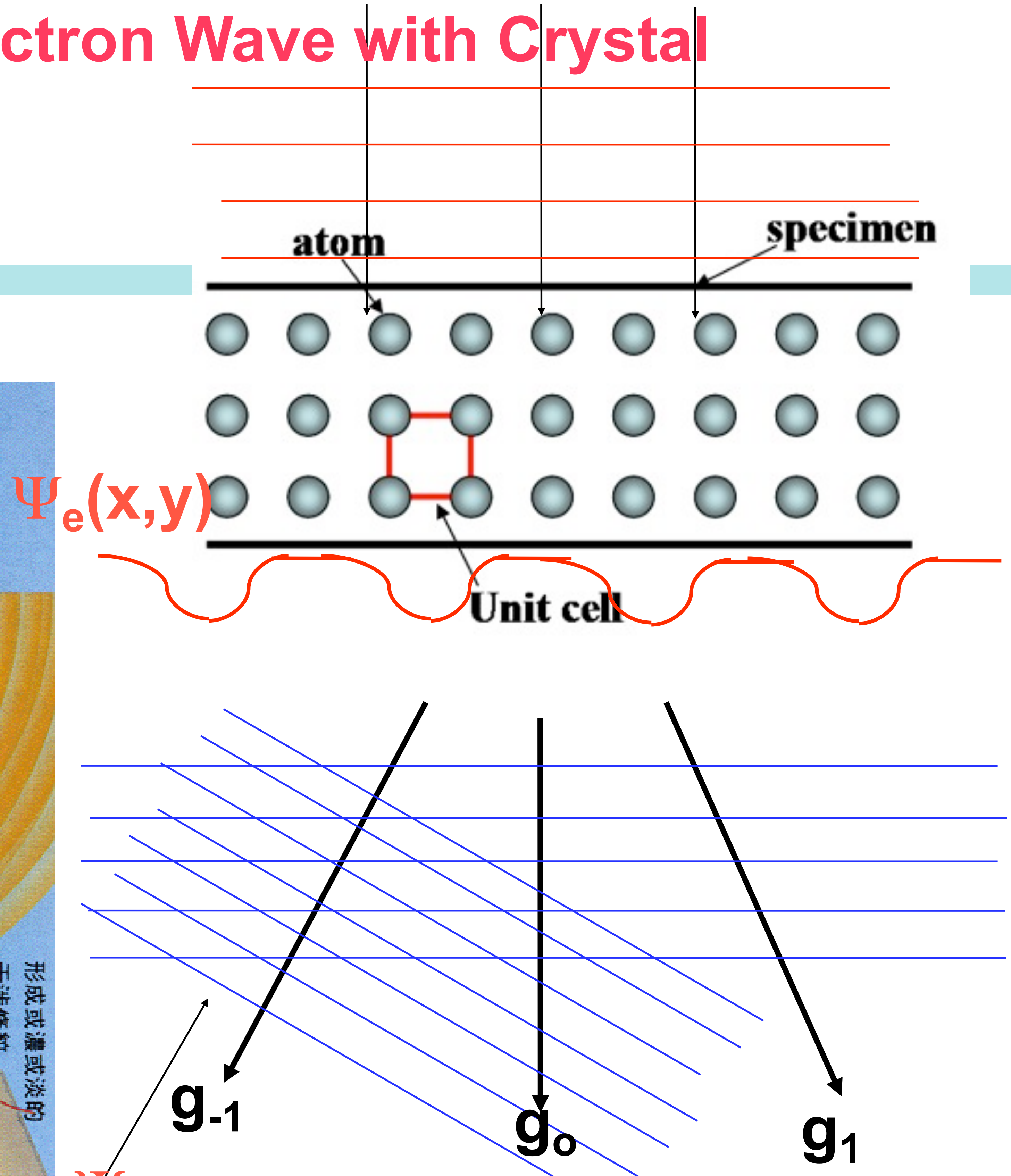

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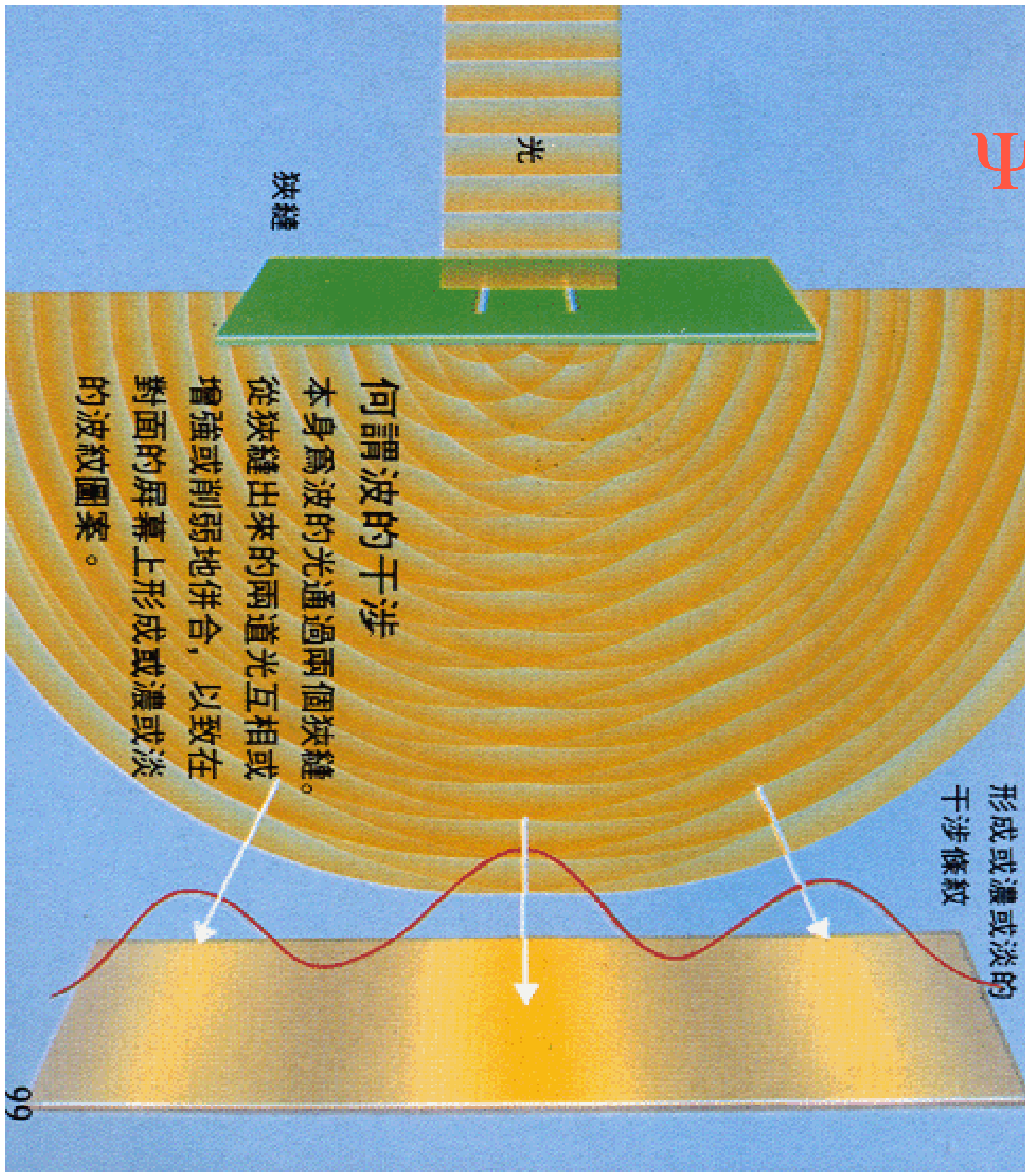

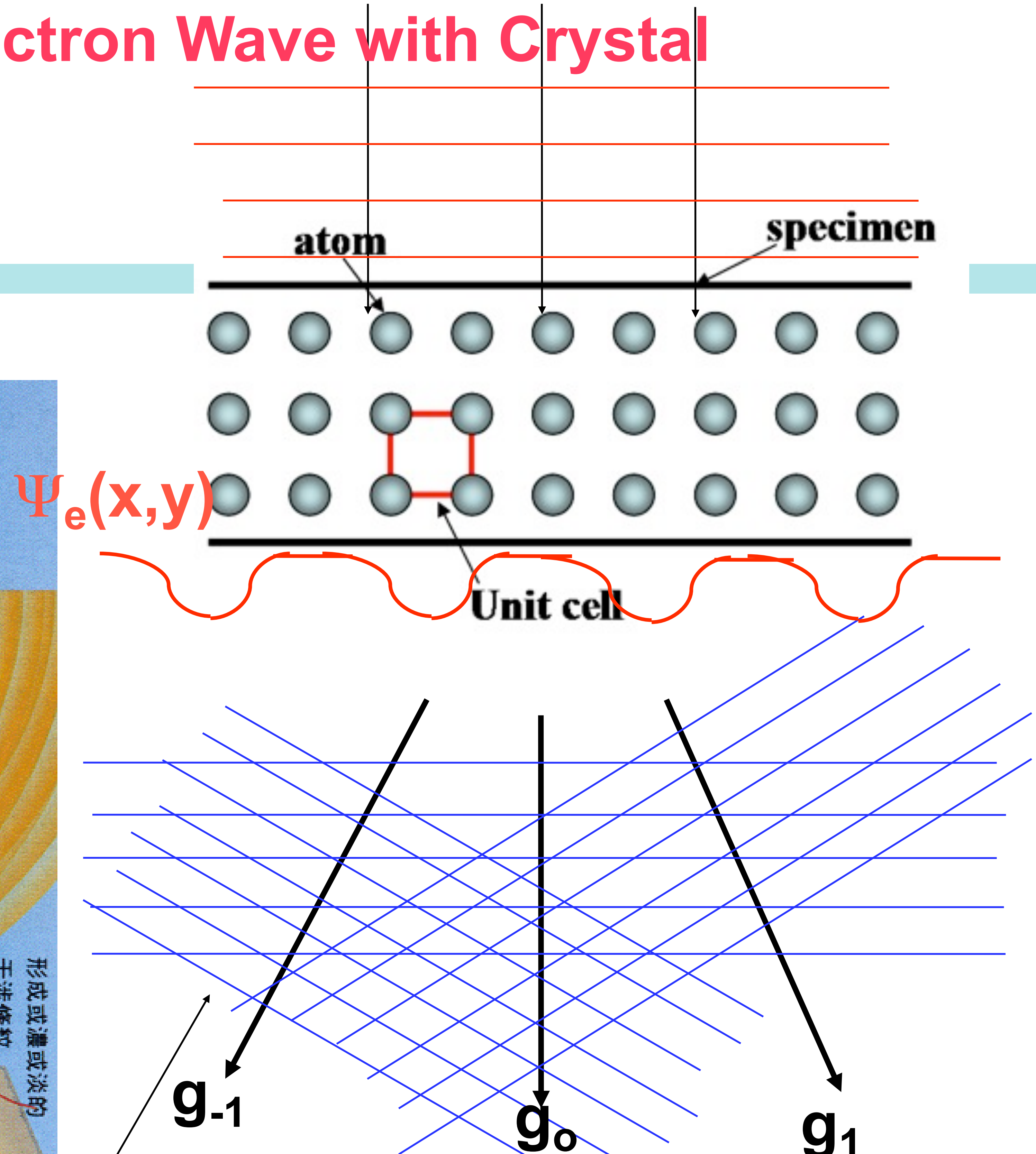

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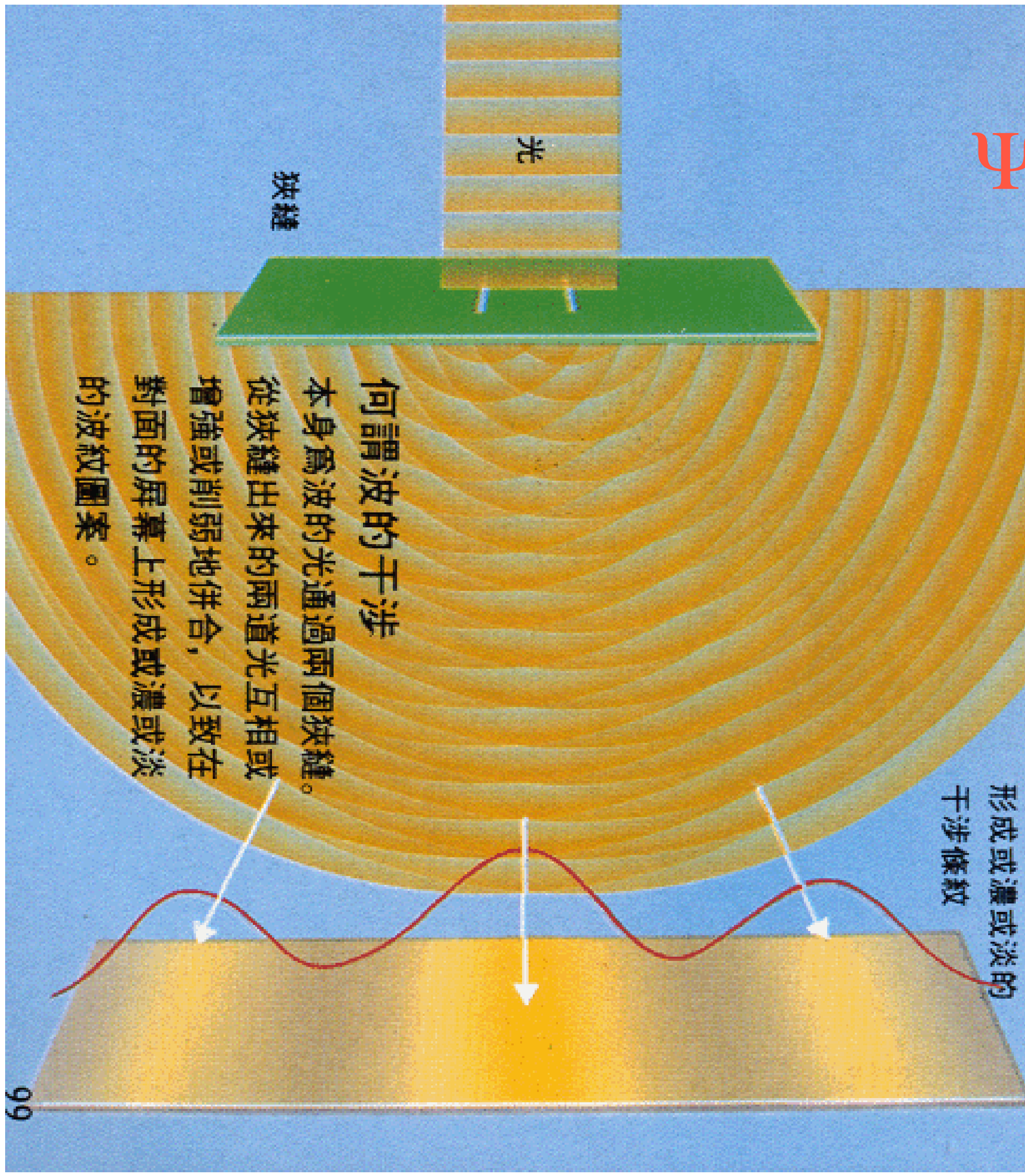

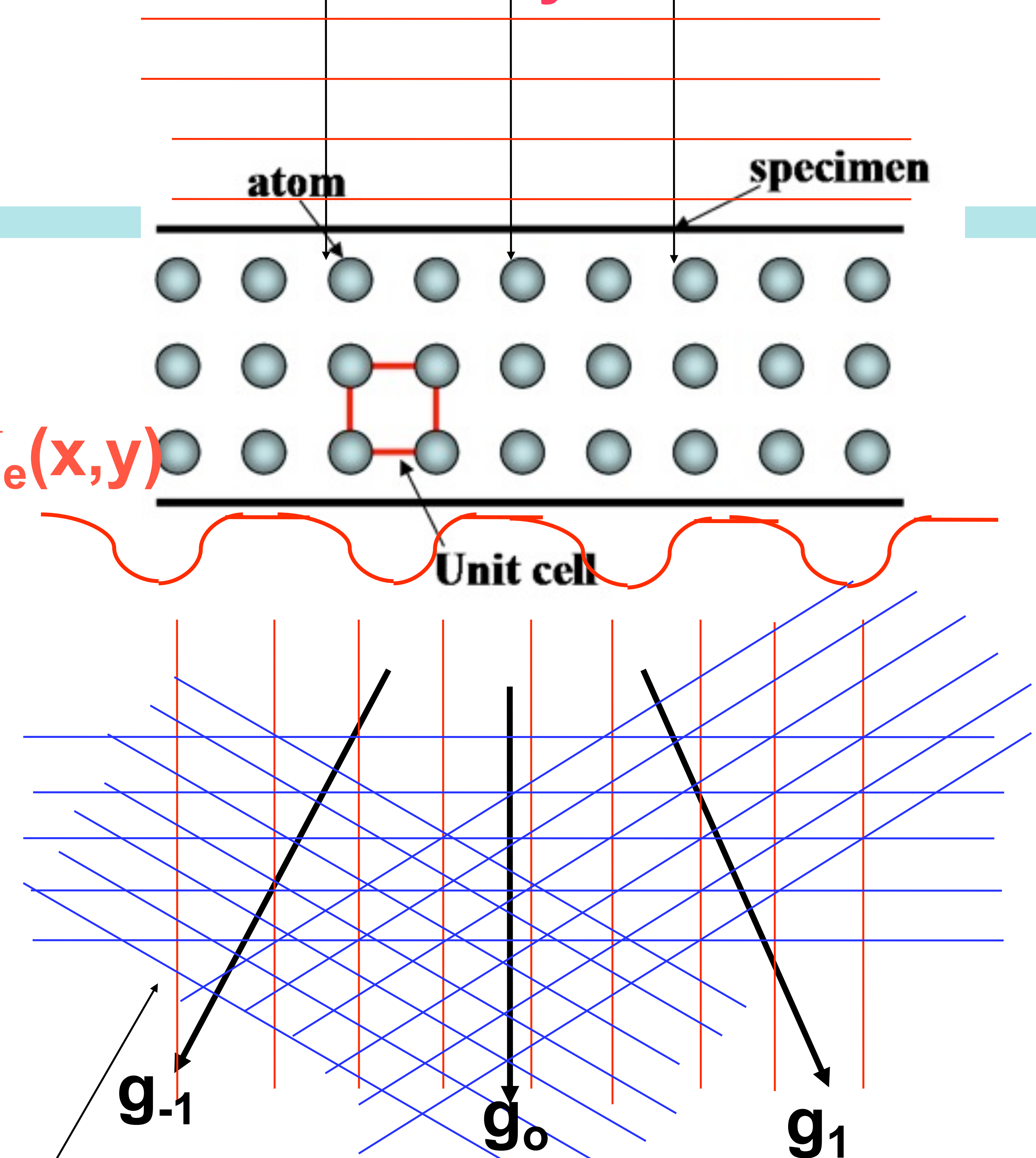

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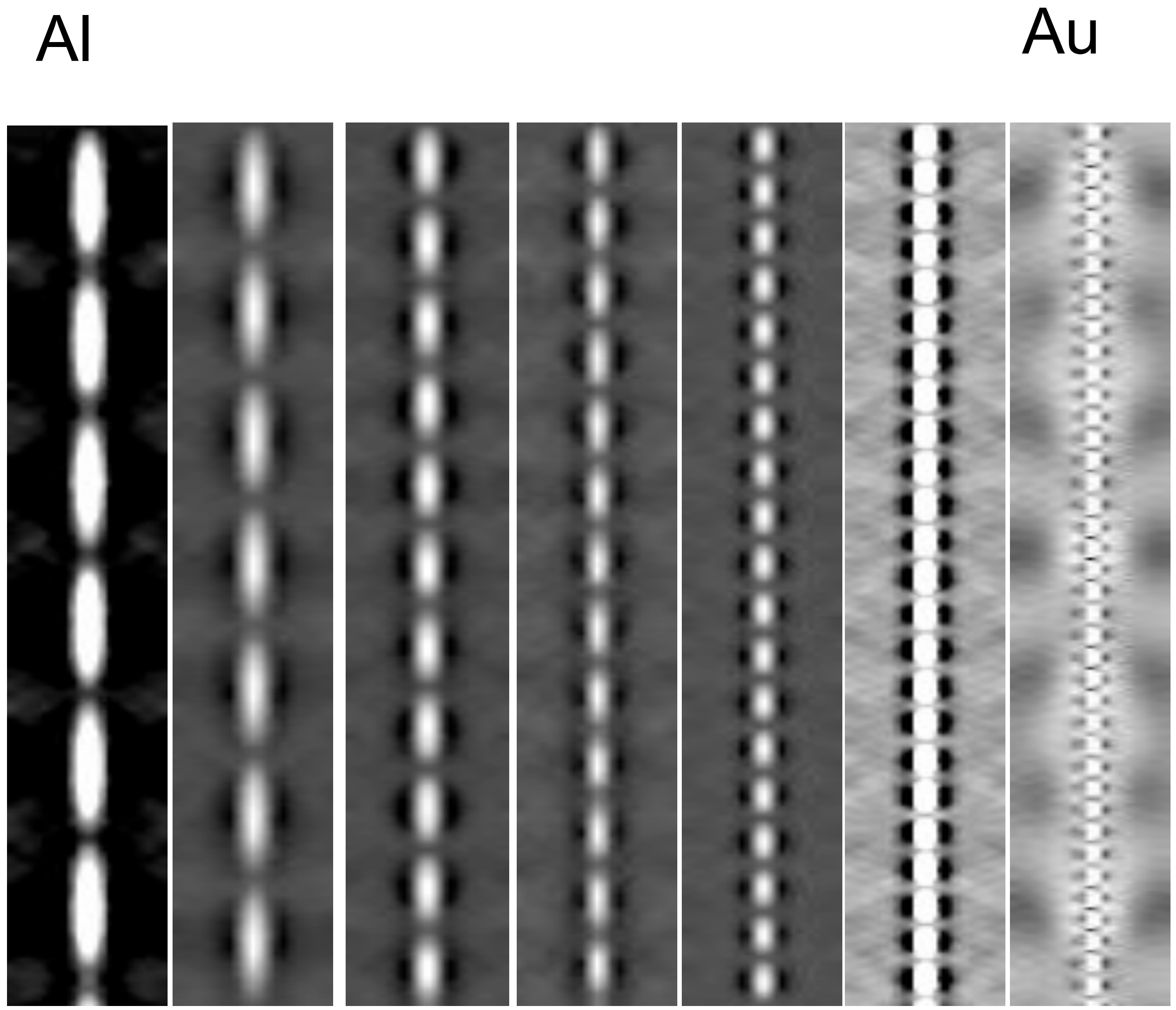
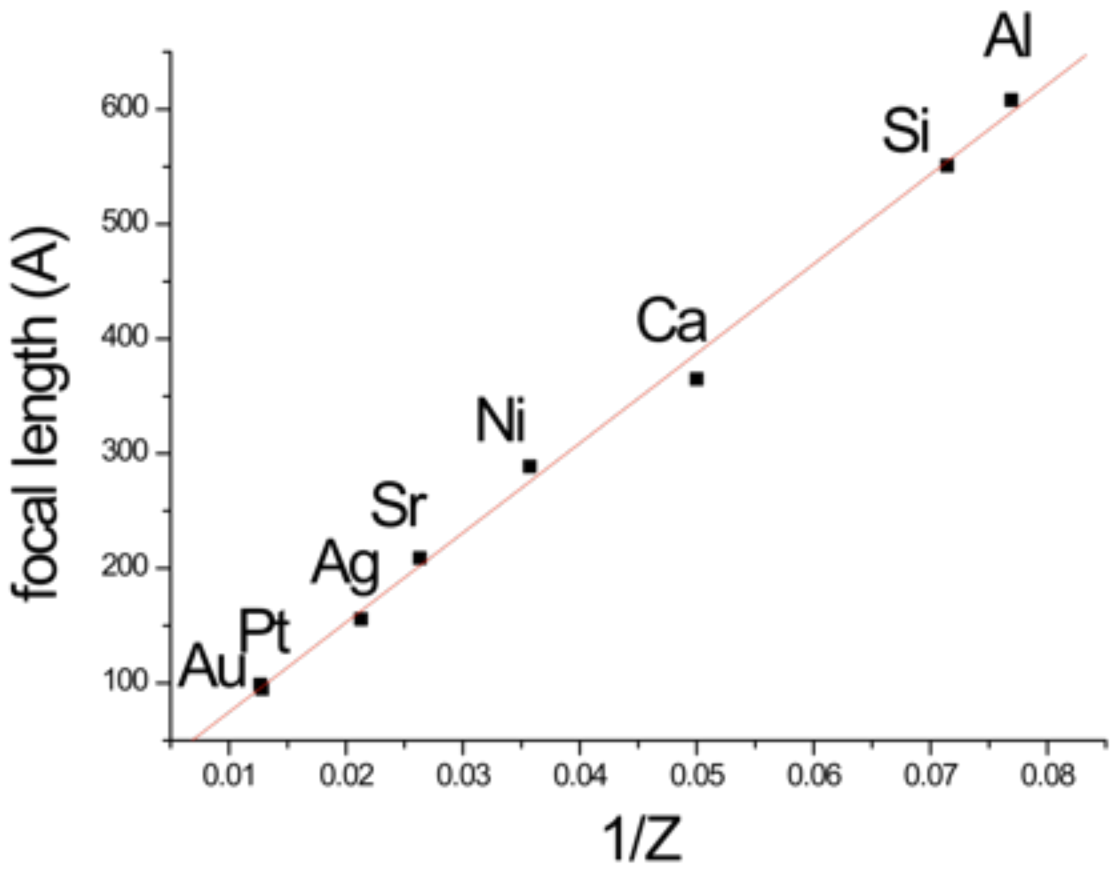
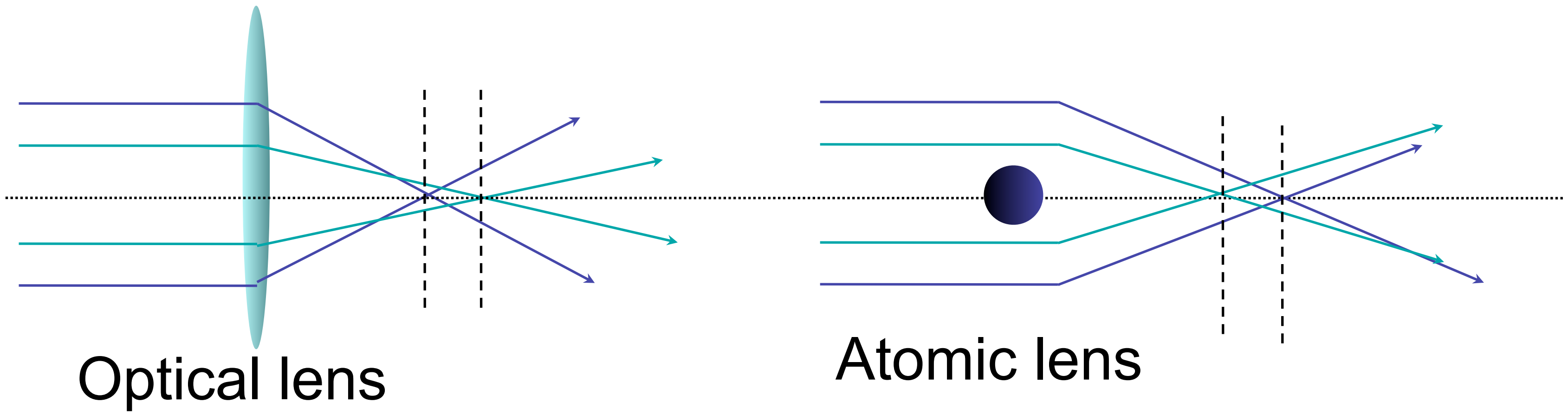
Wave Propagates inside Crystal

Channeling Theory







Fourier Synthesis

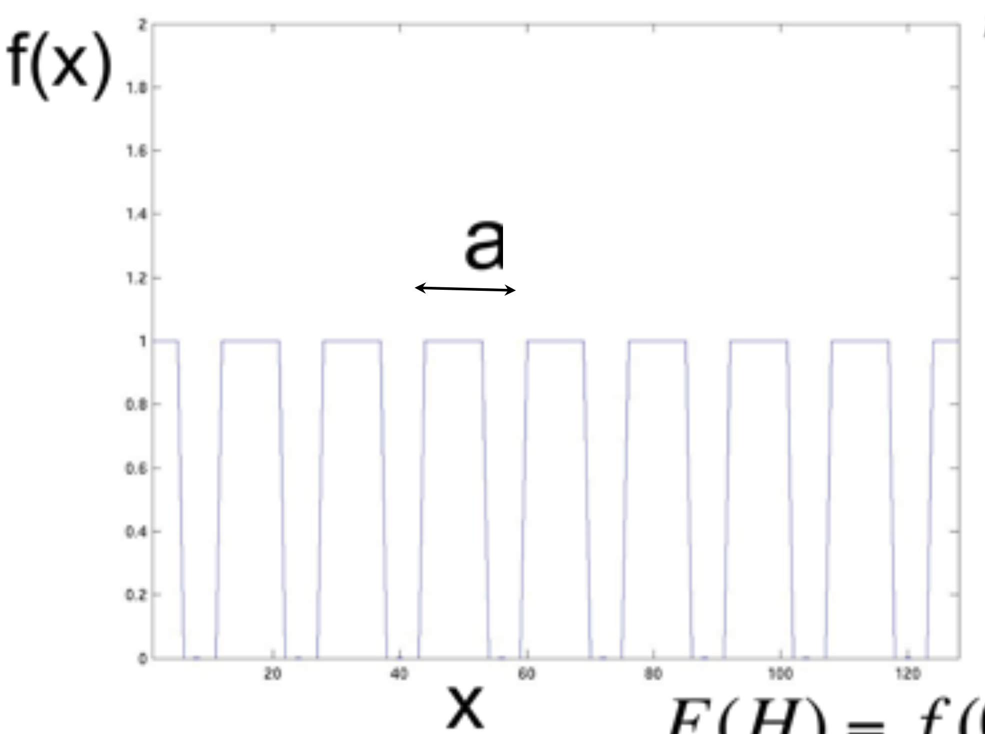
An function f(x) can be expressed in terms of sum of a series of Fourier coefficients F(H) multiply by the sine (or cosine, or exponential) functions

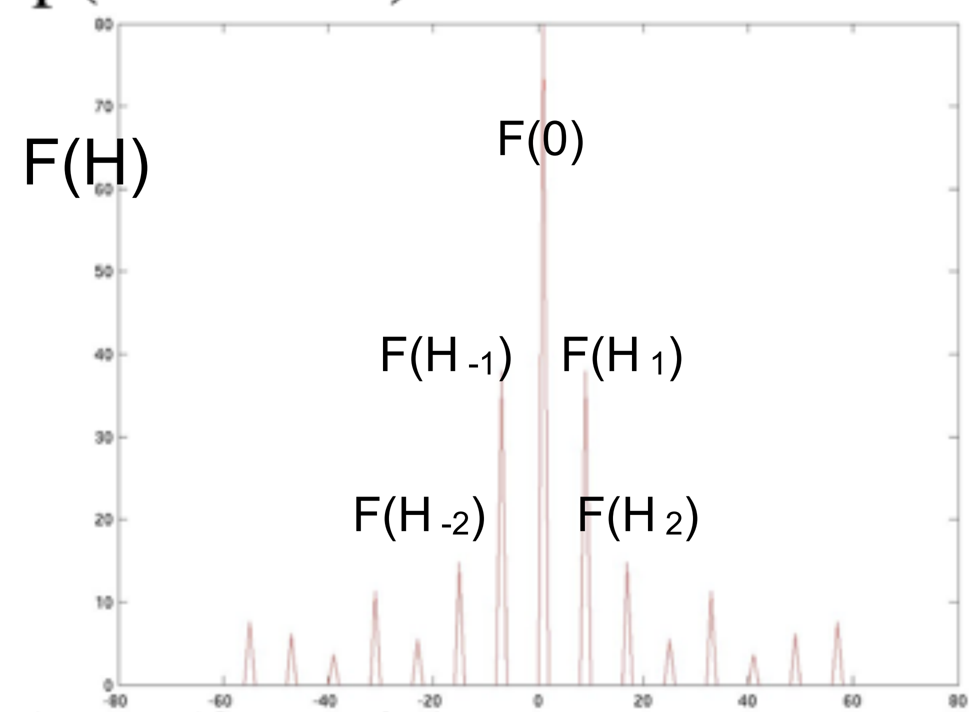
Periodicity
(real space, Crystal)

Frequency
(reciprocal space,Fourier Space, Diffraction space)

Inverse Fourier Transform

$$f(x) = F(0) + \sum_n F(H_n)\exp(-2\pi nx/a)$$





$$F(H) = f(0) + \sum_n f(x_n)\exp(2\pi nx/a)$$

H

low frequency

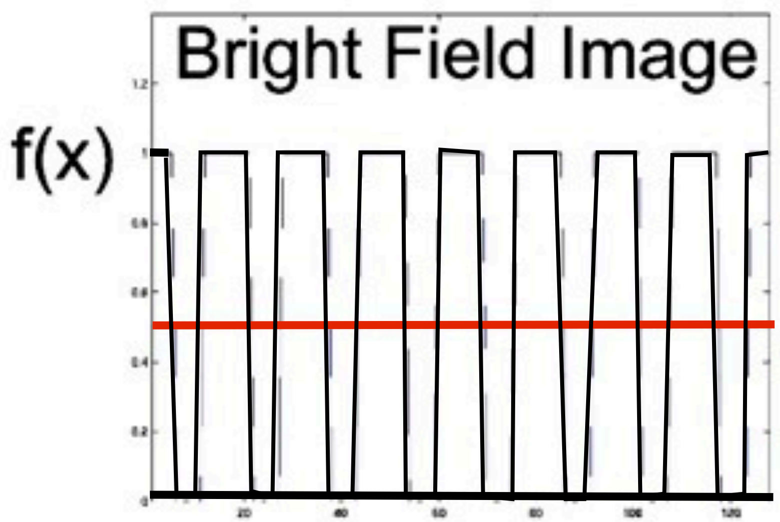
high frequency

Fourier Transform

Fourier Synthesis

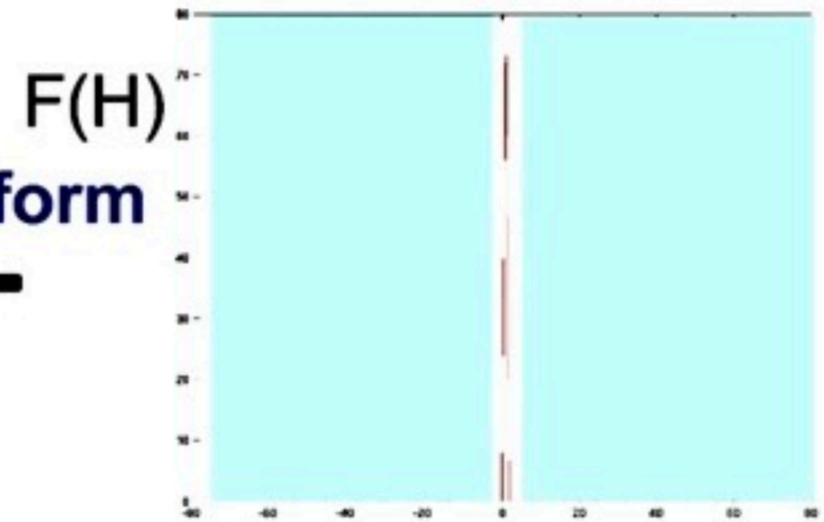
Periodicity
(real space, Crystal)

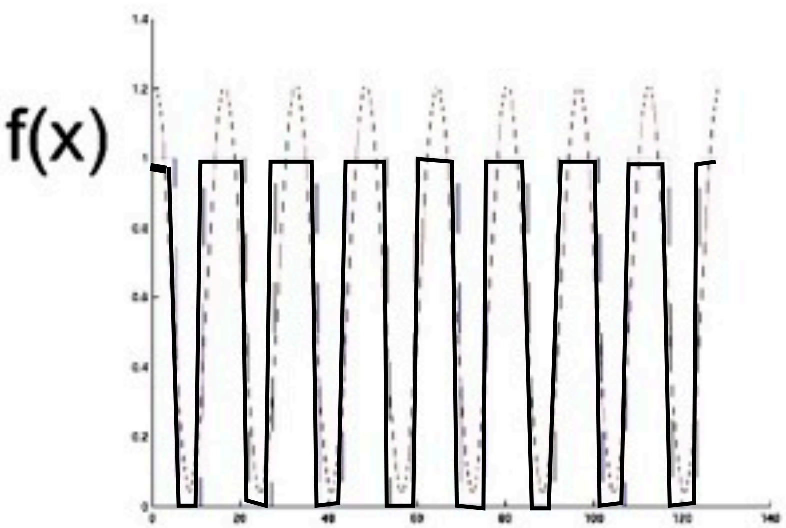
Frequency
(reciprocal space, Fourier Space, Diffraction space)



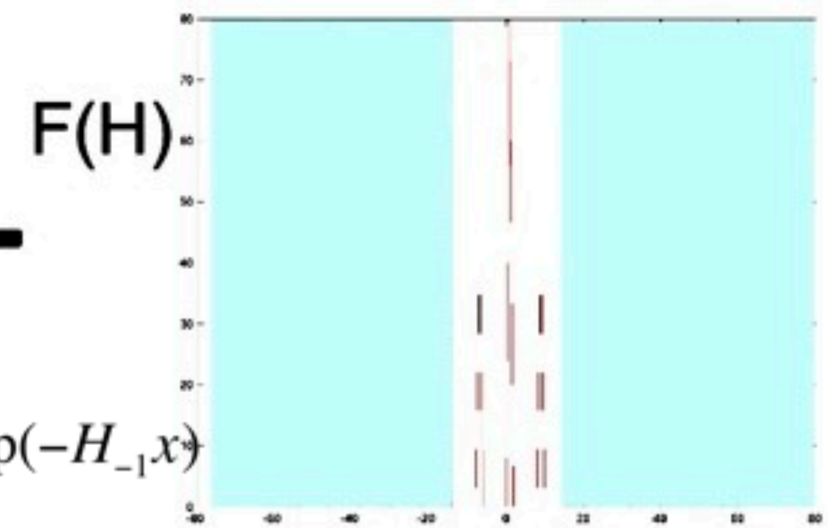
Inverse Fourier Transform

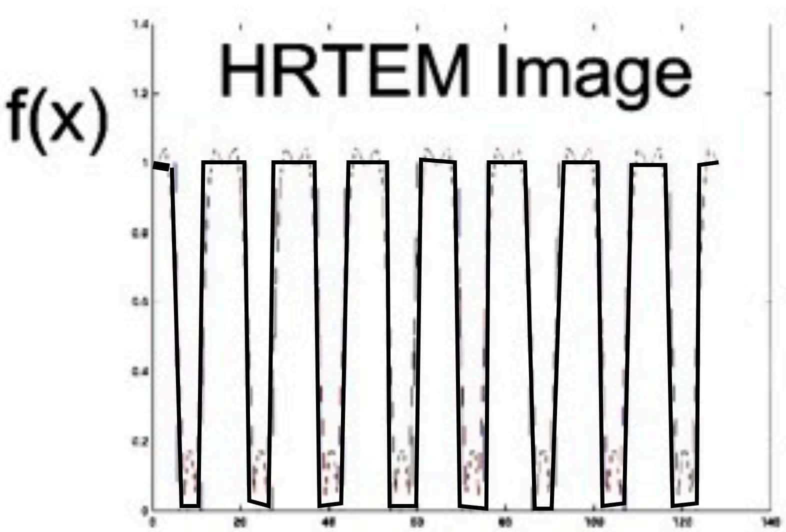
$$f(x) = F(0)\exp(-0.x)$$



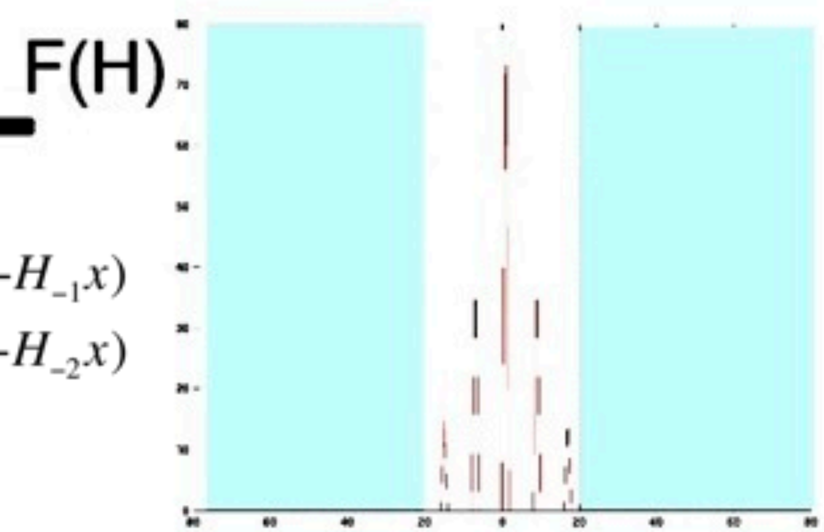


$$f(x) = F(0)$$
$$+F(H_1)\exp(-H_1x) + F(H_{-1})\exp(-H_{-1}x)$$





$$f(x) = F(0)$$
$$+F(H_1)\exp(-H_1x) + F(H_{-1})\exp(-H_{-1}x)$$
$$+F(H_2\exp(-H_2x) + F(H_{-2})\exp(-H_{-2}x)$$

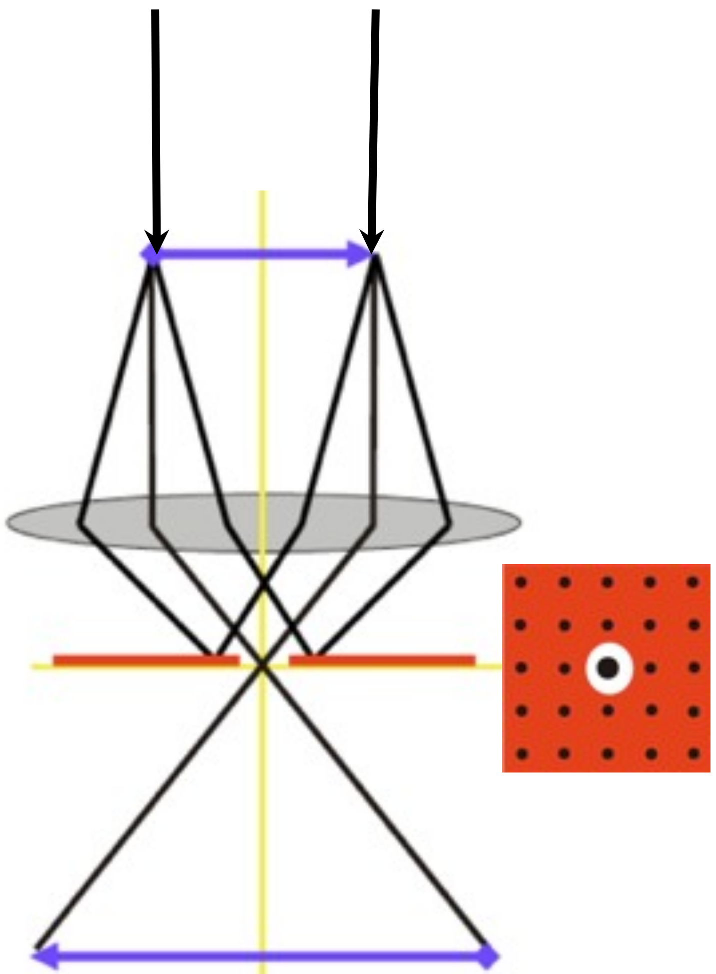


Low Frequ

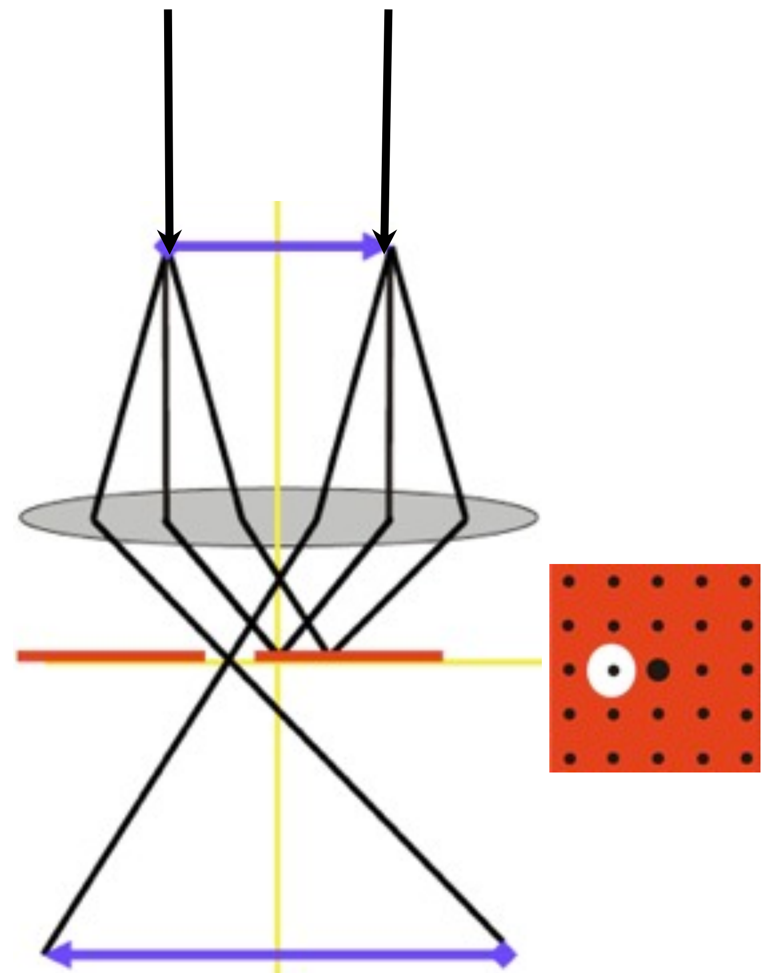
High Freque

Kinematic Contrast

- mass/ thickness contrast
- Bragg (orientation) contrast

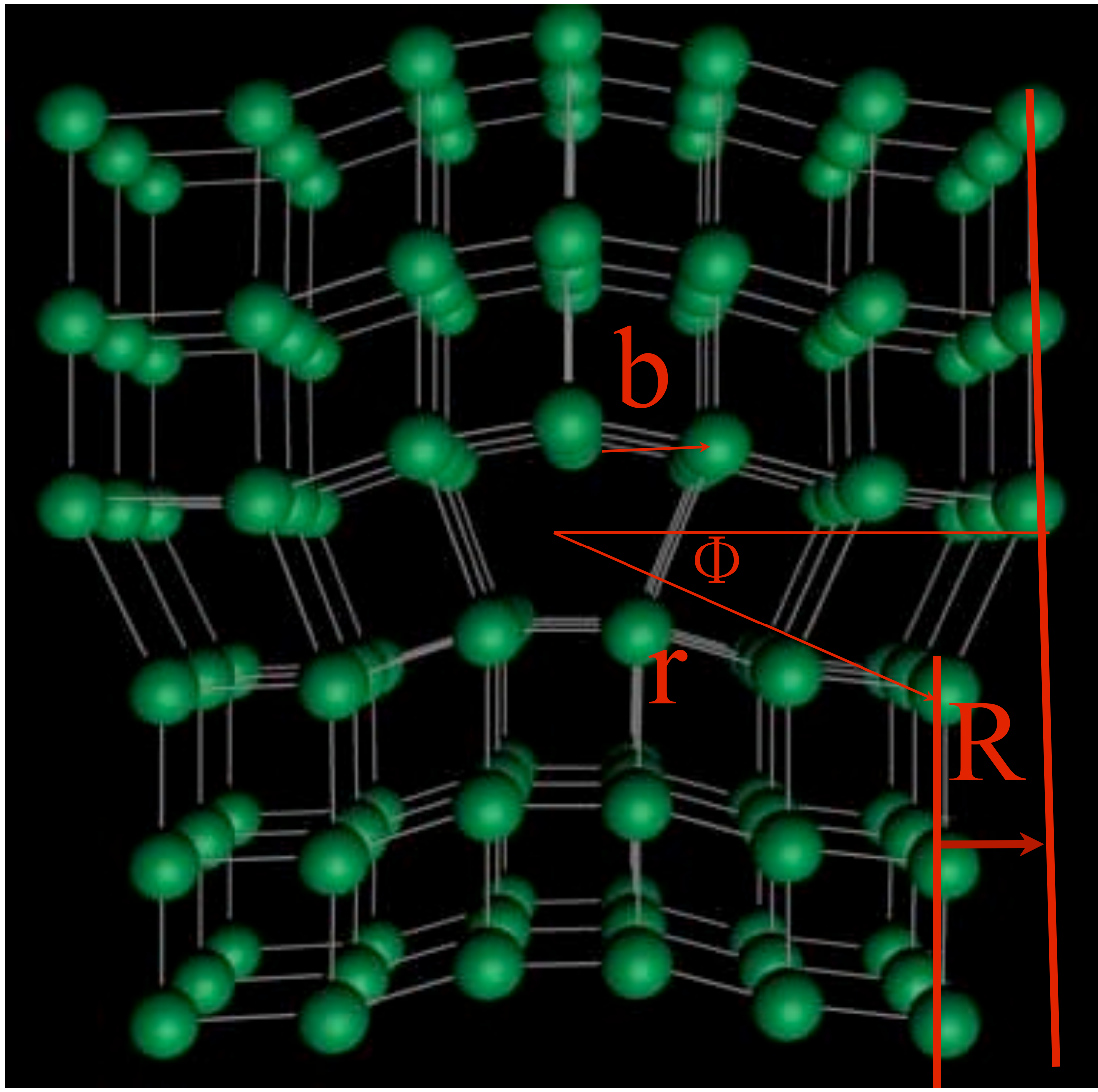


Bright Field



Dark Field

4.3.2 Line Defects

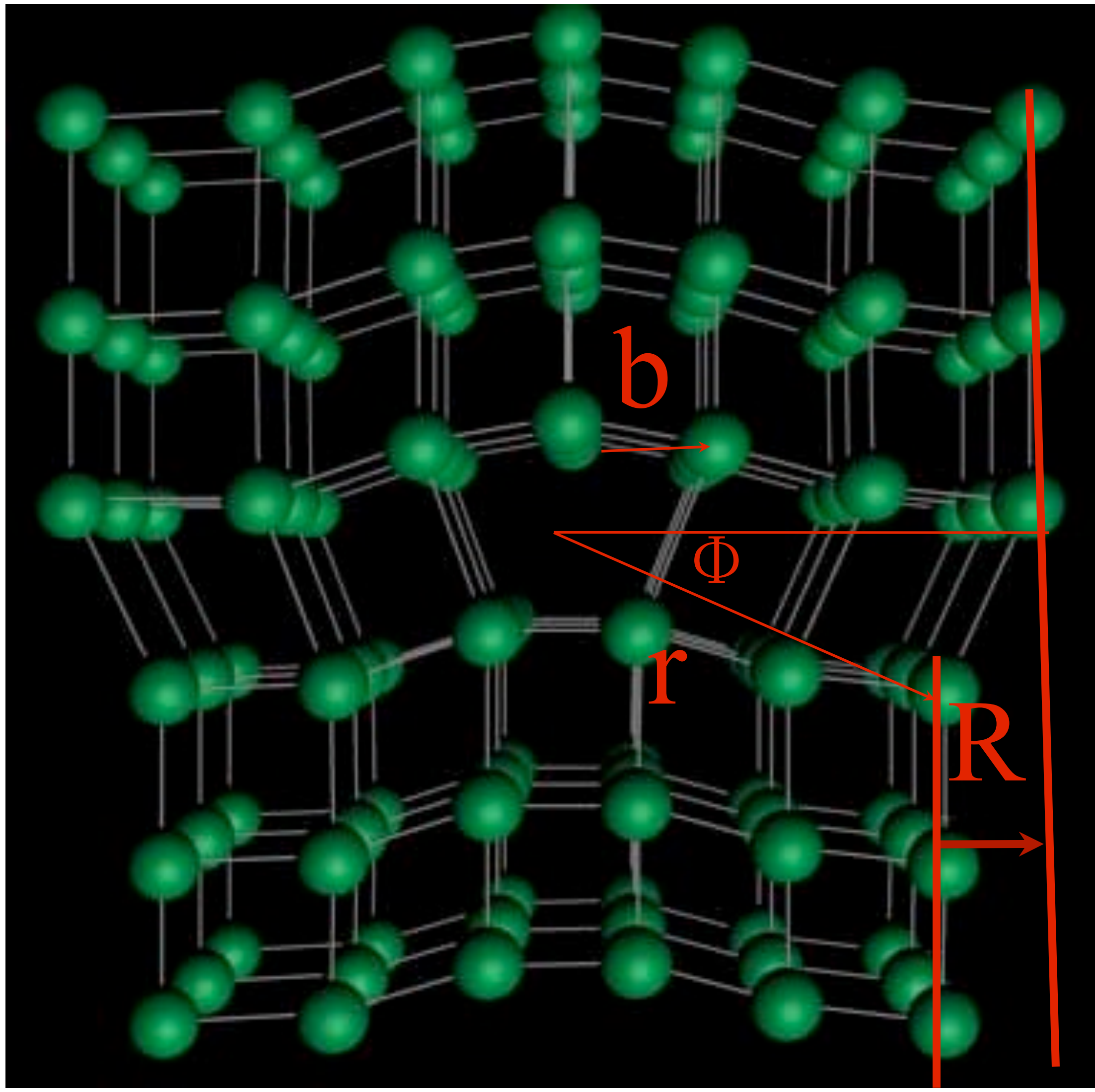


Edge Dislocation

(邊刃差排)

$$R = \frac{1}{2\pi}[\underline{b}\frac{Sin2\Phi}{4(1-\nu)} + (b \wedge u)]\{\frac{1-2\nu}{2(1-\nu)}\ln r + \frac{Cos2\Phi}{4(1-\nu)}\}$$

4.3.2 Line Defects



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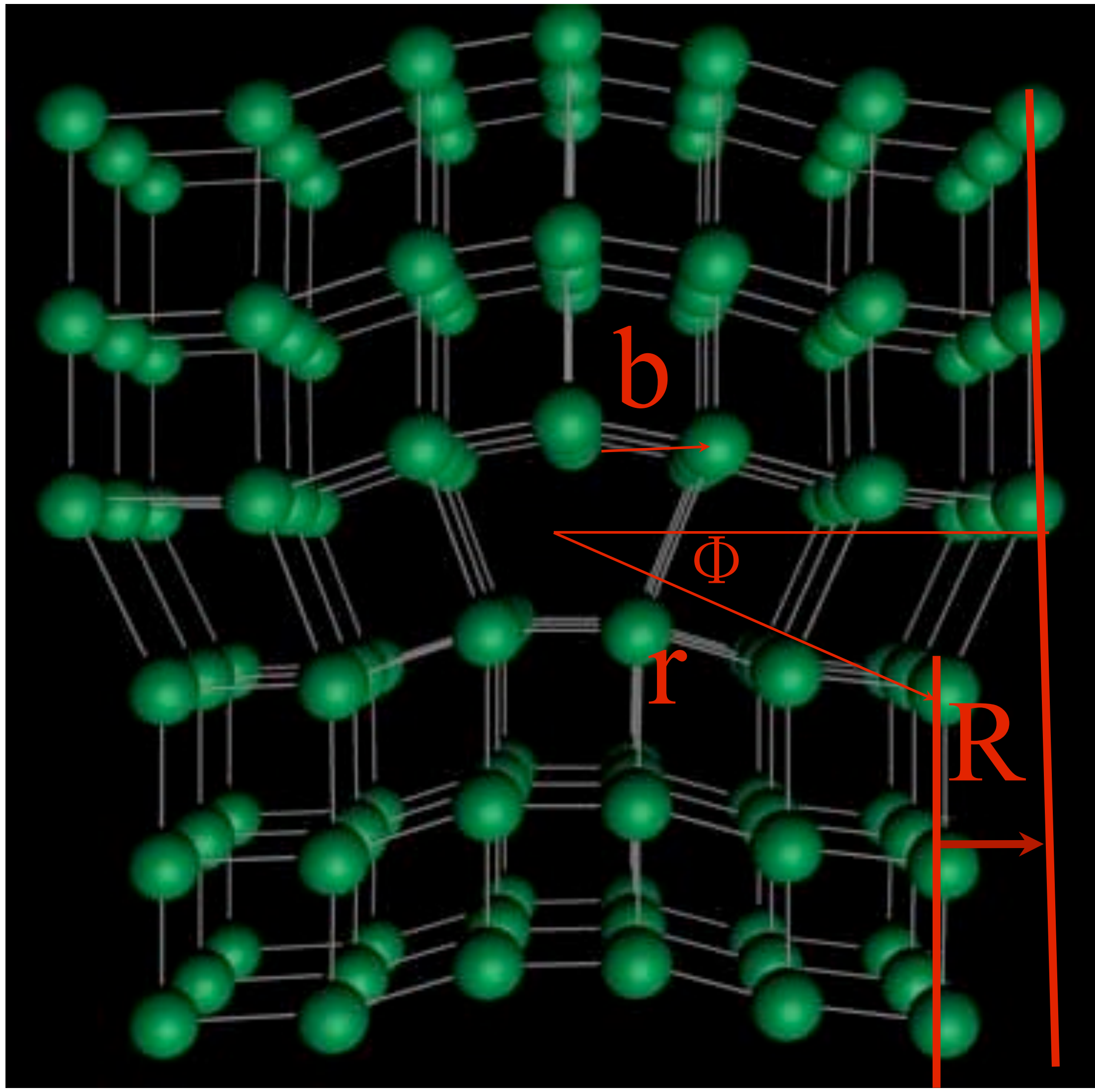

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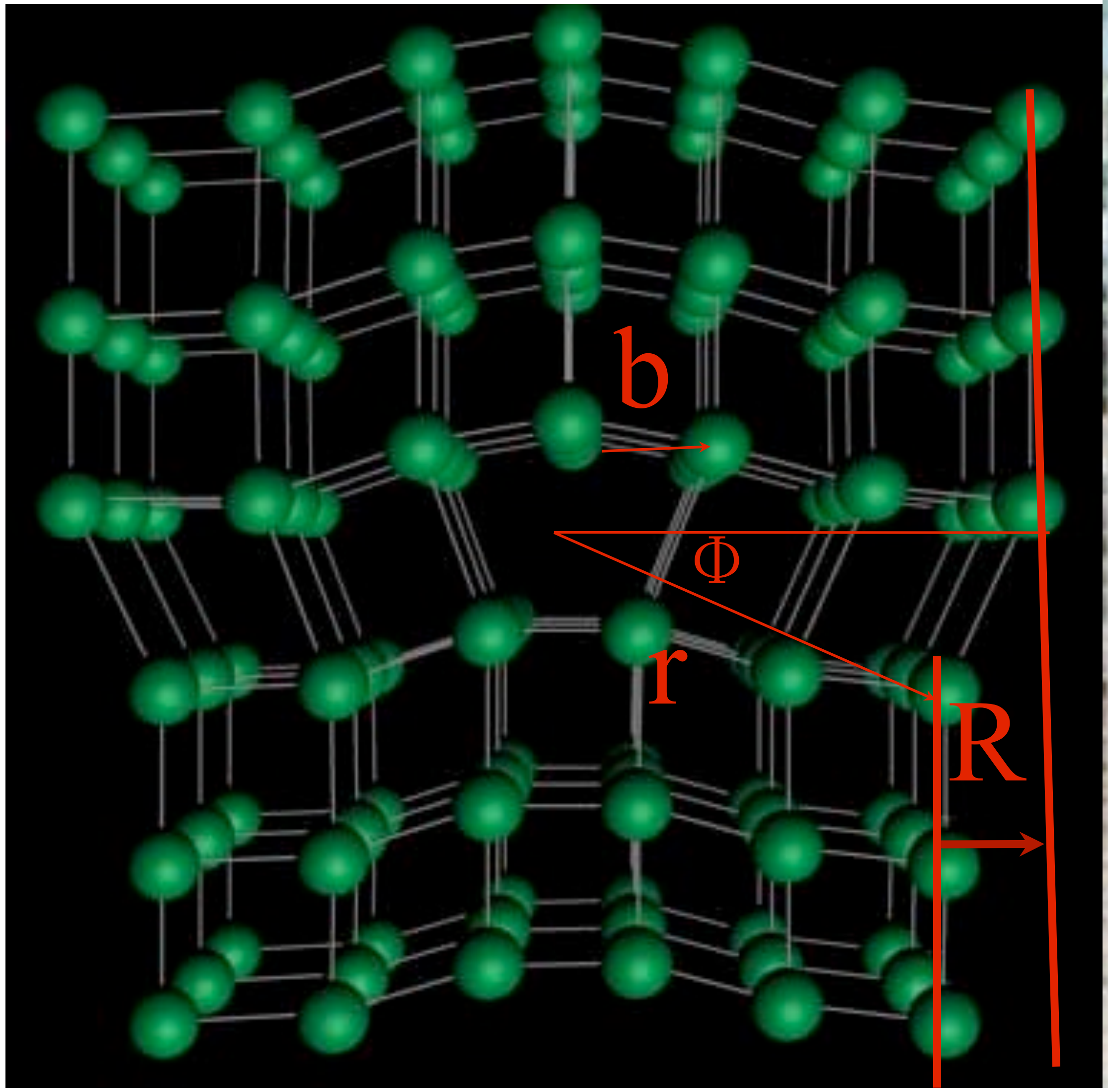
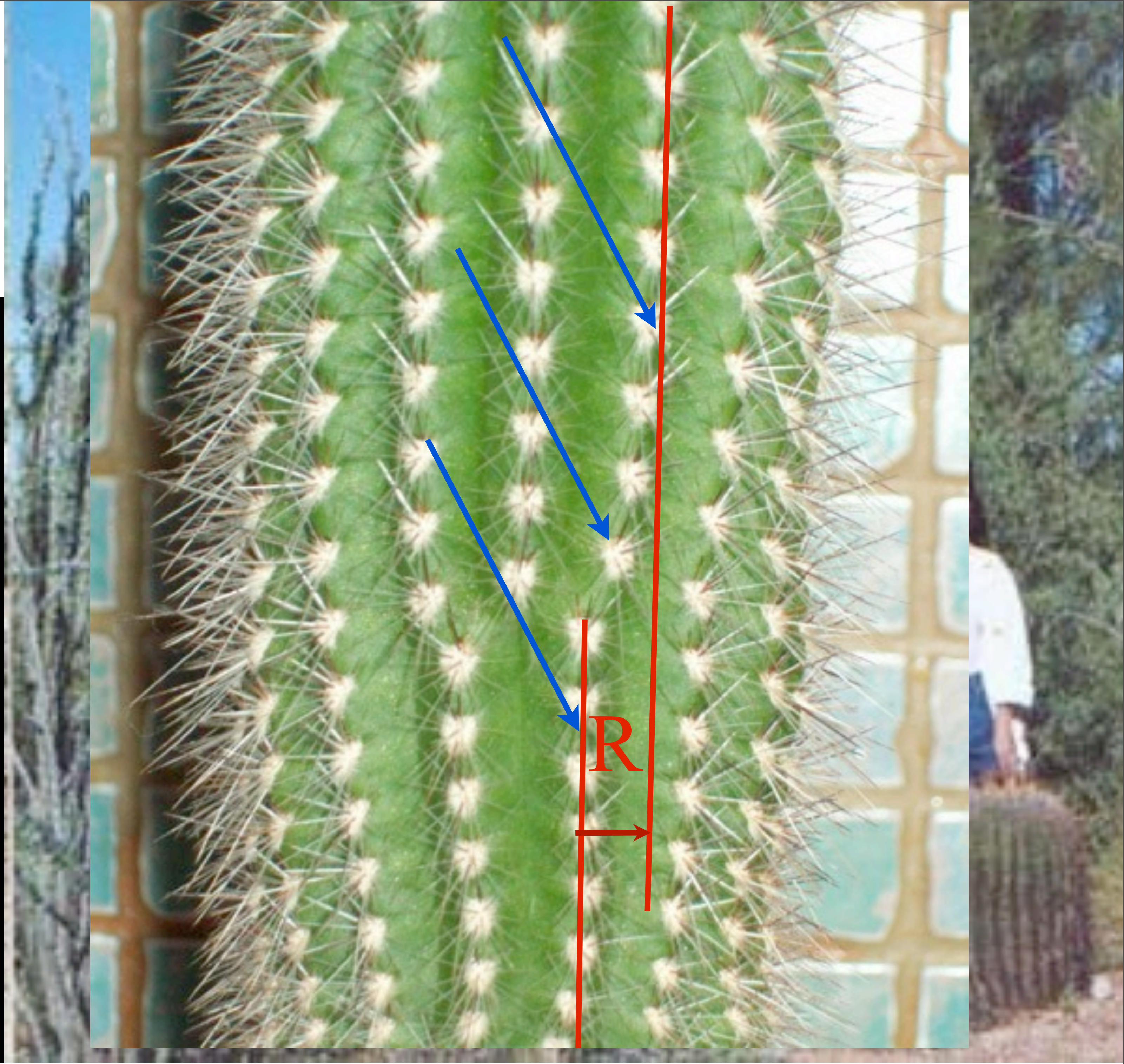
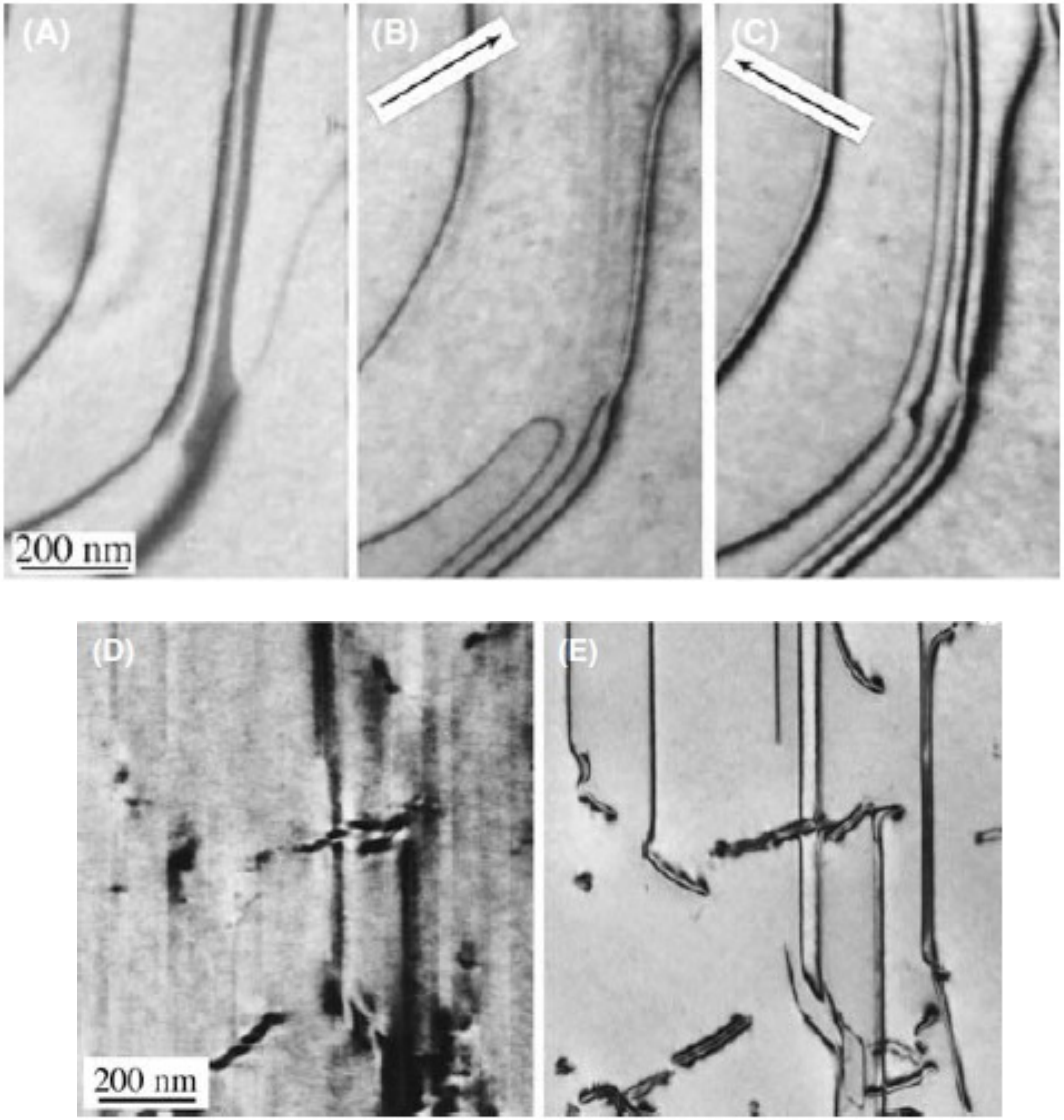




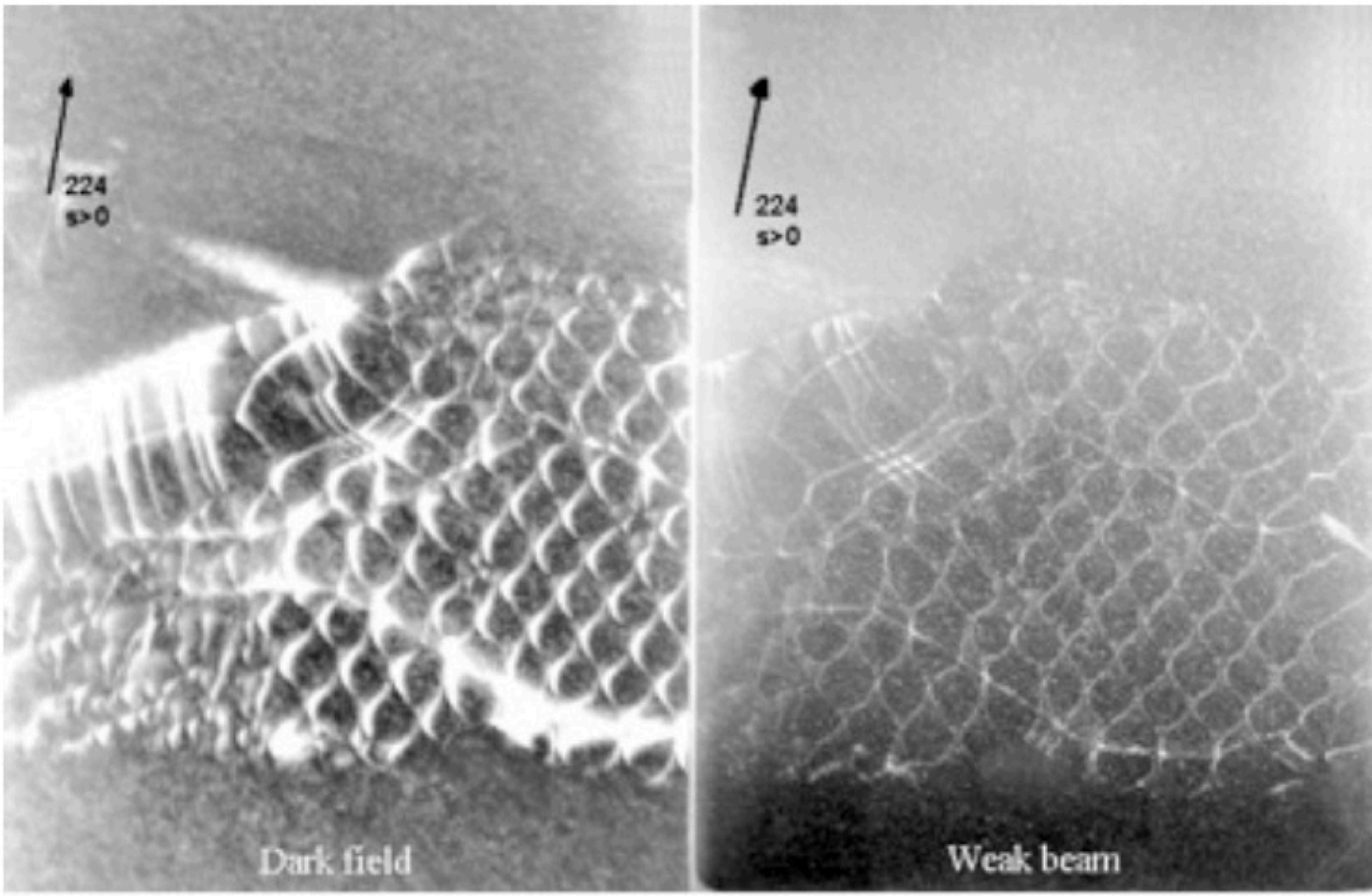
Edge Dislocation
(邊刃差排)

g-R 引起的方向變化

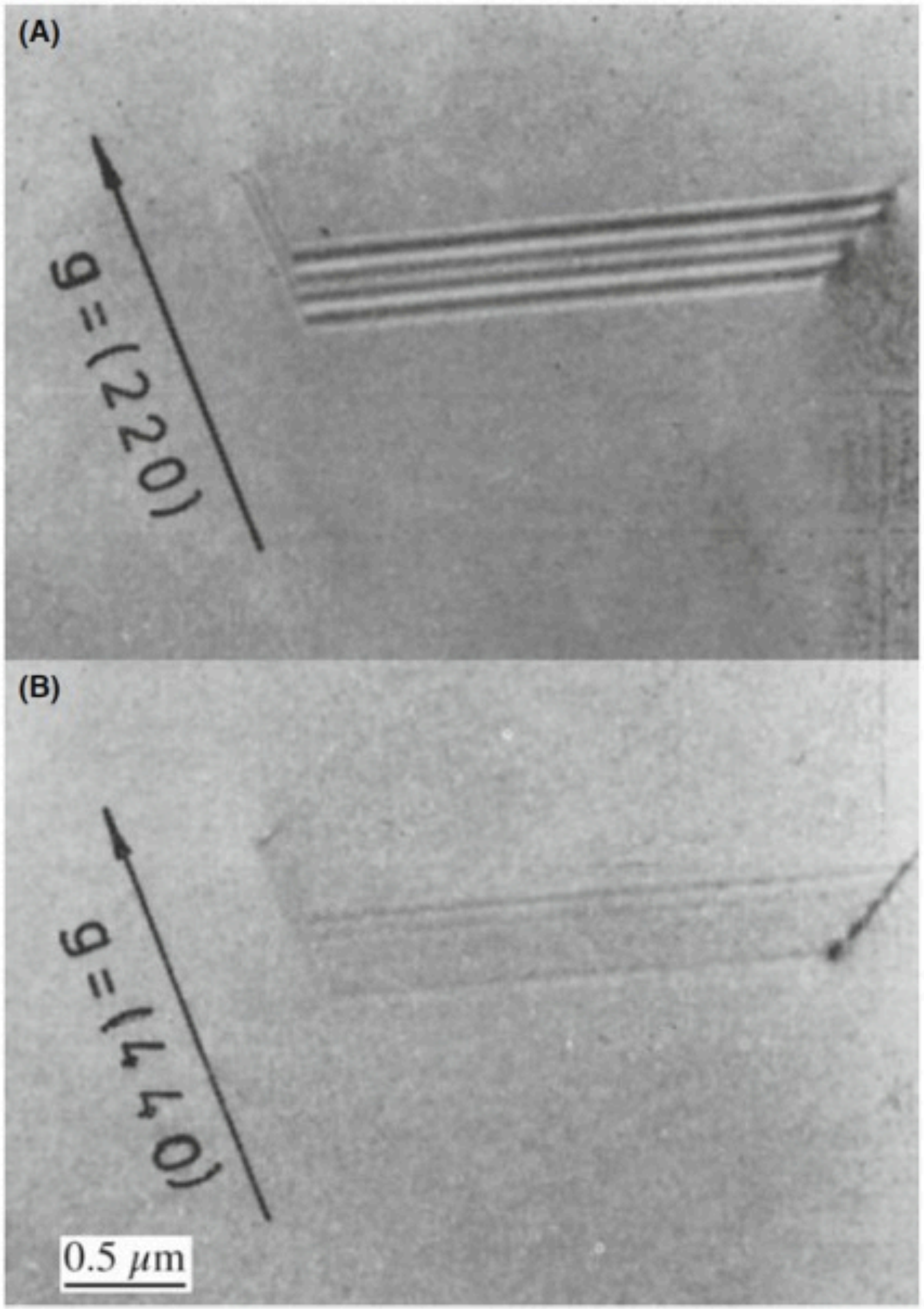
$$R = \frac{1}{2\pi}[\underline{b}\frac{Sin2\Phi}{4(1-\nu)} + (b \wedge u)]\{\frac{1-2\nu}{2(1-\nu)}\ln r + \frac{Cos2\Phi}{4(1-\nu)}\}$$

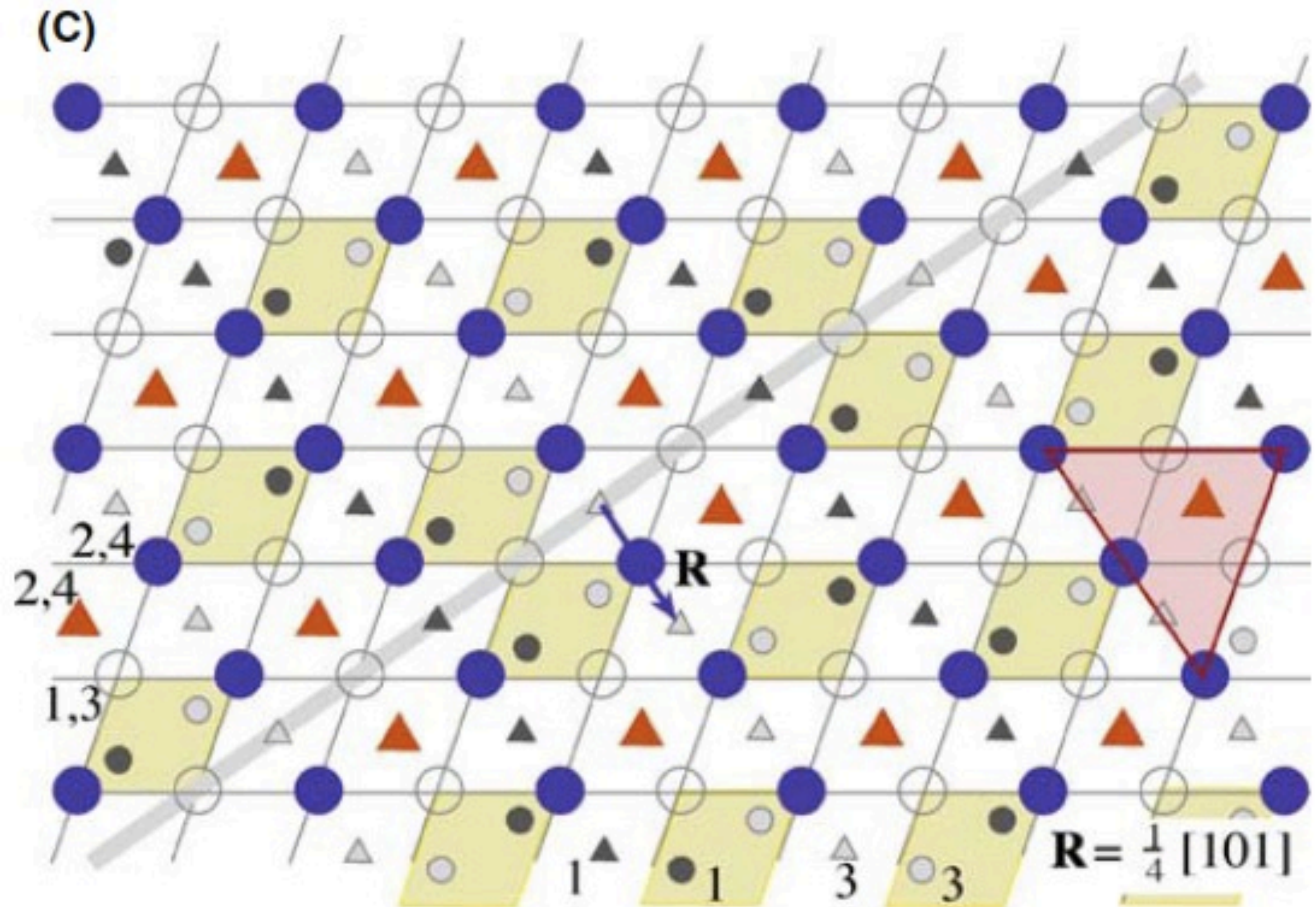

(A)
(B)
(C)
200 nm
(D)
(E)
200 nm

Dark field and Weak beam

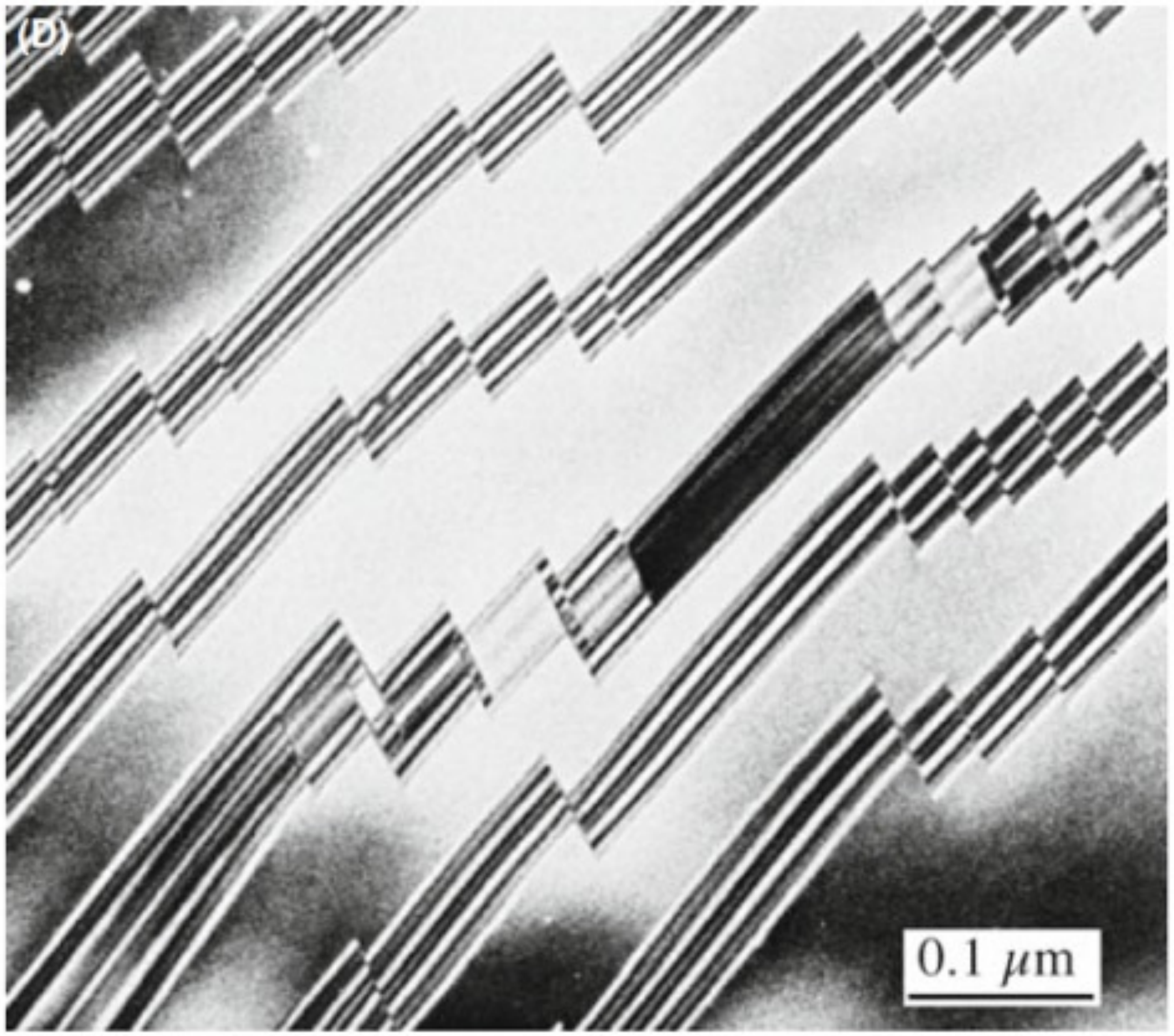


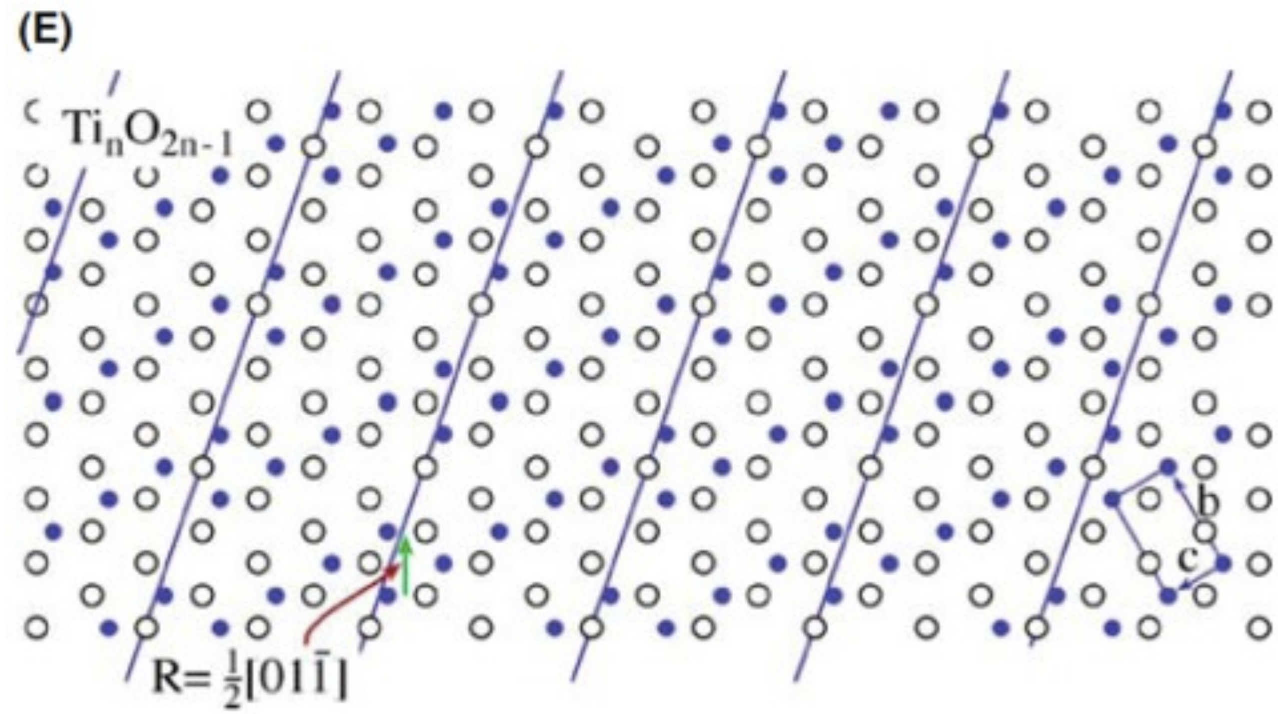
APBs in TiO_2



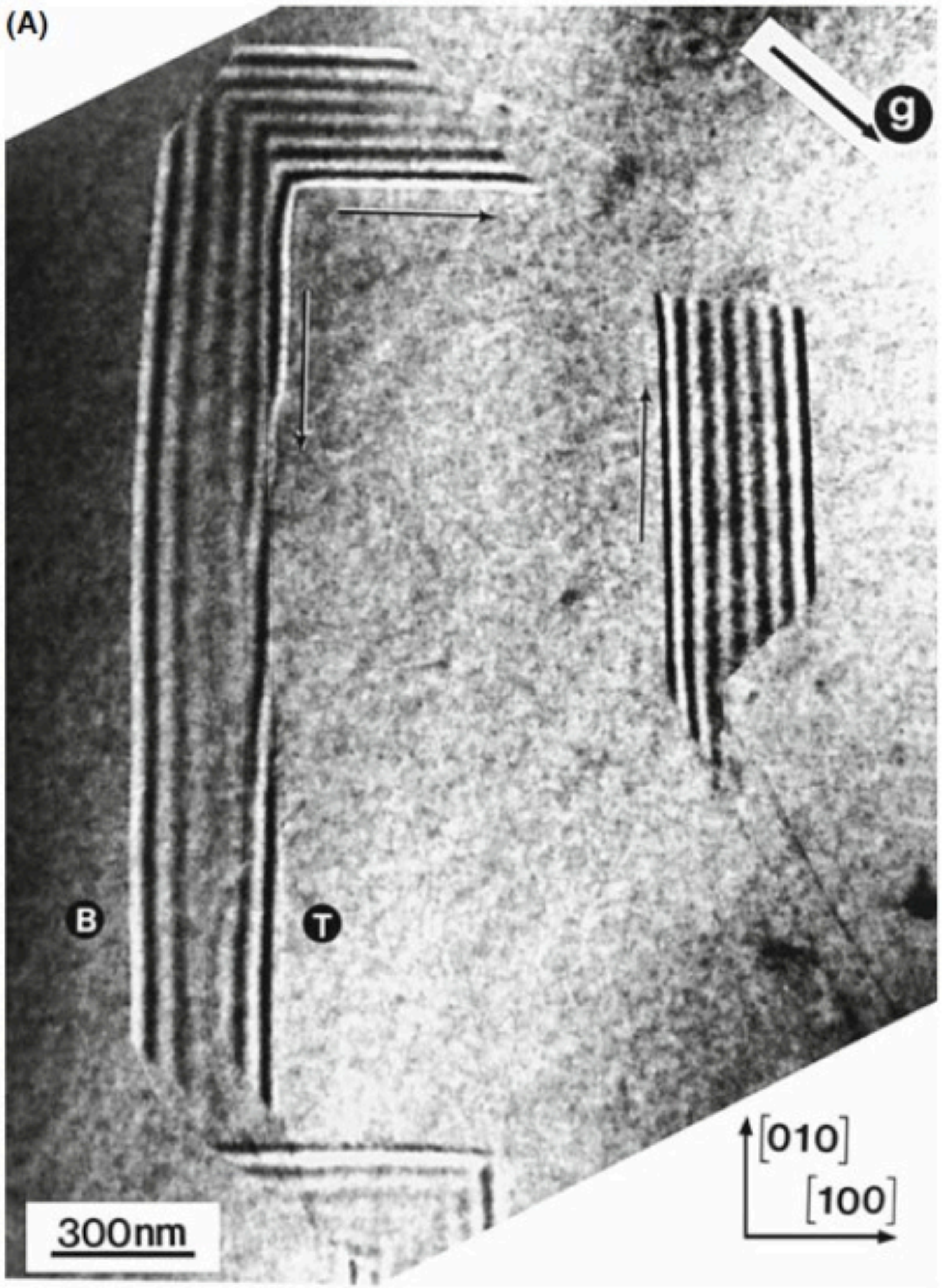


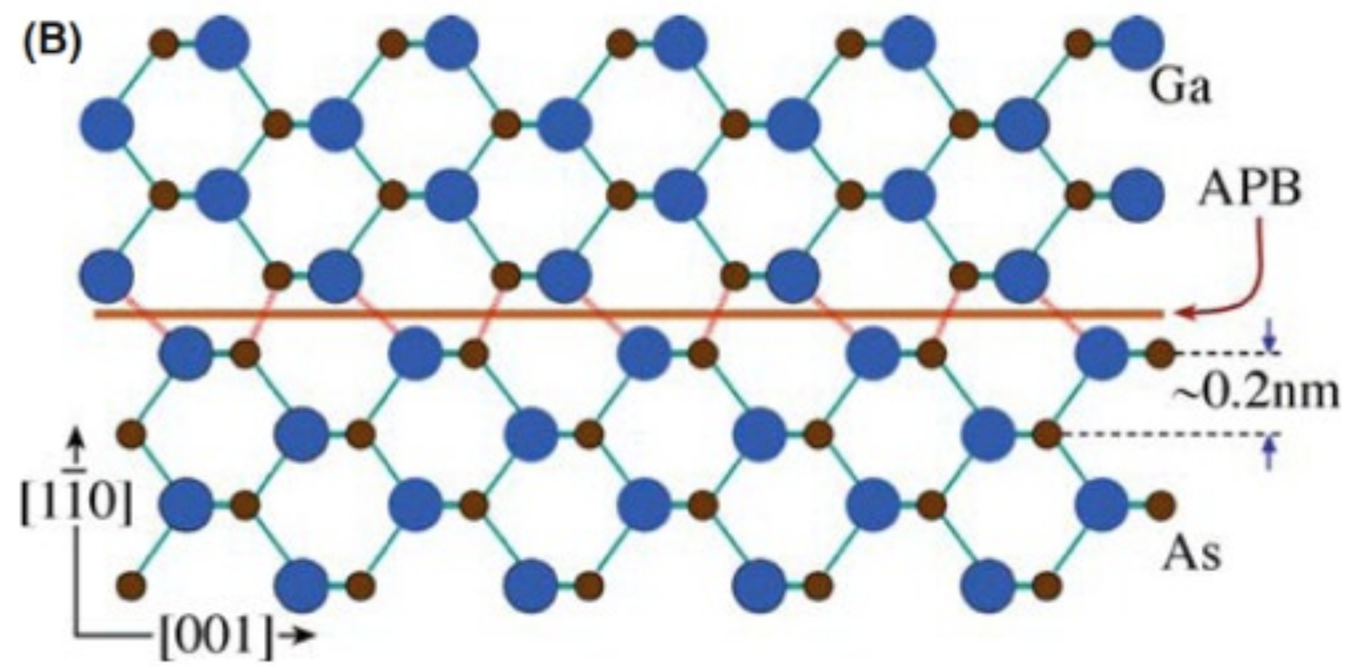
APBs in TiO_2



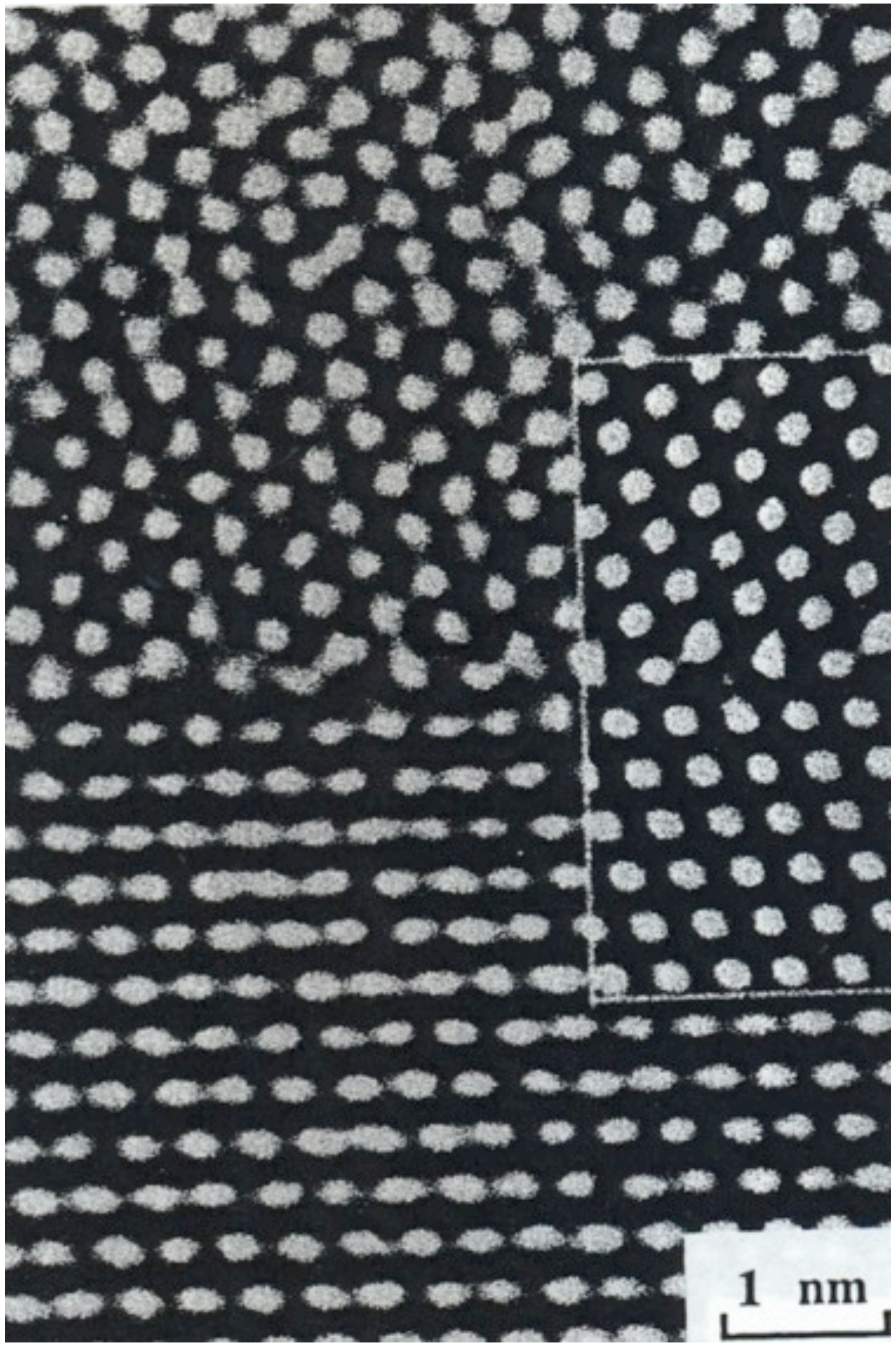


APB (or IDB) of GaAs



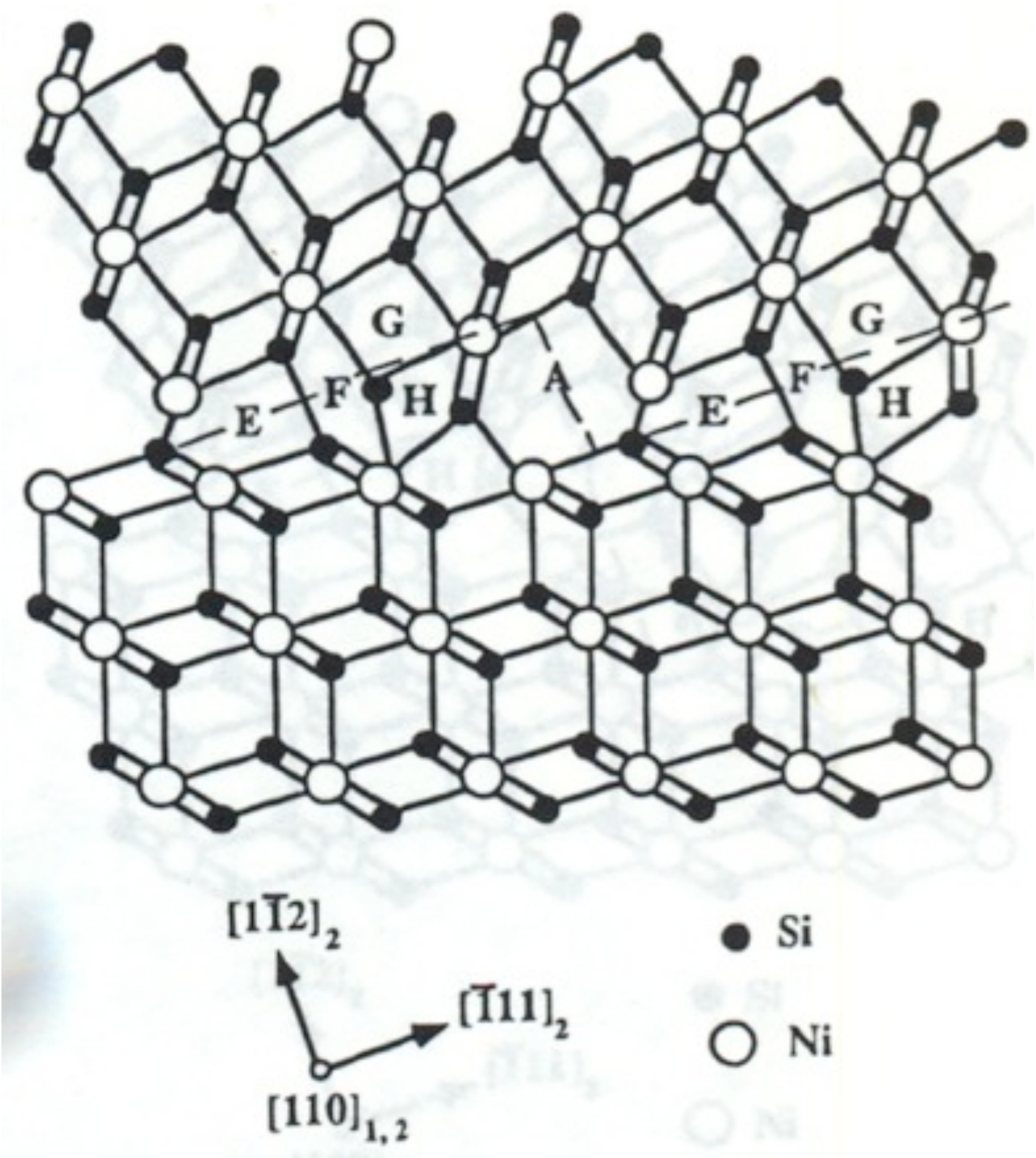


Example: $NiSi_2$ {115}/{111} Twin Boundary



{115}

{111}



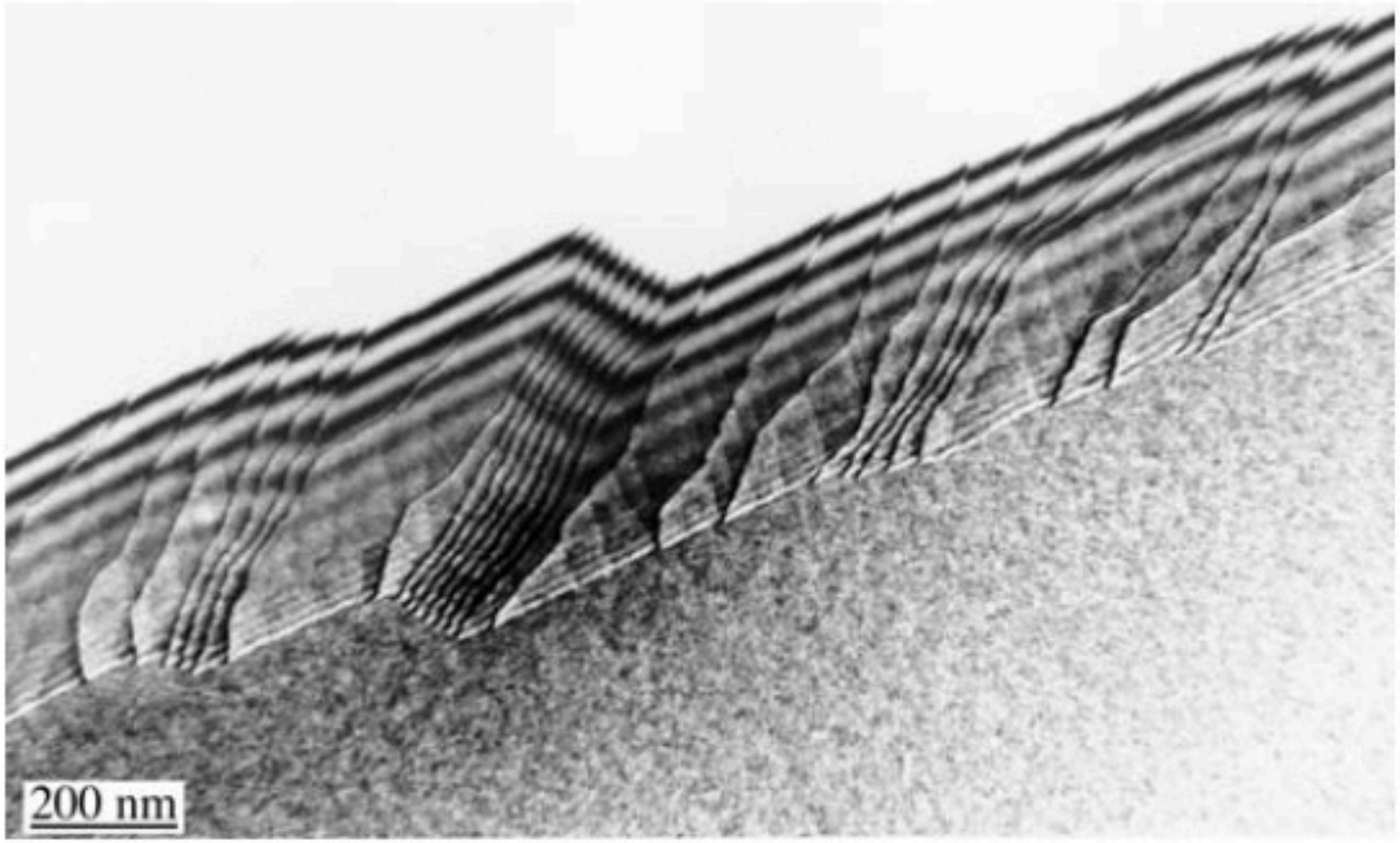
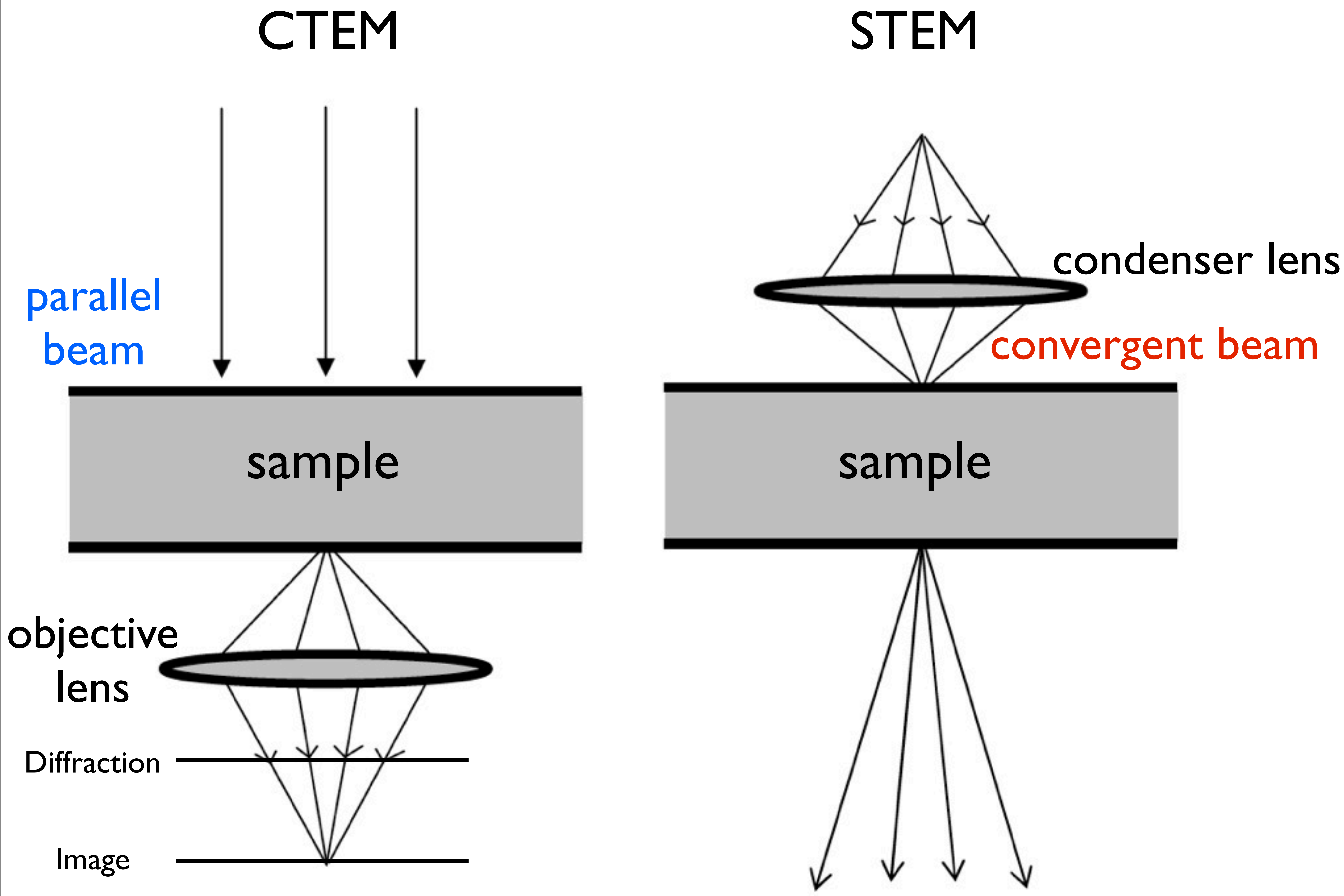
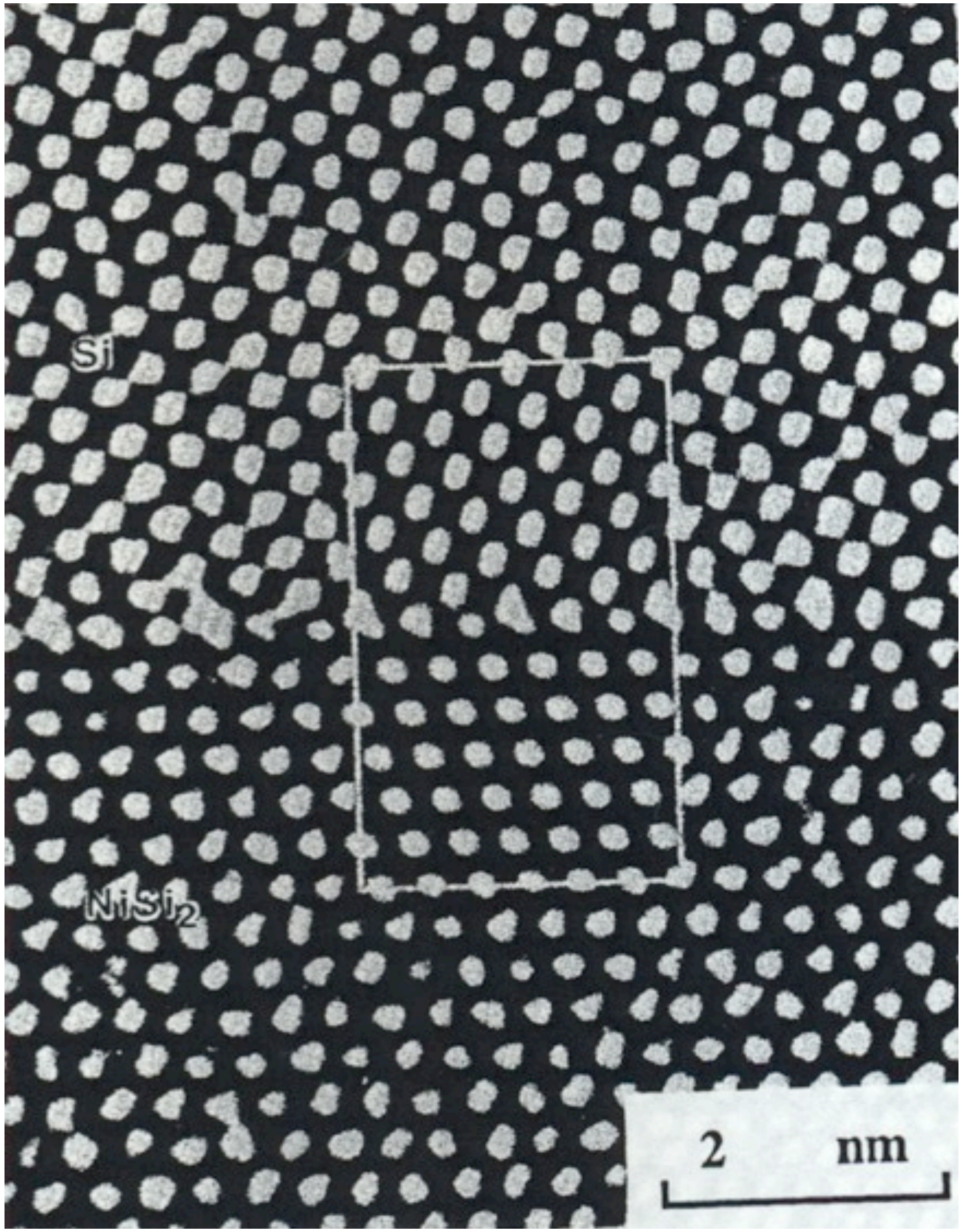


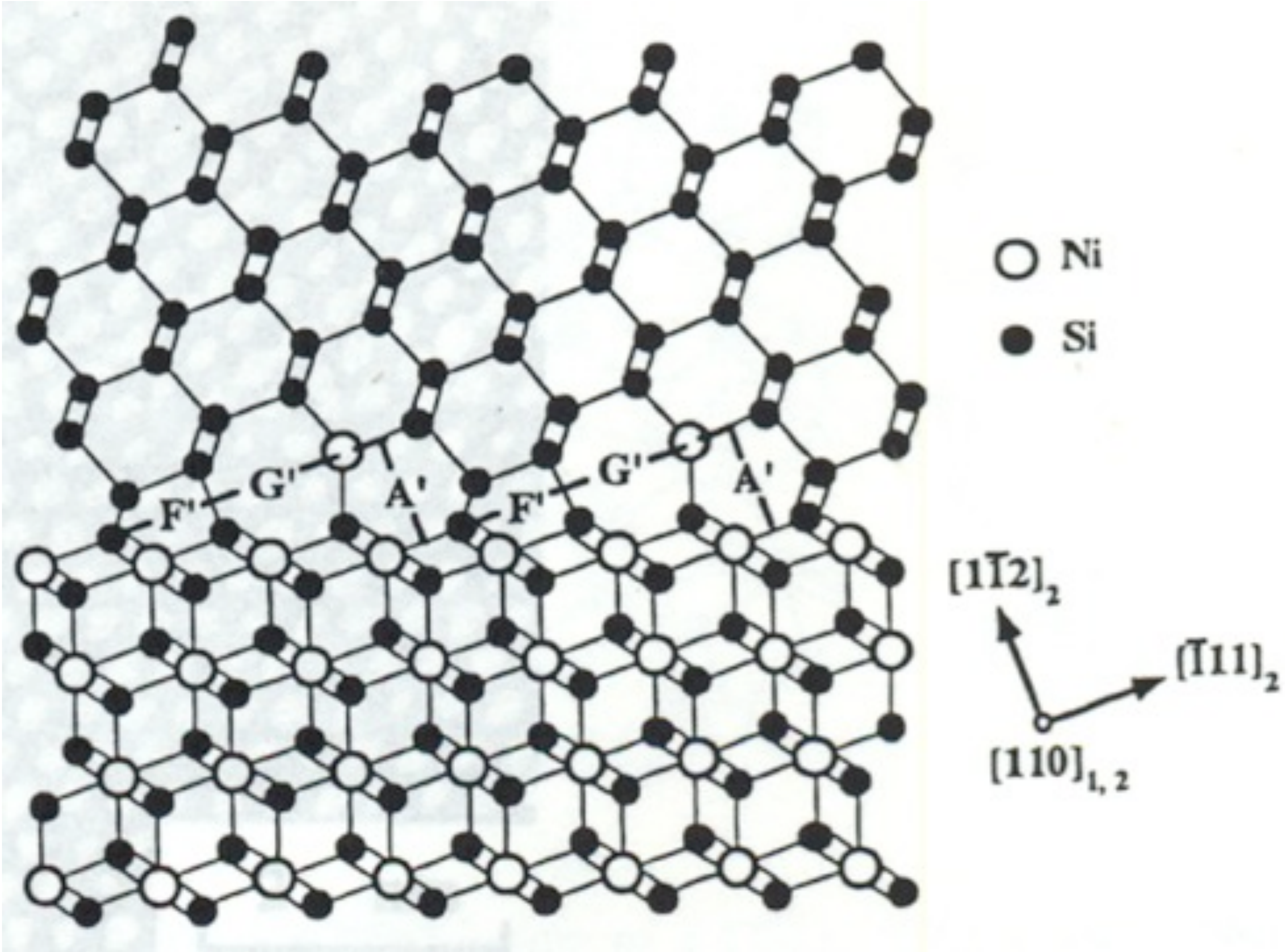
FIGURE 26.21. Steps at interfaces may also cause diffraction contrast when associated with strain. In this Ge specimen, the steps displace the thickness fringes in the GB so they are readily visible. The fringe spacing is different at the top and bottom of the boundary because the diffraction conditions are different at each grain.

Geometry of CTEM and STEM

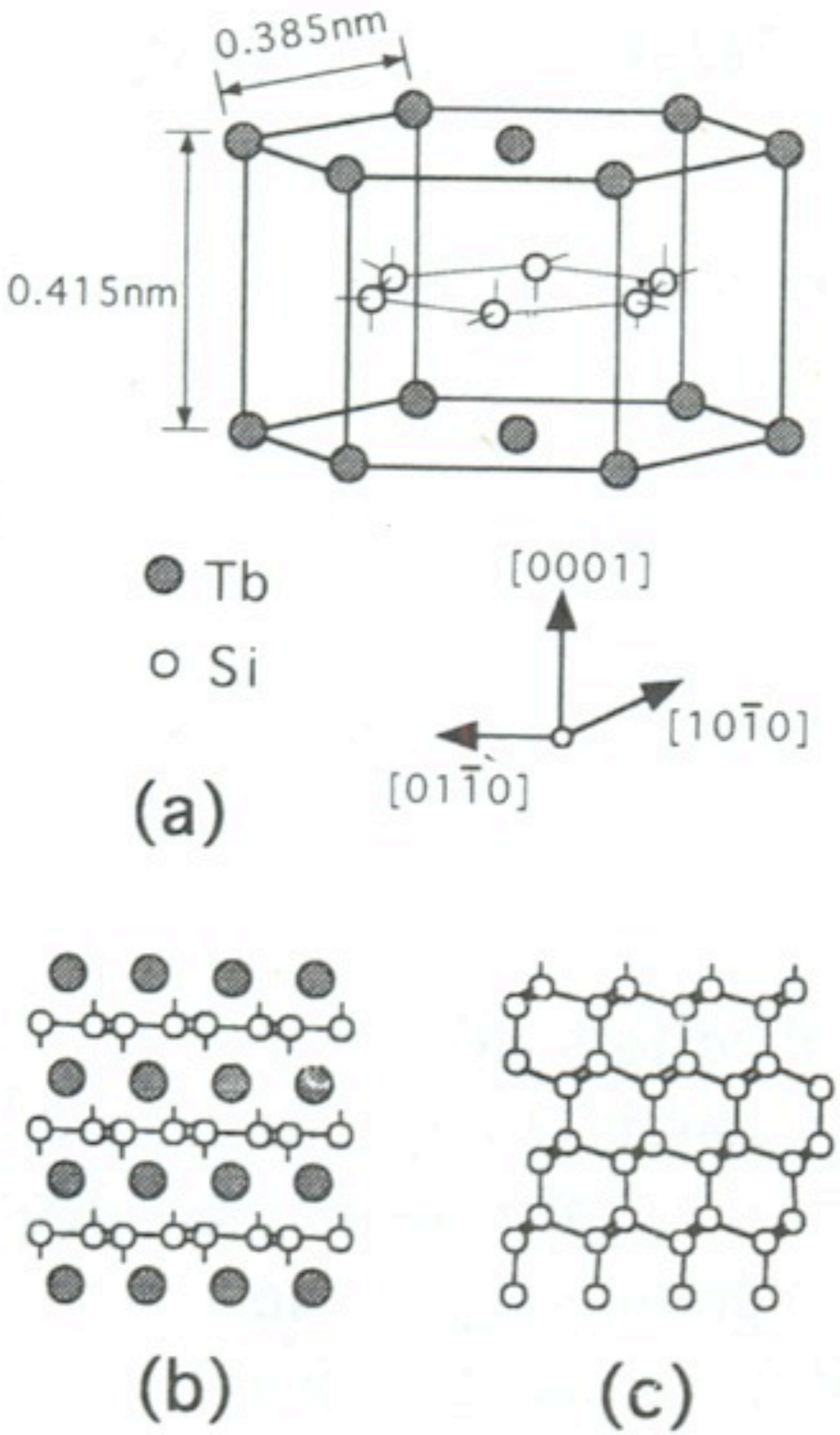


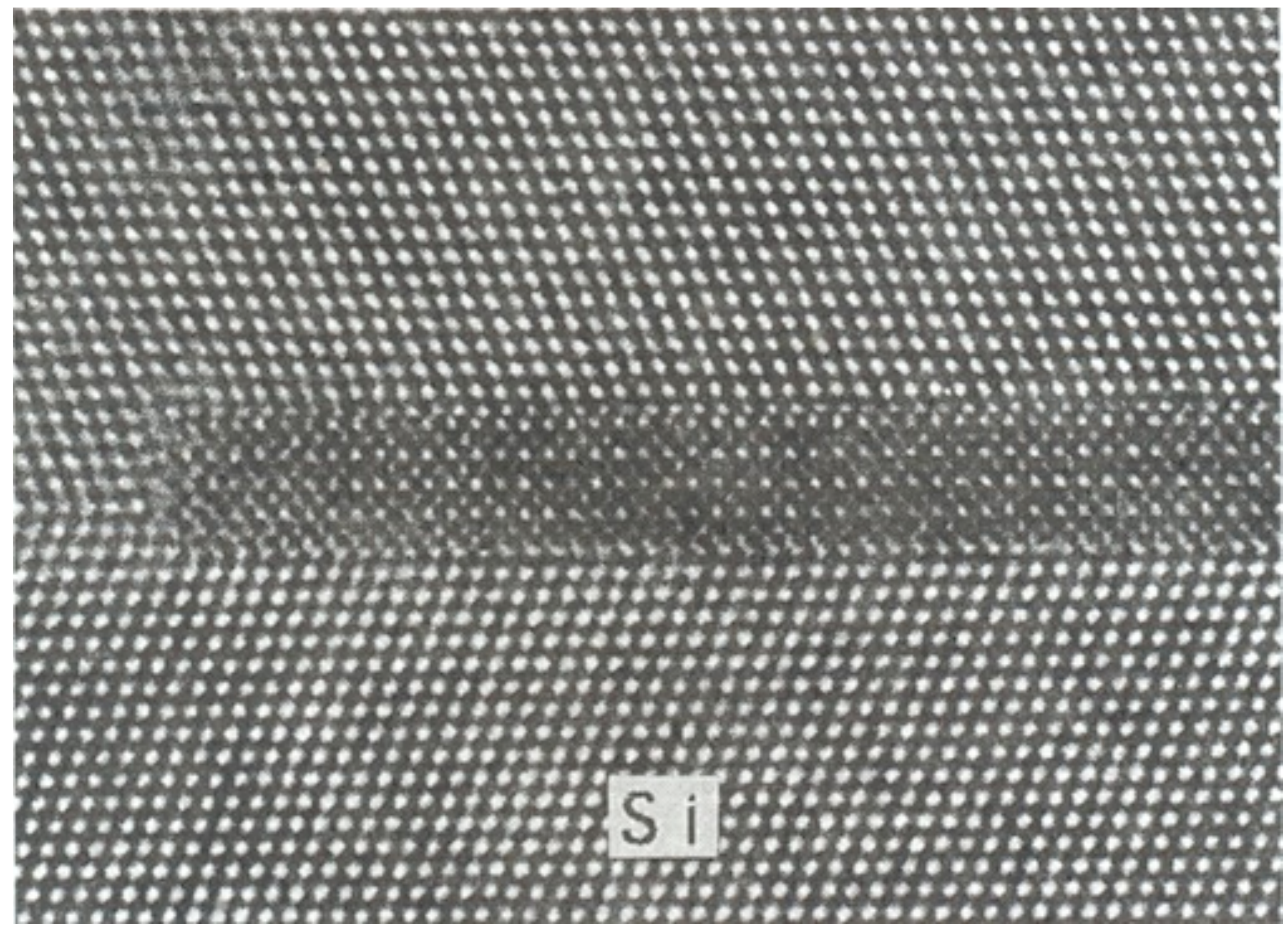
Example: Si{115}/ $NiSi_2$ {111} Twin Boundary



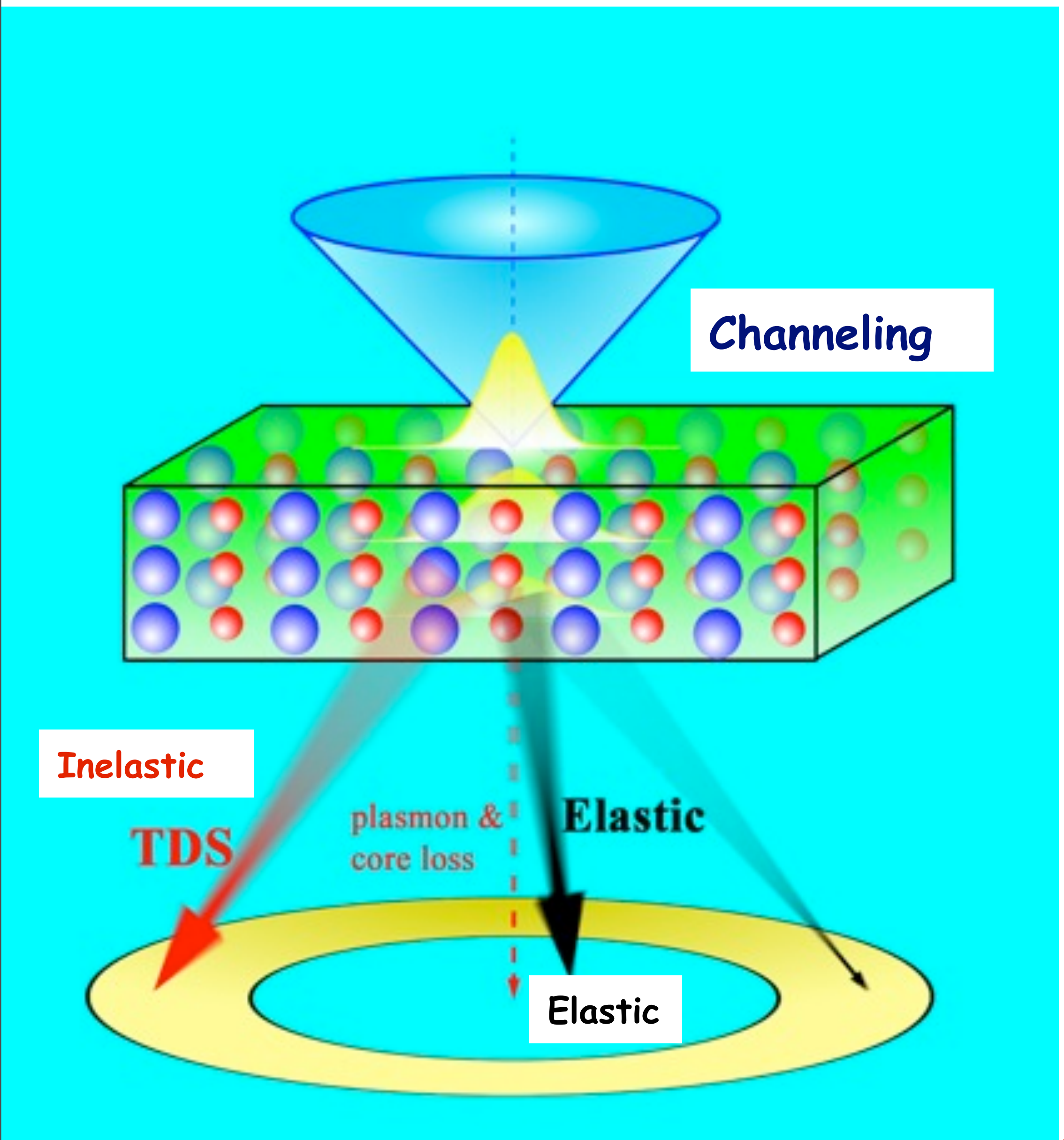


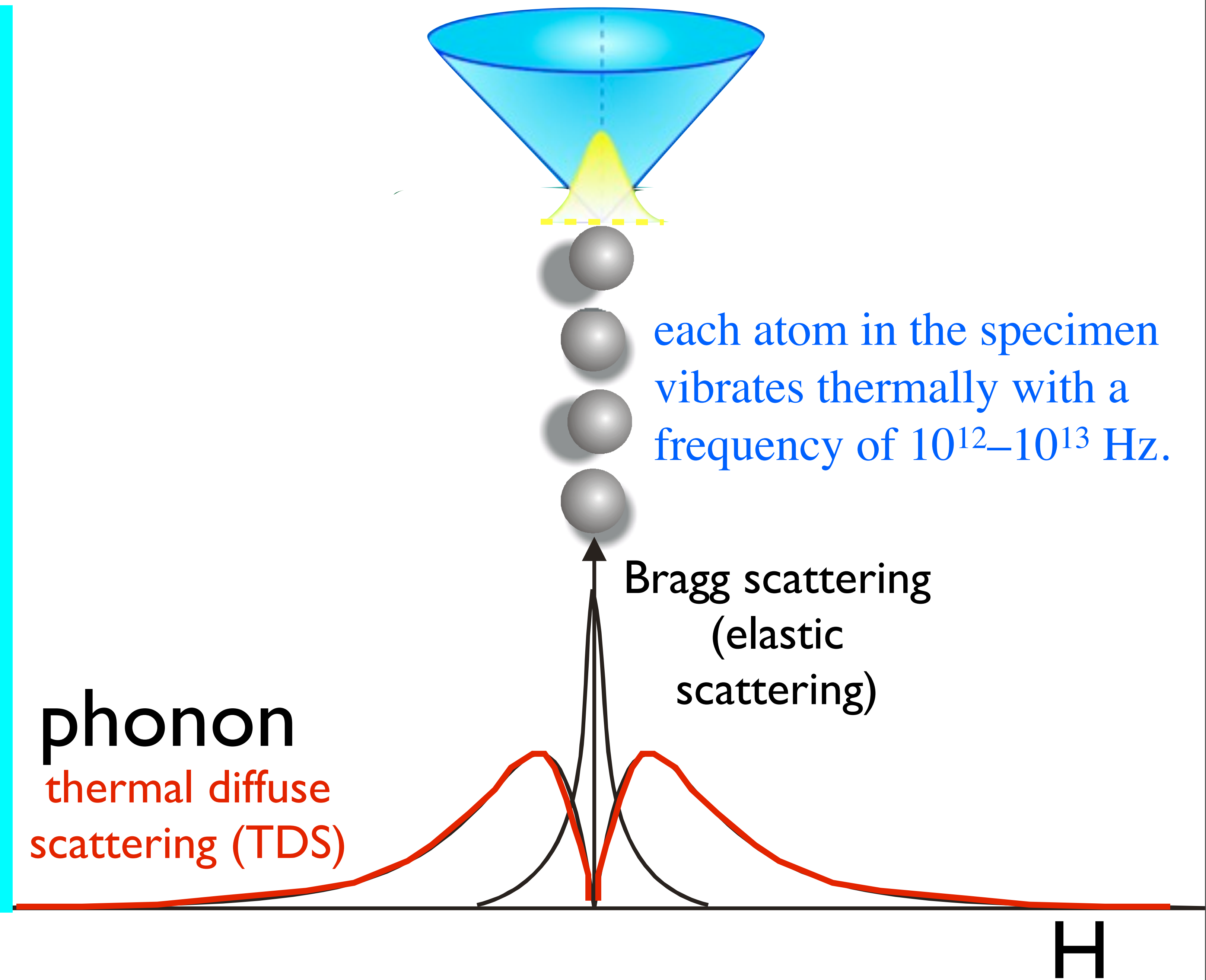
Example: $TbSi_2$/ Si Interface





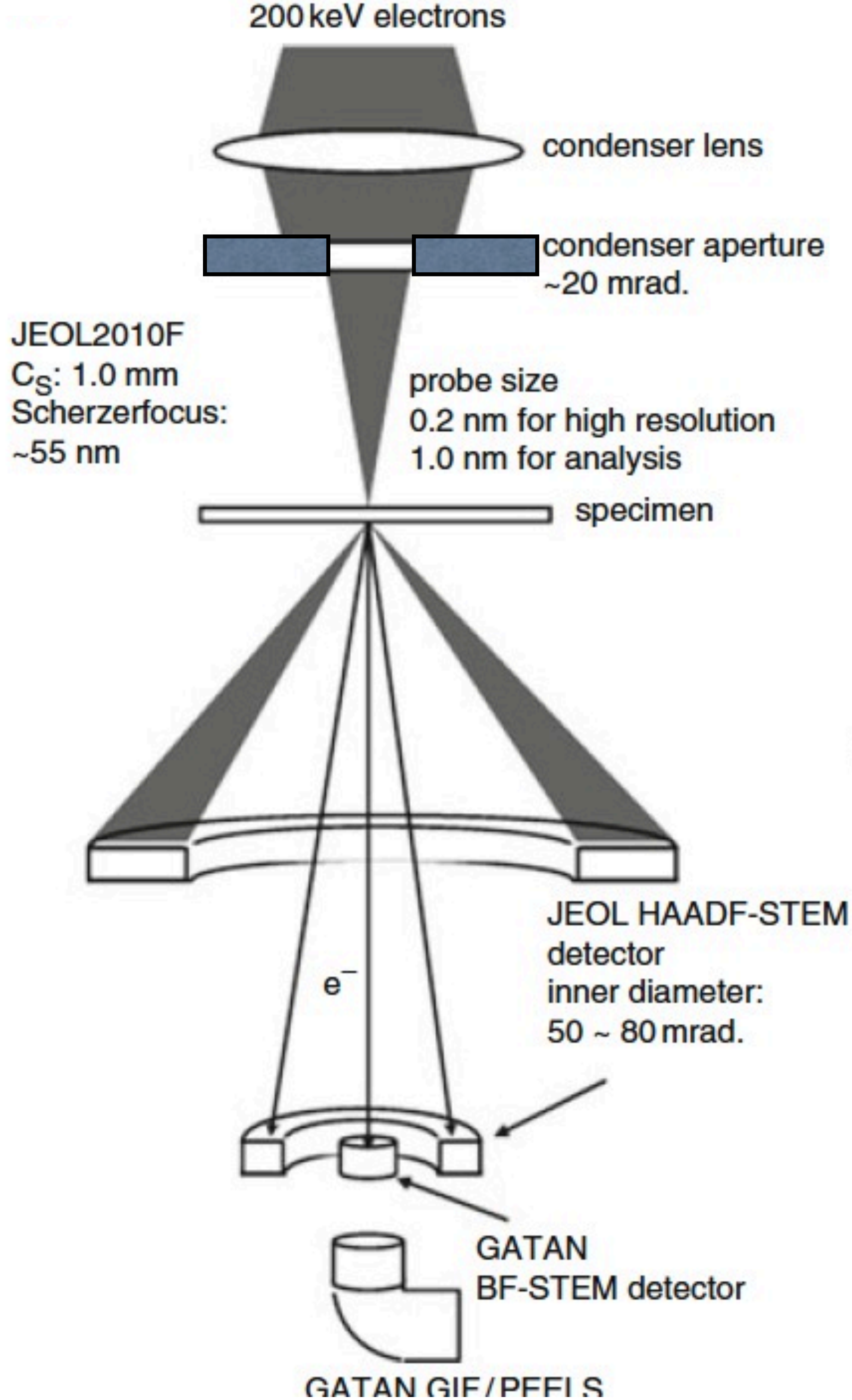
thermal diffuse scattering (TDS)

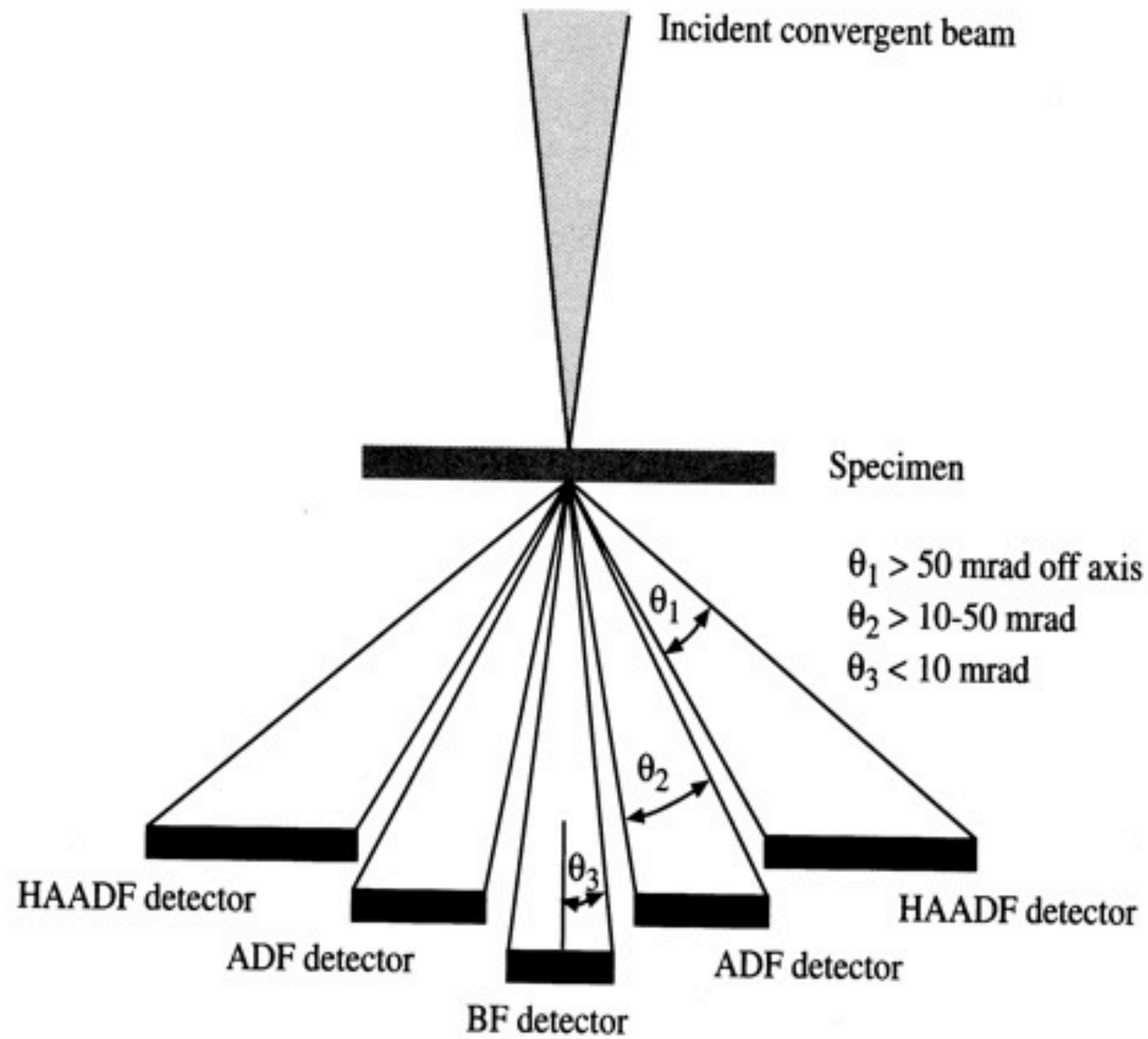




Thermal diffuse scattering (TDS), which is a signal used to form the image in HAADF-STEM and which was previously considered as “background intensity,” became a powerful source of information by using an HAADF detector.

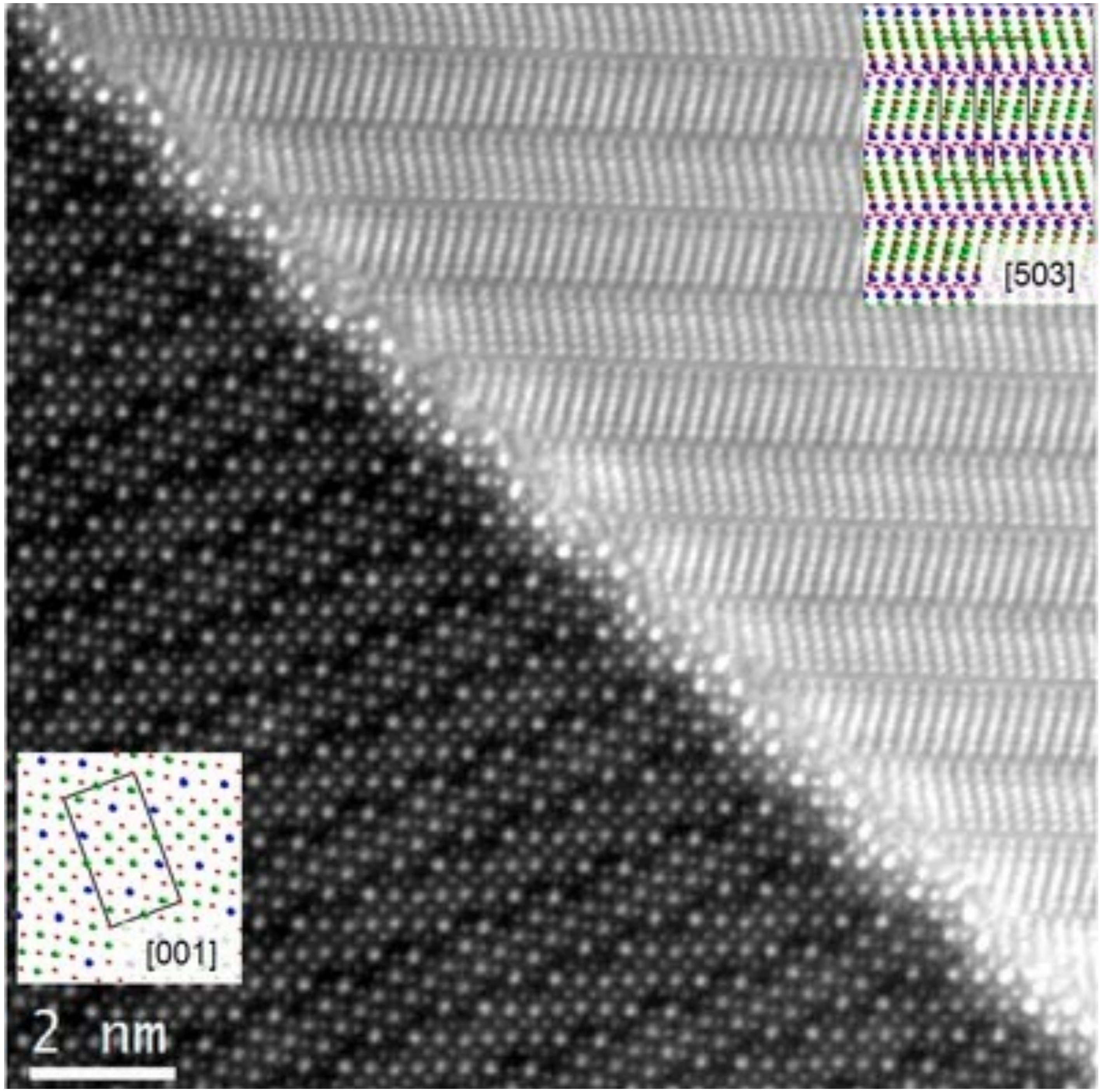
HAADF- STEM (High Angle Annual Dark Field)

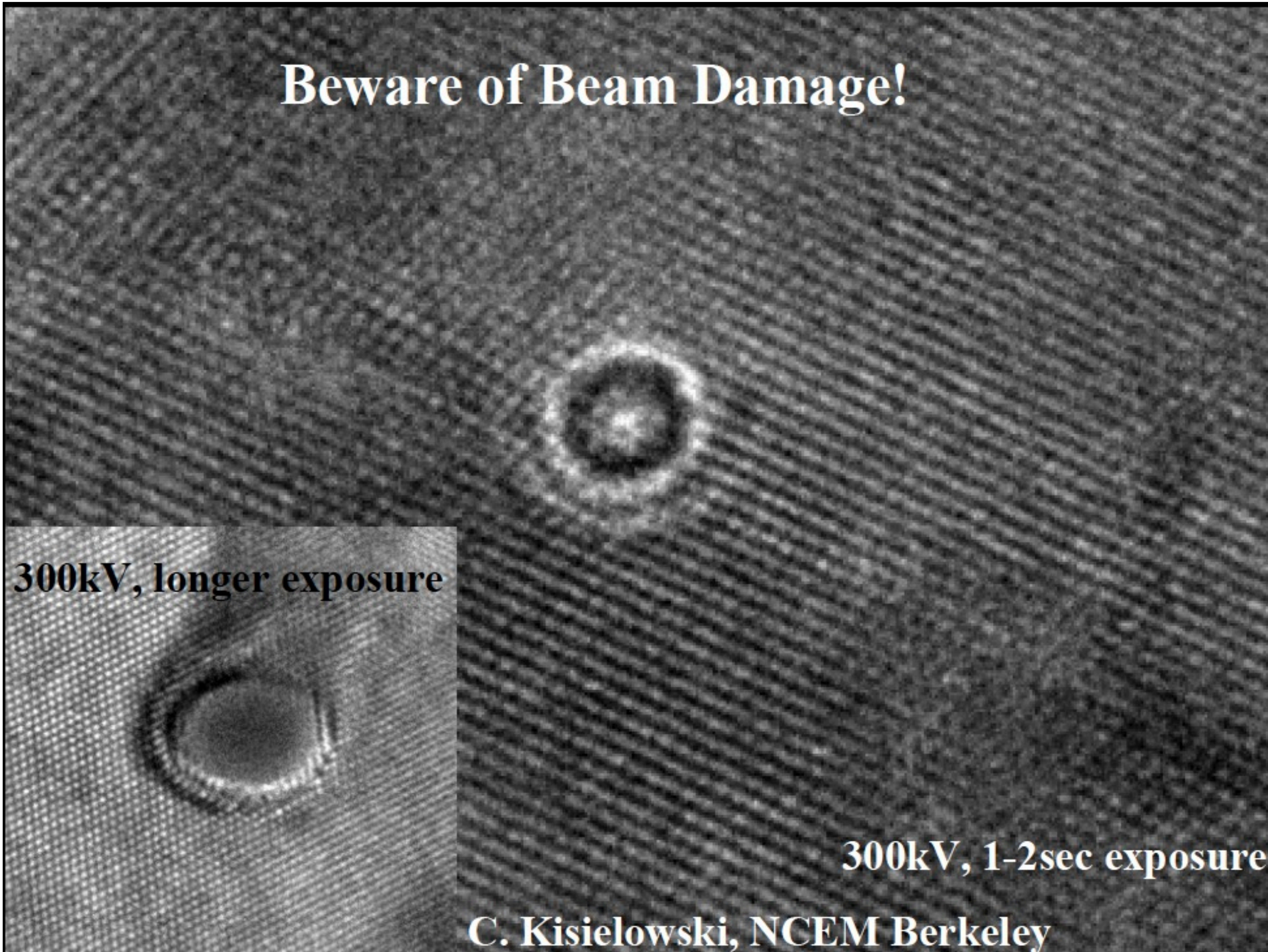




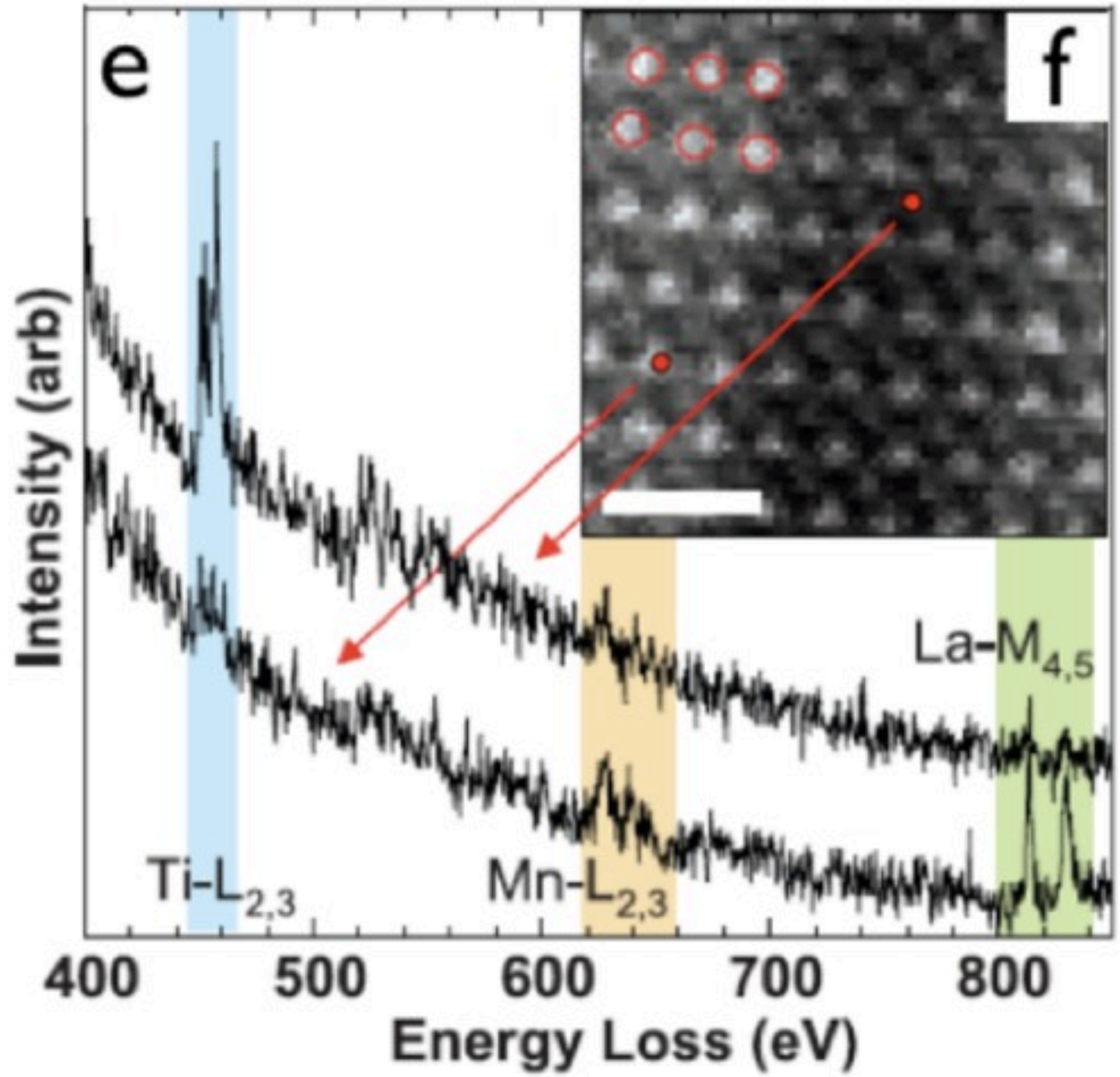
Examples of STEM images

MAADF image of grain boundary in $Ba_{6-3x}Nd_{8+2x}Ti_{18}O_{54}$ (BNT)




Beware of Beam Damage!
300kV, longer exposure
300kV, 1-2sec exposure
C. Kisielowski, NCEM Berkeley

Atomic resolution of EELS of $La_{0.7}Sr_{0.3}MnO_3/SrTiO_3$ multilayer



- D. A. Muller, et al, SCIENCE **319** 1073-1075 (2008)

8.7 Atomic Resolution Spectrum Imaging

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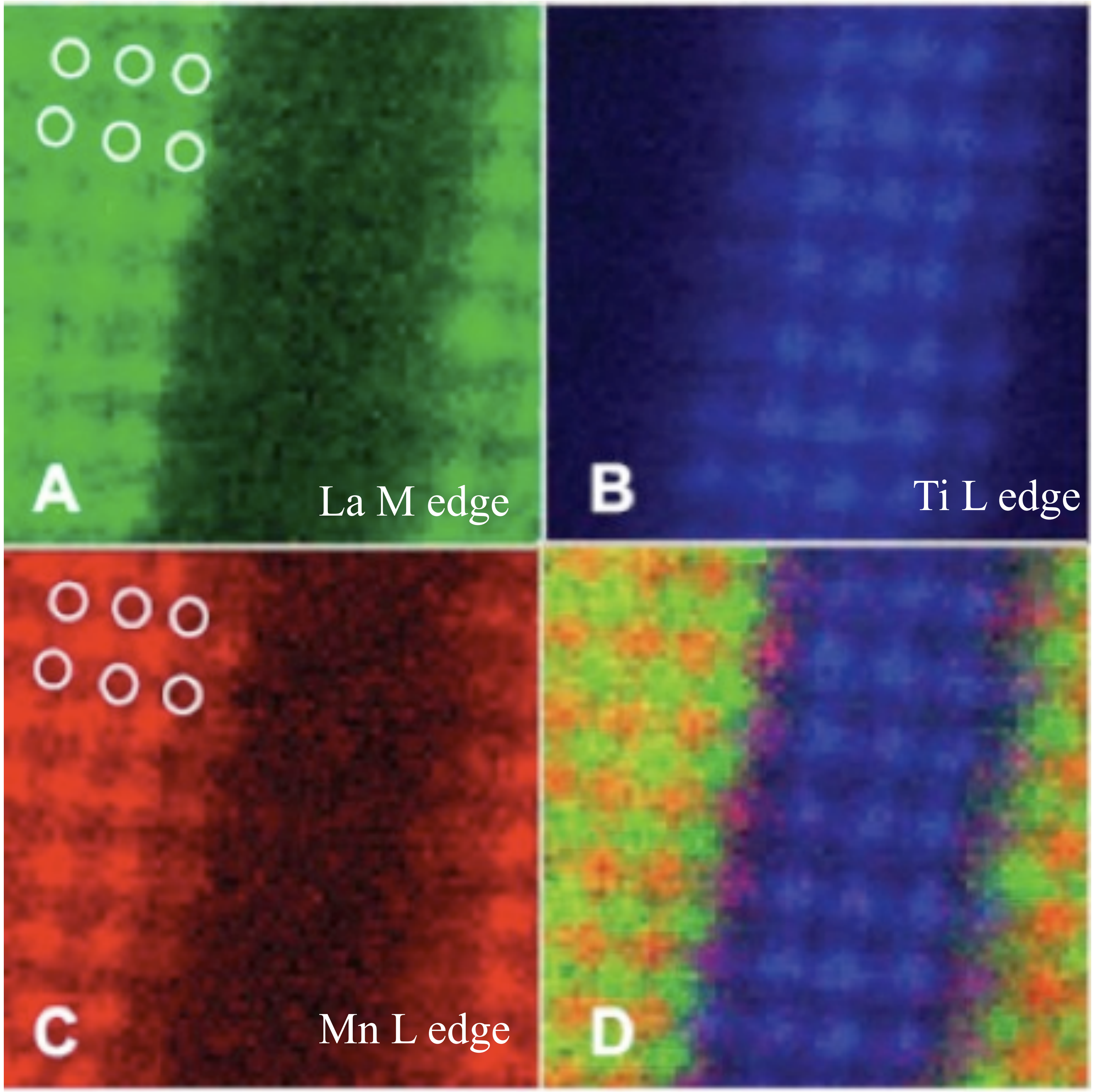

Atomic resolution compositional and bonding maps