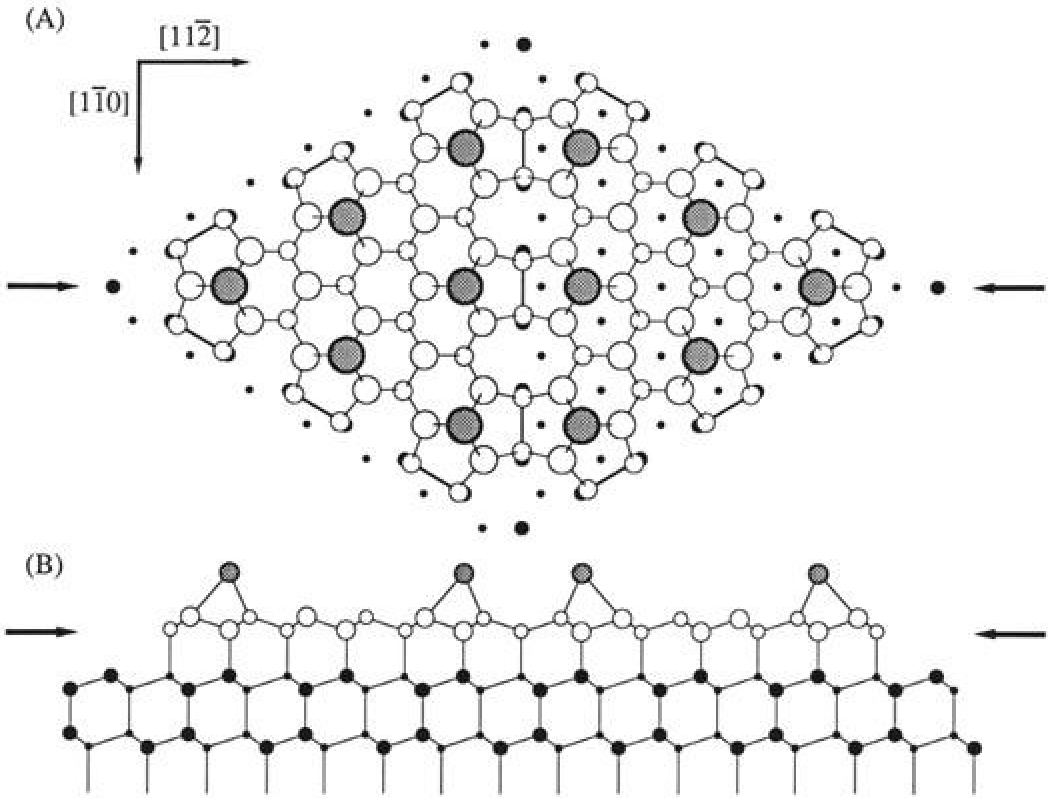
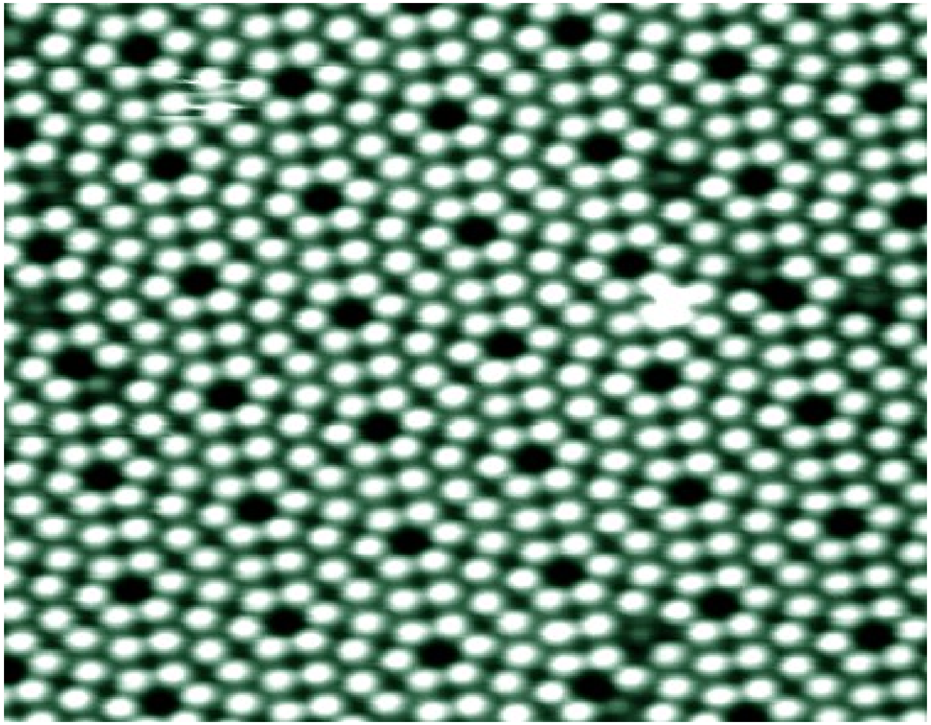
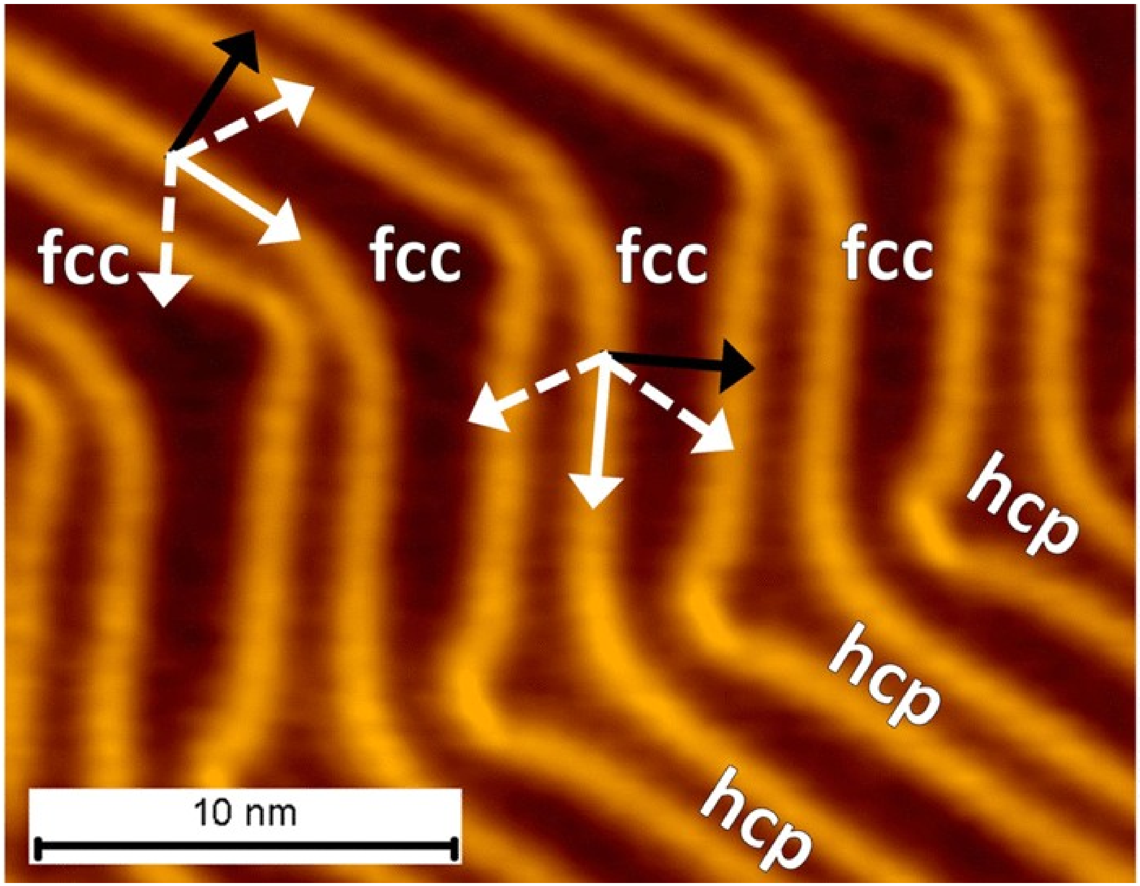
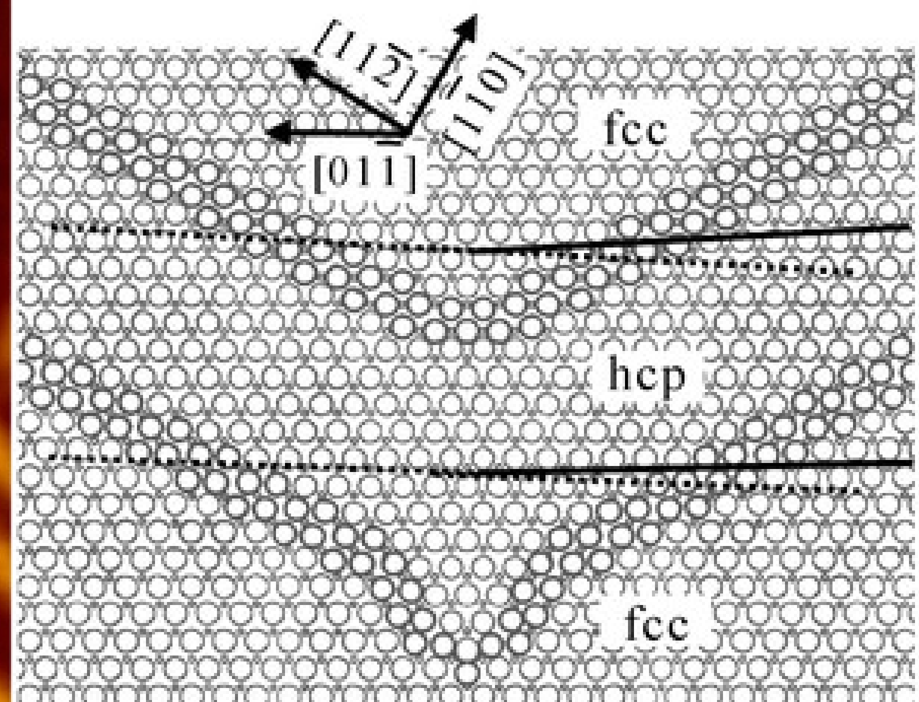
Si(111) 7x7





Au(111) „Herringbone-Reconstrcution“





Geometrische Struktur (von Oberflächen) AKüFi

Streuung *''periodisch''*

LEED, RHEED, SPALEED, SPLEED

HAS oder TEAS

GXRD (Grazing Incidence X-ray Diffraction)

LEIS, MEIS, HEIS

NEXAFS

PED

Abbildung *''beliebig''*

STM AFM

LEEM (Low Energy Electron Microscopy)

FIM (Field Ion Microscopy)

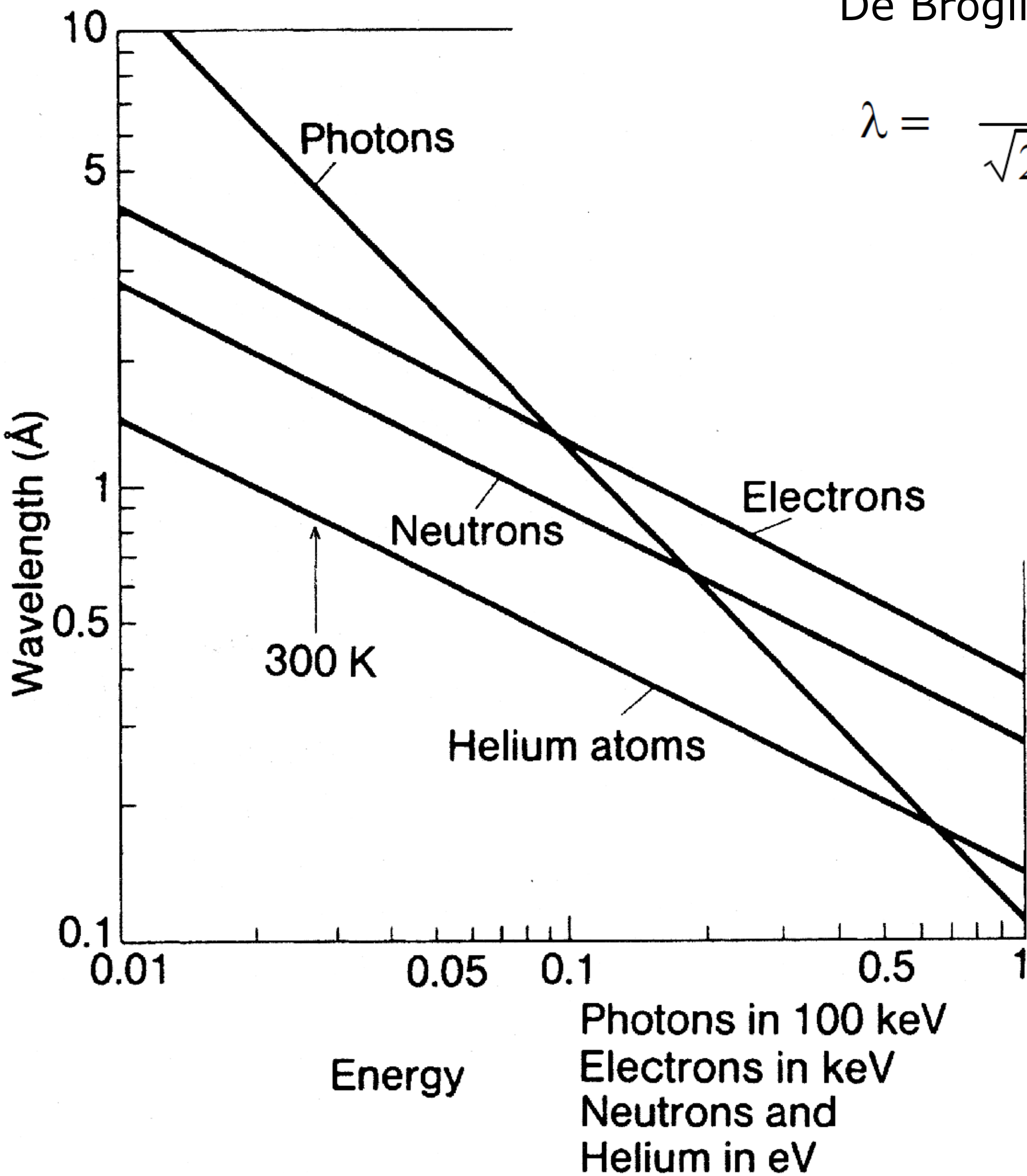
TEM SEM

De Broglie Wellenlänge von Elektronen

$$\lambda = \frac{\hbar}{\sqrt{2mE}} = \sqrt{\frac{150.4\text{eV}}{E}}\ \text{Å}$$

typ. 0.6 – 3.9 Å

… passt zur Gitterkonstante



Faustformel

(senkrechter Einfall)

sin(α) = 1/a √(150/U)

(a in Å, U in V)

LEED

Second Series *December, 1927* *Vol. 30, No. 6*

THE

PHYSICAL REVIEW

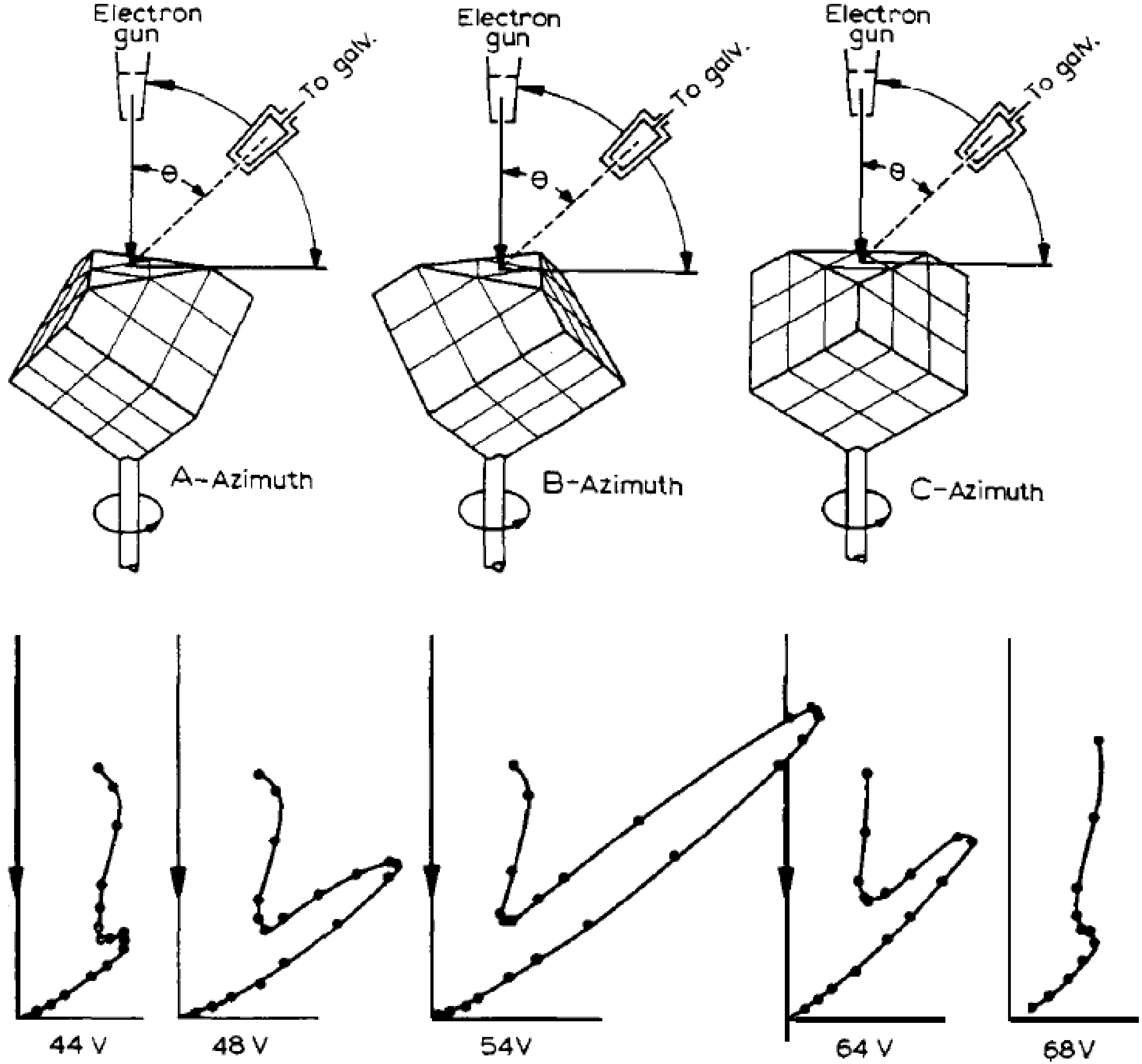
DIFFRACTION OF ELECTRONS BY A CRYSTAL OF NICKEL

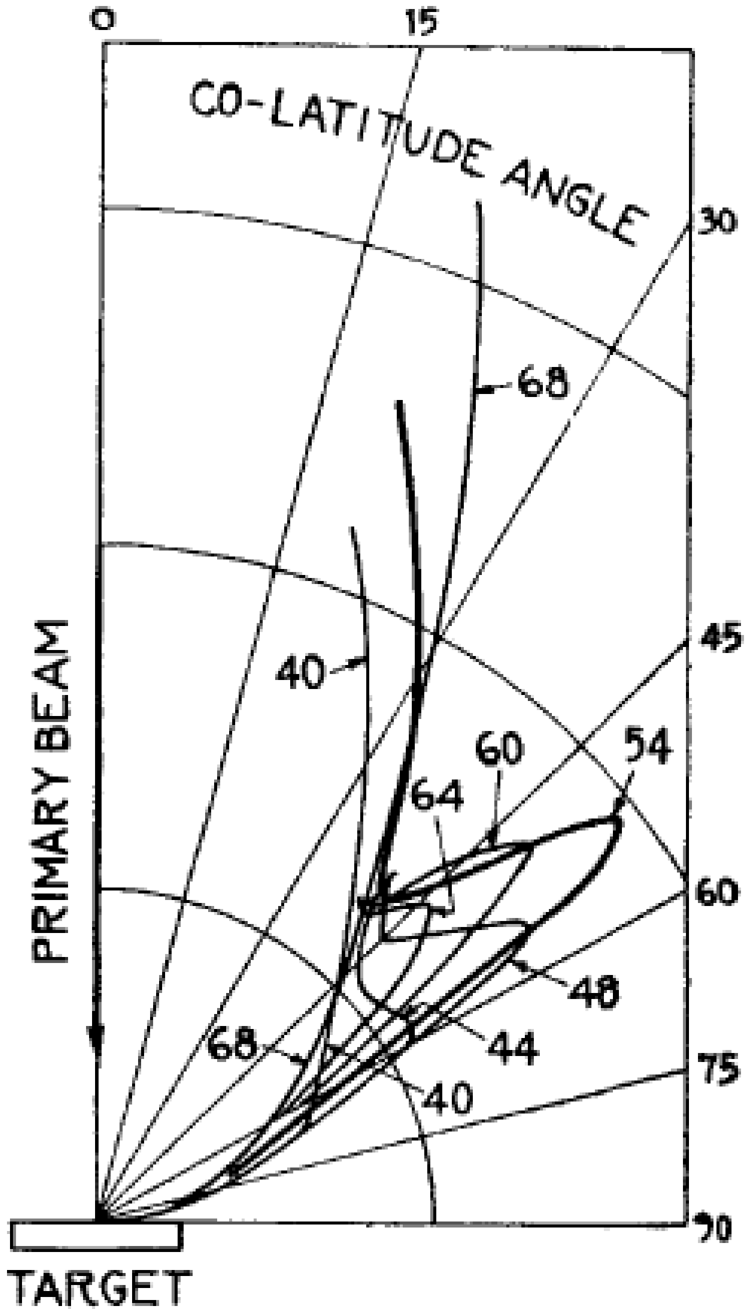
By C. Davisson and L. H. Germer

The most striking characteristic of these beams is a one to one correspondence, presently to be described, which the strongest of them bear to the Laue beams that would be found issuing from the same crystal if the incident beam were a beam of x-rays. Certain others appear to be analogues, not of Laue beams, but of optical diffraction beams from plane reflection gratings—the lines of these gratings being lines or rows of atoms in the surface of the crystal. Because of these similarities between the scattering of electrons by the crystal and the scattering of waves by three- and two-dimensional gratings a description of the occurrence and behavior of the electron diffraction beams in terms of the scattering of an equivalent wave radiation by the atoms of the crystal, and its subsequent interference, is not only possible, but most simple and natural. This involves the association of a wave-length with the incident electron beam, and this wave-length turns out to be in acceptable agreement with the value h/mv of the undulatory mechanics, Planck's action constant divided by the momentum of the electron.

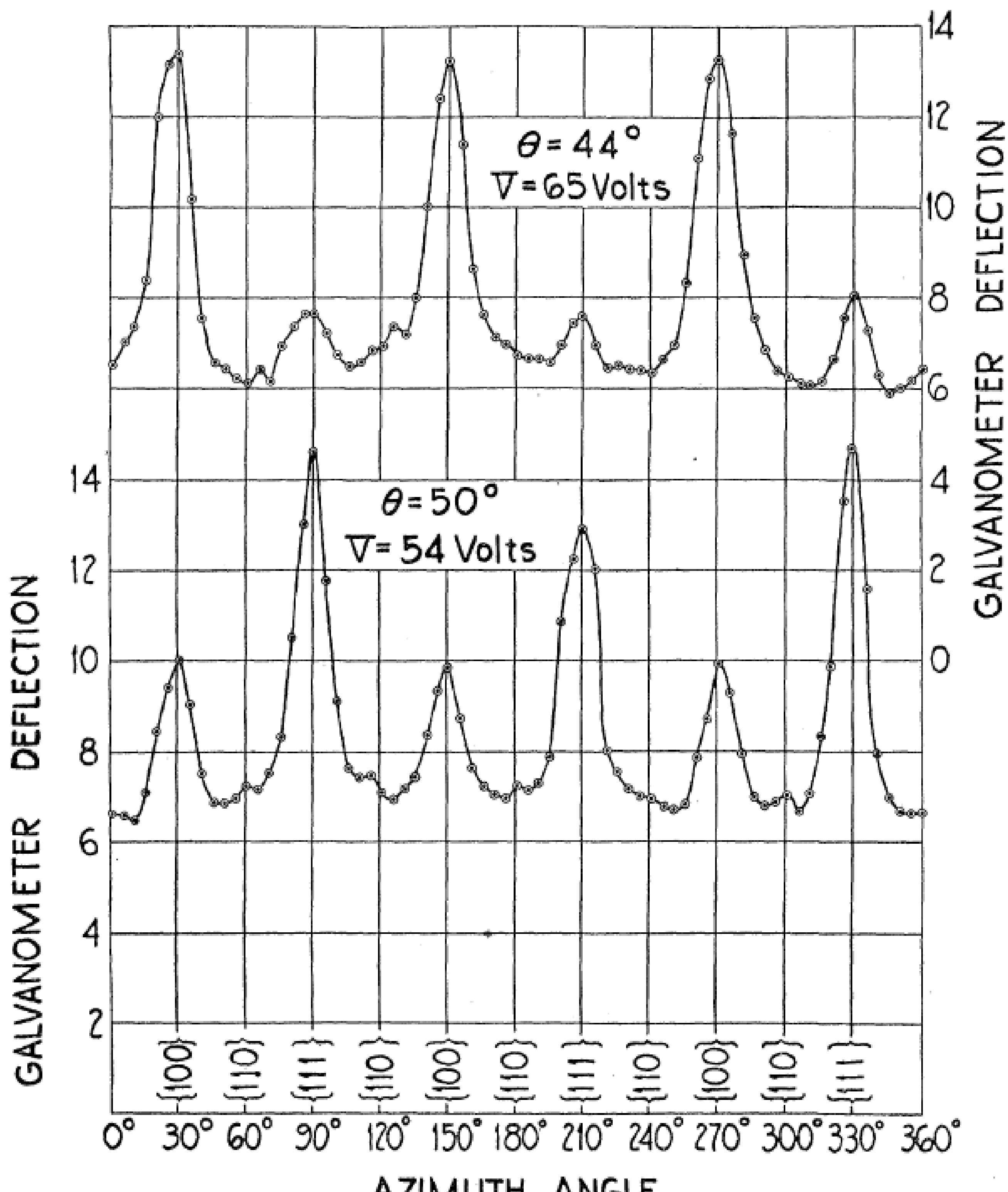
Elektronenbeugung

Germer & Davisson 1927





C. Davisson, L. H. Germer, Nature **119**, 558 (1927).



θ=44°
V=65 Volts
θ=50°
V=54 Volts
GALVANOMETER DEFLECTION
GALVANOMETER DEFLECTION
14
12
10
8
6
4
2
0
{100}
{110}
{111}
{110}
{100}
{110}
{111}
{110}
{100}
{110}
{111}
0° 30° 60° 90° 120° 150° 180° 210° 240° 270° 300° 330° 360°
AZIMUTH ANGLE

Electron attenuation length

$I(r) = I_0 \exp(-r/\lambda)$

λ depends on

elastic scattering

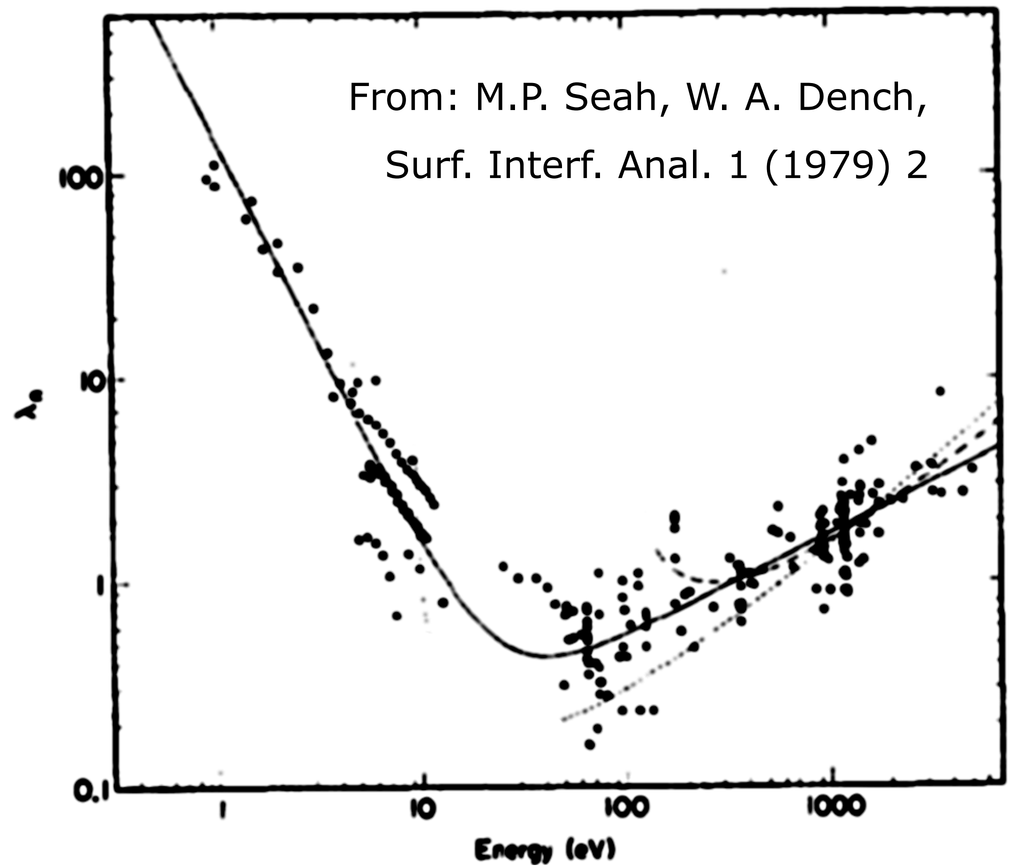
inelastic scattering *(shown)*

mass density

+ low-energy electrons are VERY surface sensitive

- intense interaction begs for multiple scattering model

Compilation for elements of IMFP measurements (a) in nanometres



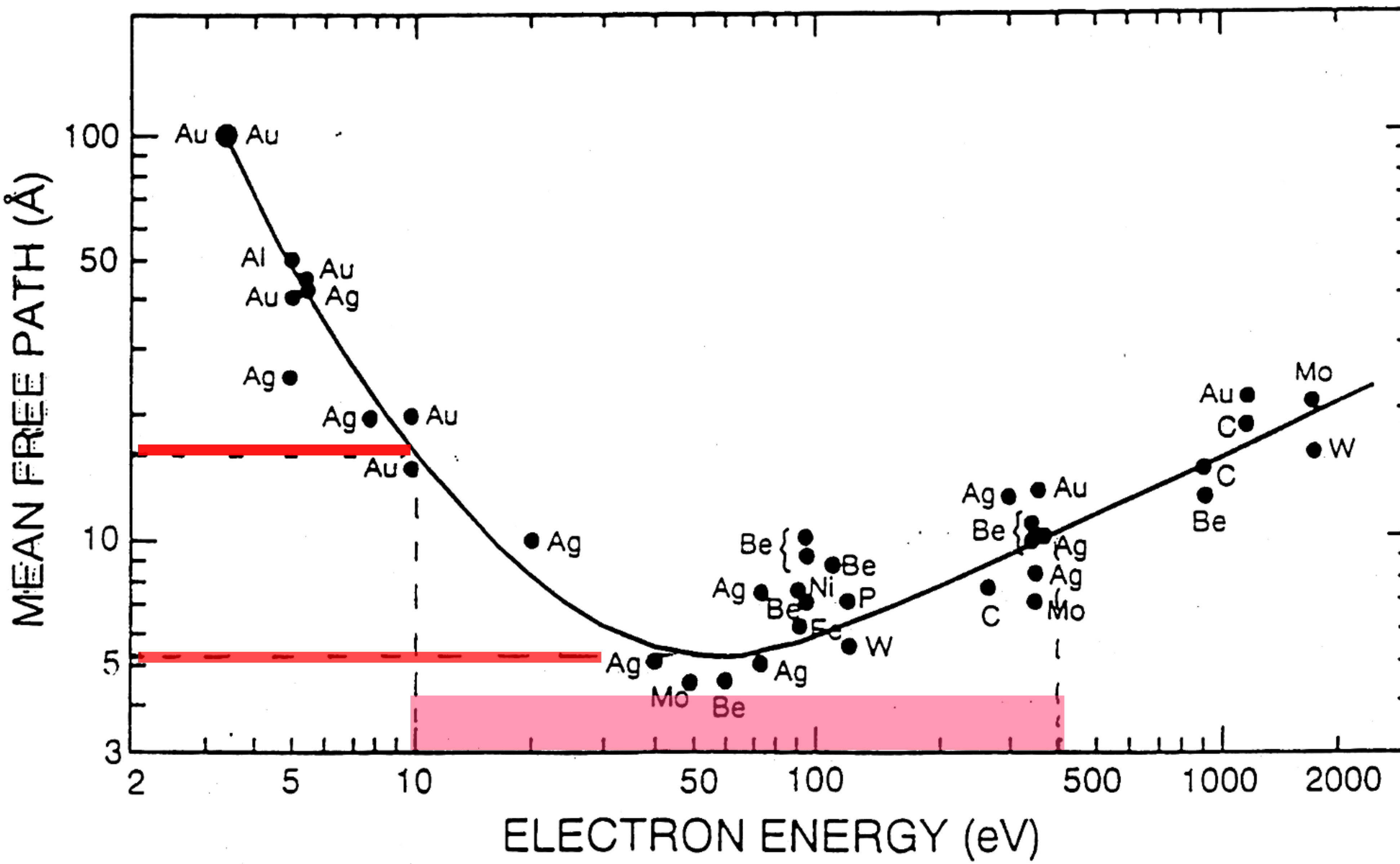
Very low E: $\lambda \sim E^{-2}$

phase space: $n_{occ}\, n_{unocc} \sim E\, n(E_F)\, E\, n(E_F)$

Large E: $\lambda \sim E/(a_V \ln(E+b_V))$

e-h and plasmon excitation probability

cf. D. R. Penn, Phys. Rev. B 13, 5248 (1976)



MEAN FREE PATH (Å)
ELECTRON ENERGY (eV)
100
50
10
5
3
2
5
10
50
100
500
1000
2000
Au
Al
Ag
Be
Ni
Fe
P
W
Mo
C

LEED Setup

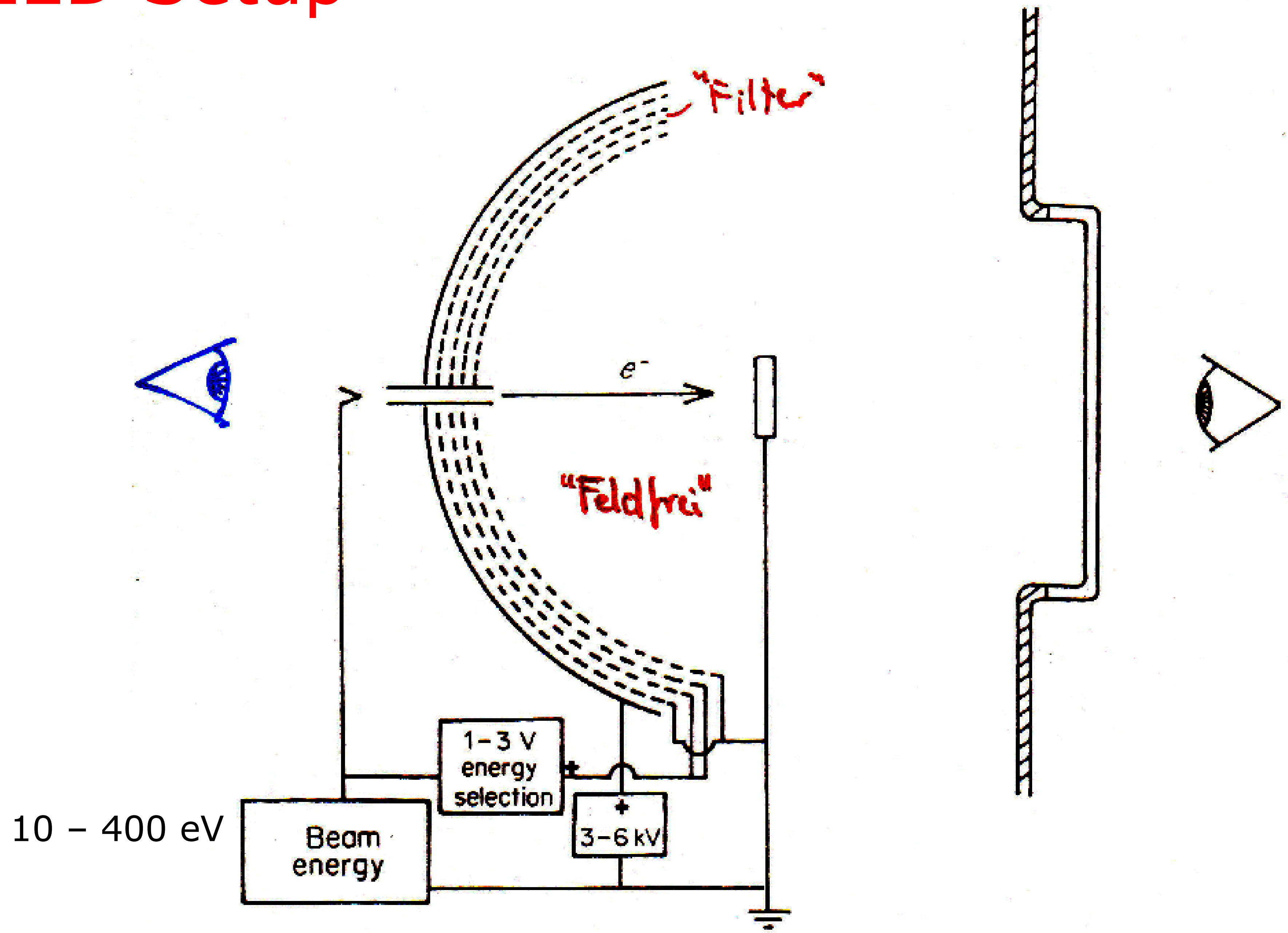
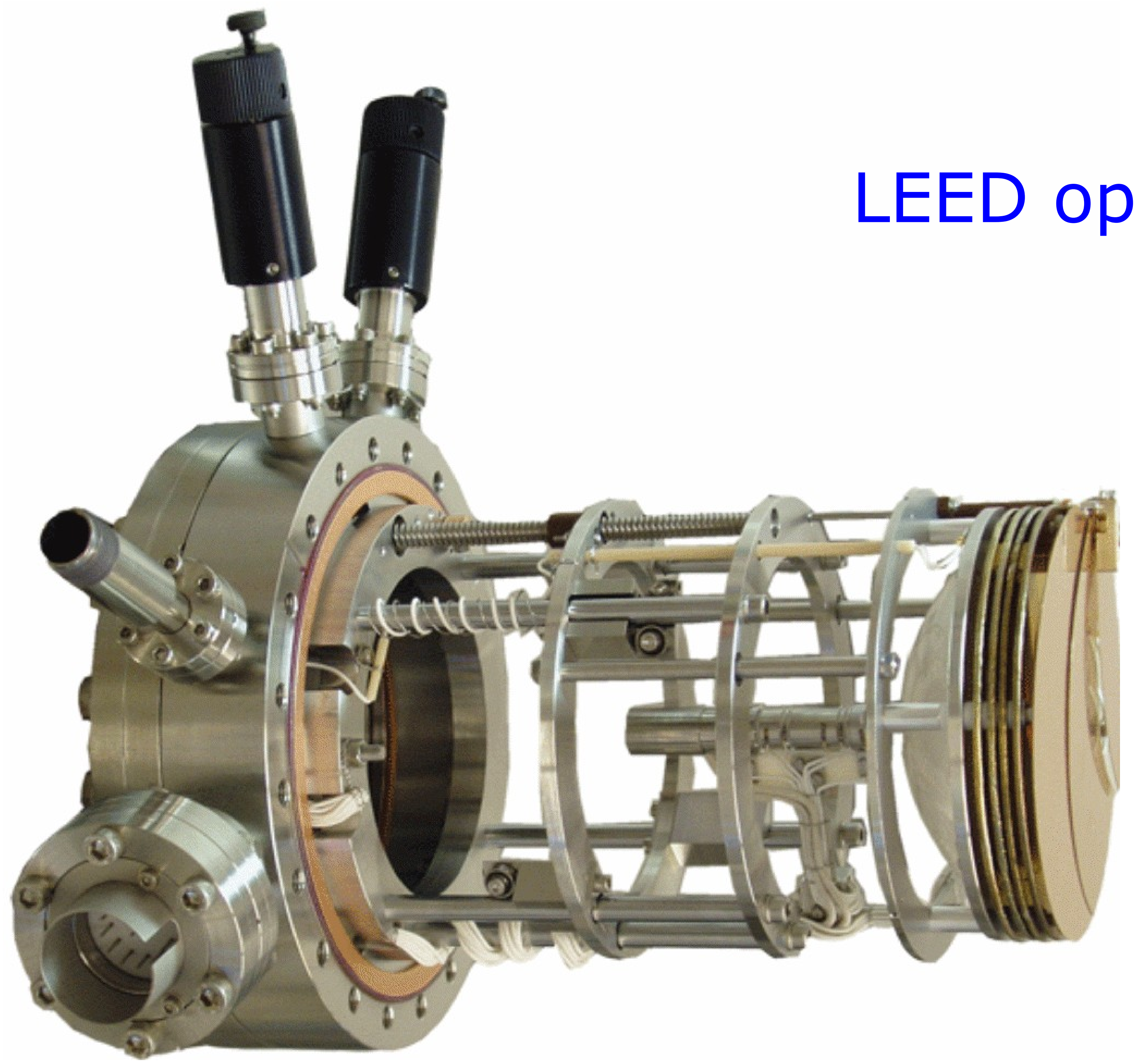
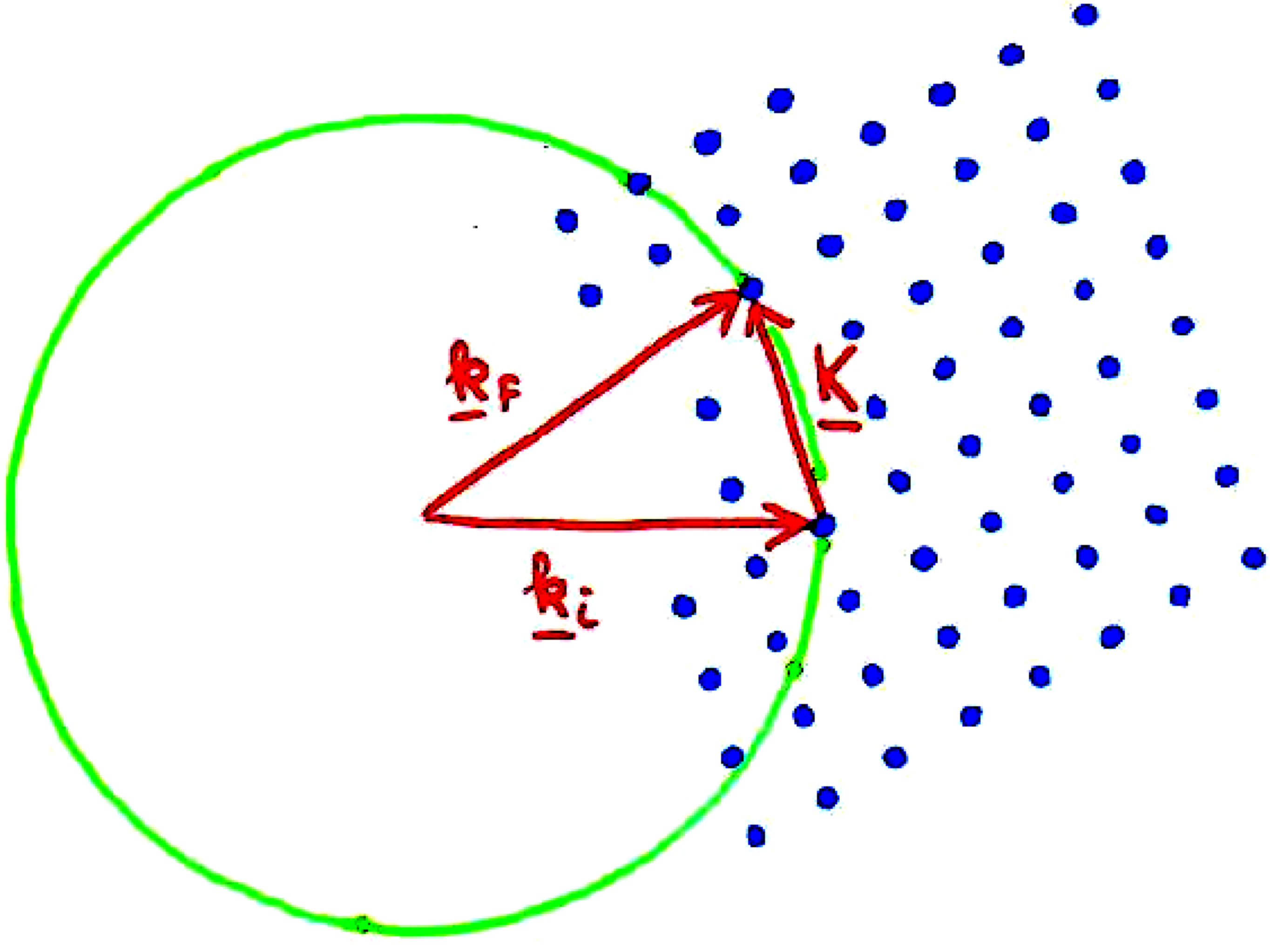


Figure 2.1. Schematic diagram of a typical ('standard') LEED system

LEED optics



Ewaldkonstruktion in "3" Dimensionen



Noether-Theorem:
zweidimensionale Gitterinvarianz – $k_{||}$-Erhaltung (mod g)

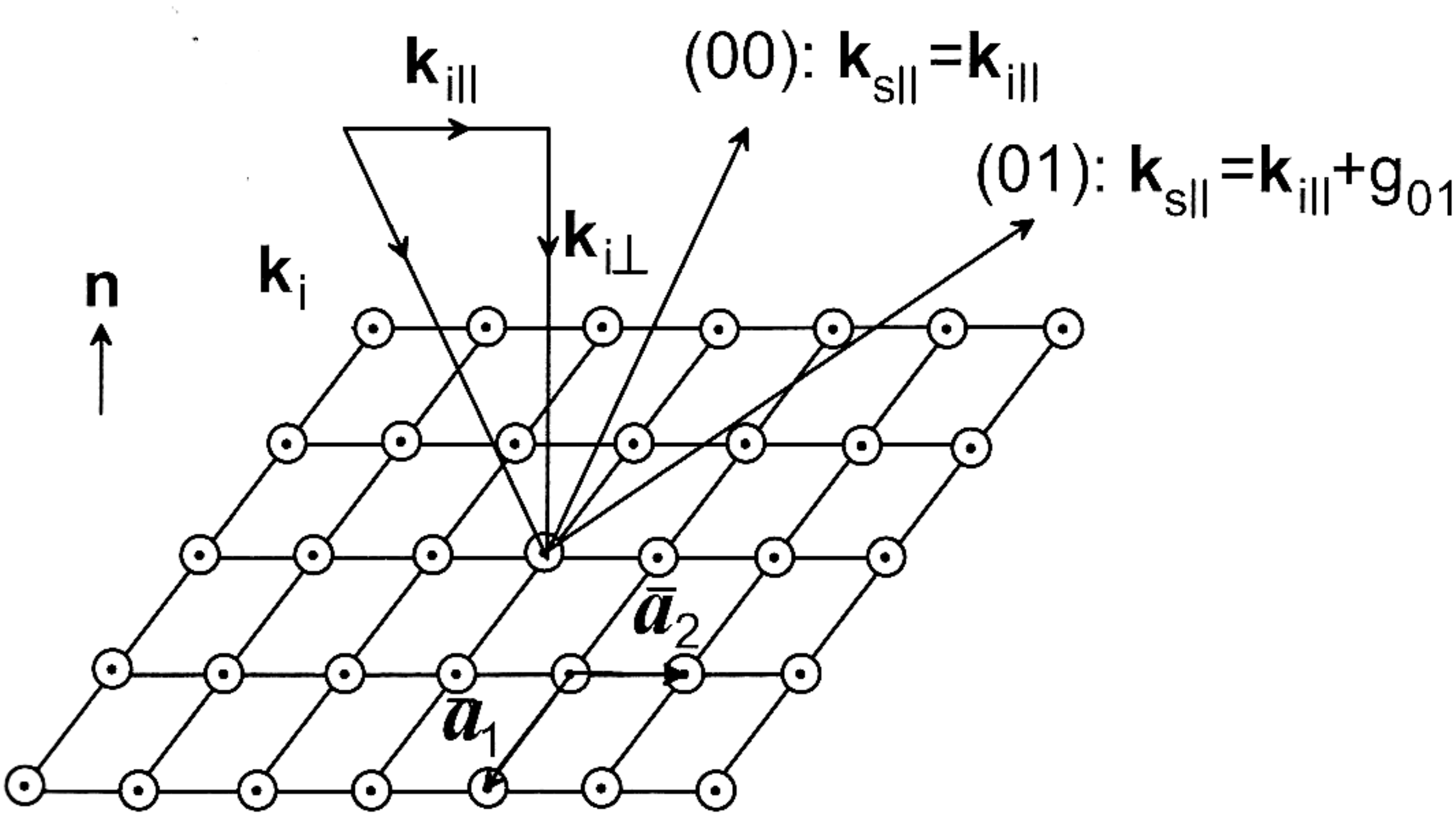
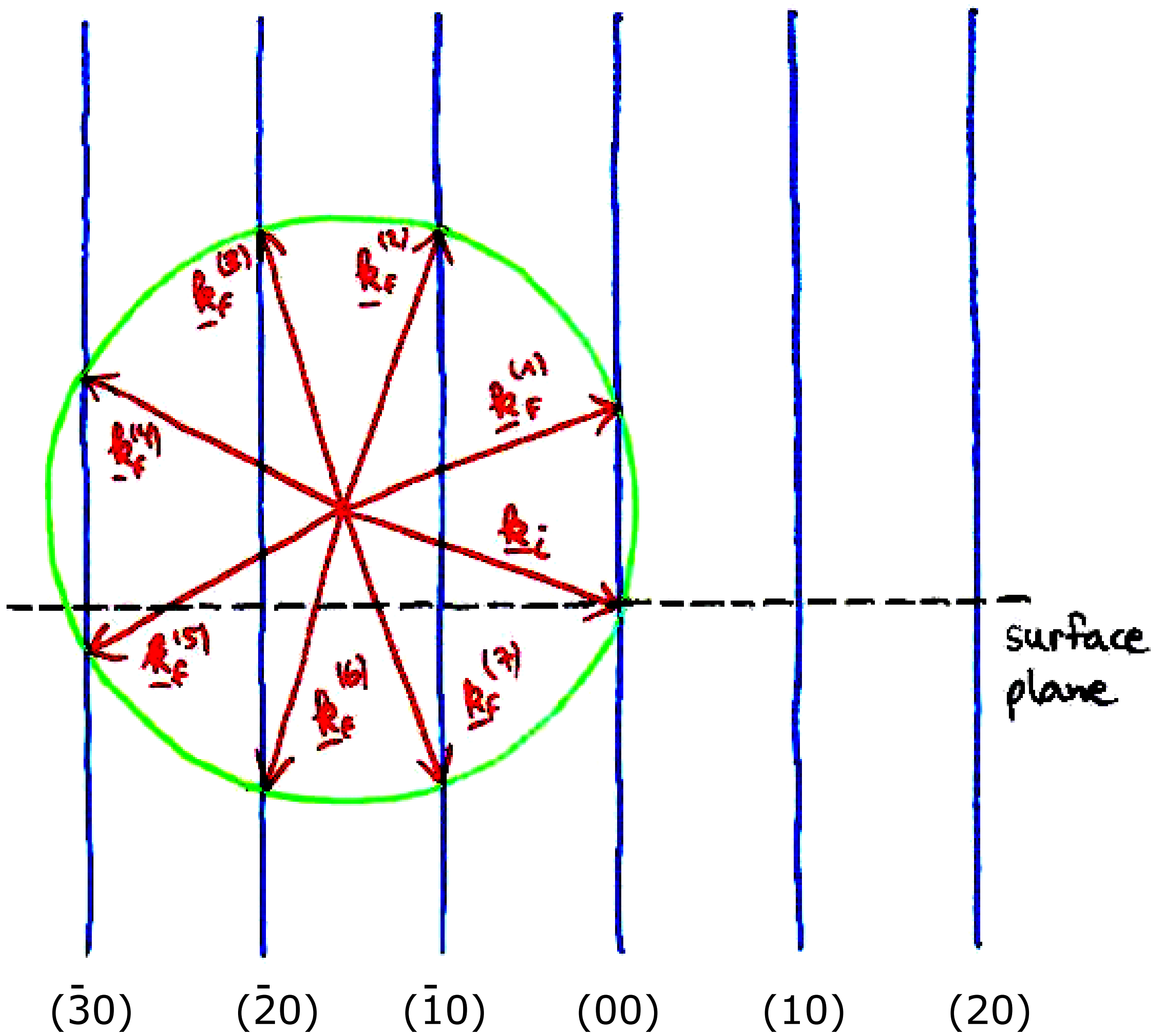


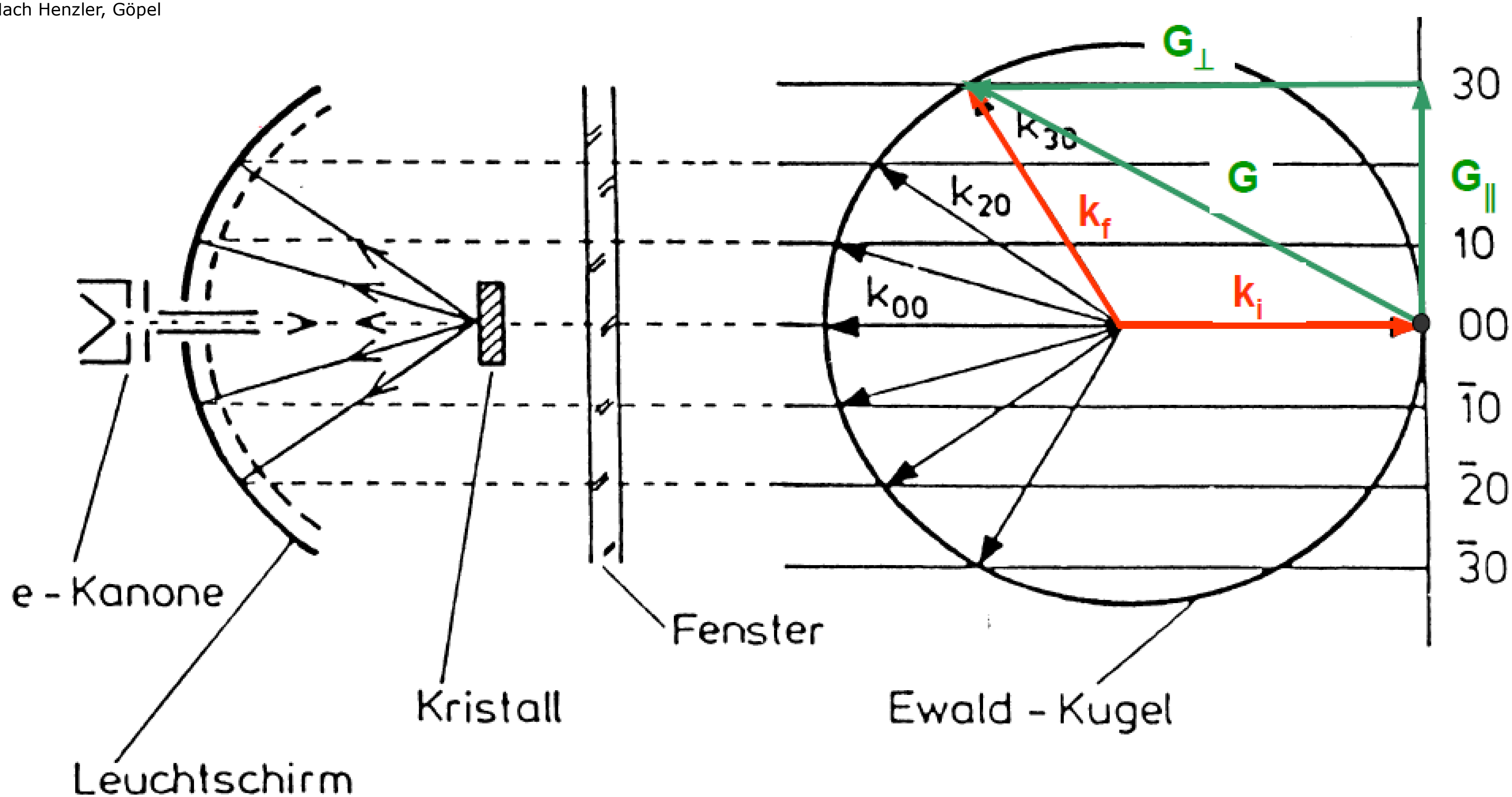
Fig. 1.18. Diffraction of an incident plane wave with wave vector $\boldsymbol{k}_\mathrm{i}$. The surface is represented by the corresponding 2D Bravais lattice. Parallel momentum conservation with any reciprocal lattice vector $\boldsymbol{g}_{hk}$ creates well-defined diffracted beams (hk).

Ewaldkonstruktion in 2 Dimensionen



LEED zeigt ein Abbild des reziproken Gitters!

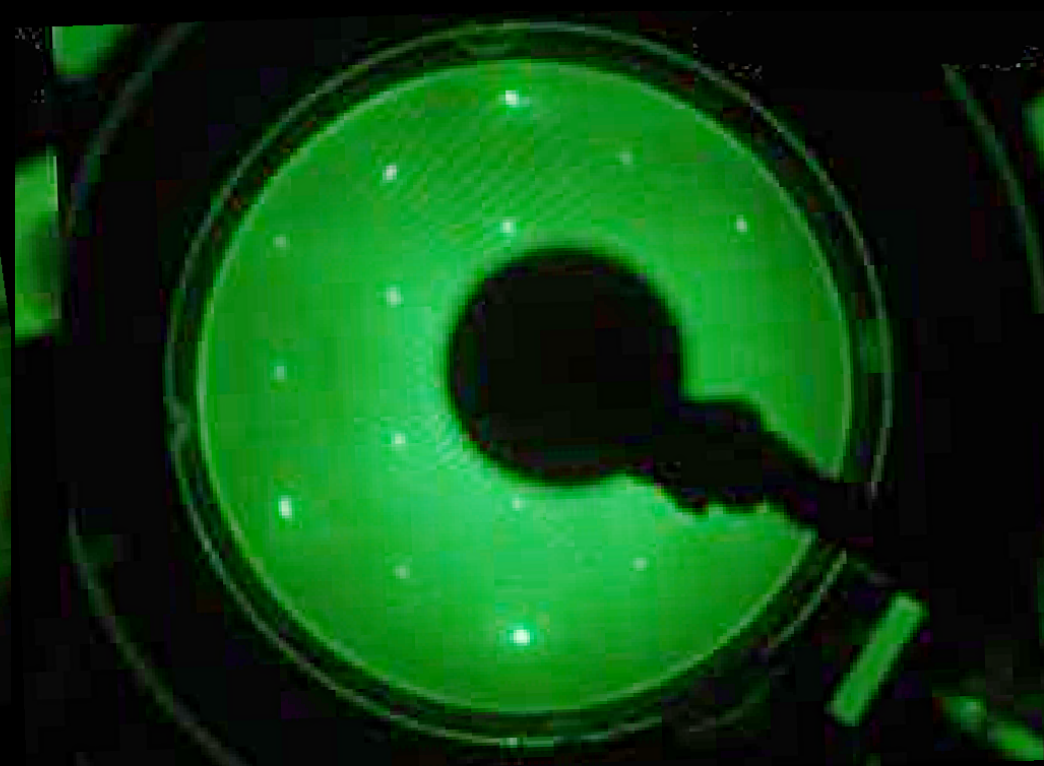
Nach Henzler, Göpel



Obacht: das ist nur die kinematische Näherung

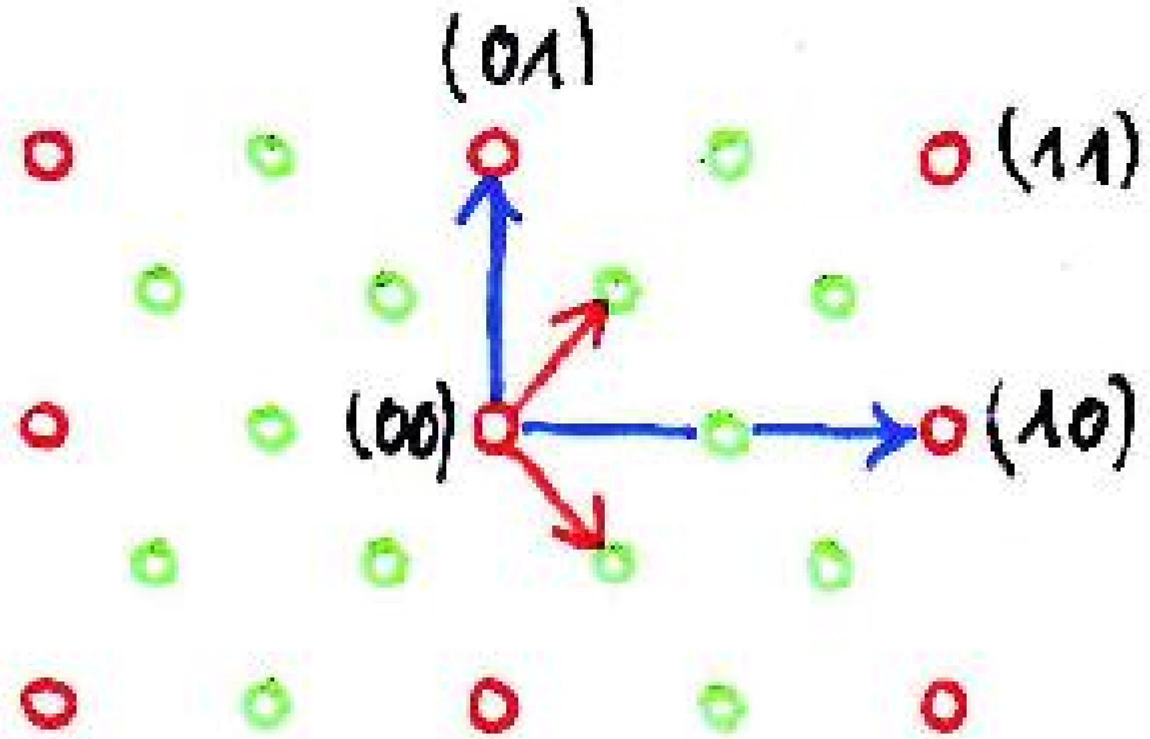
Cu(111)

Cu(111)-p(2x2) Cs

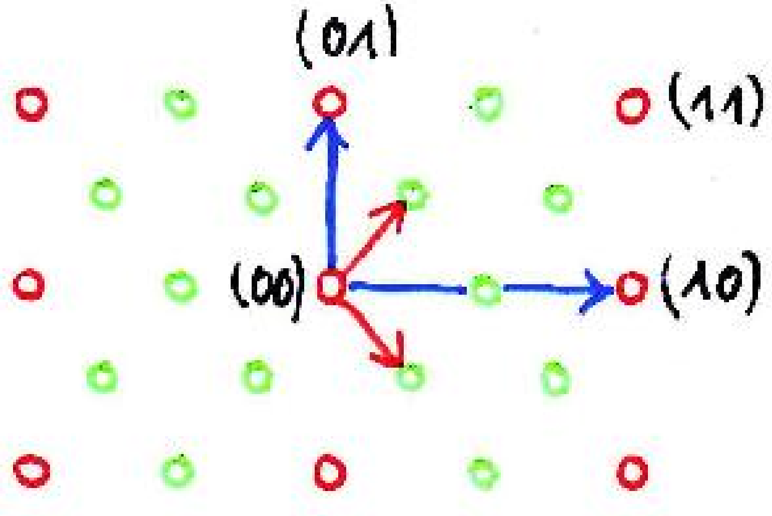


von Hofe, Kröger, Berndt, Phys. Rev. B **73**, 245434 (2006)

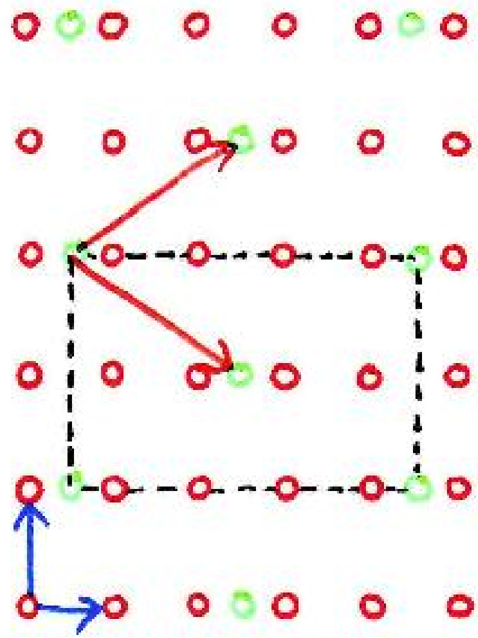
Eine Beugungsbild:



Rot/grün: hohe/niedrige Intensität



Diffraction pattern



Direct space

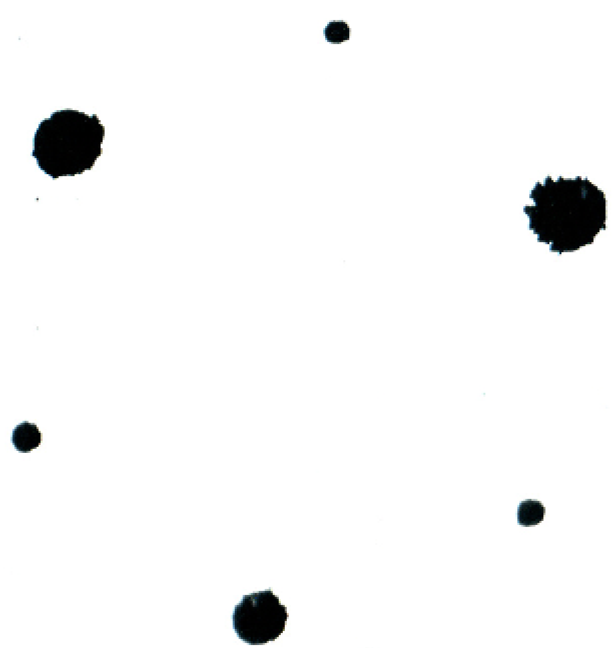
LEED: Metall + Adsorbat

Ni(111)

fcc(111)

3 fach?

6 fach?

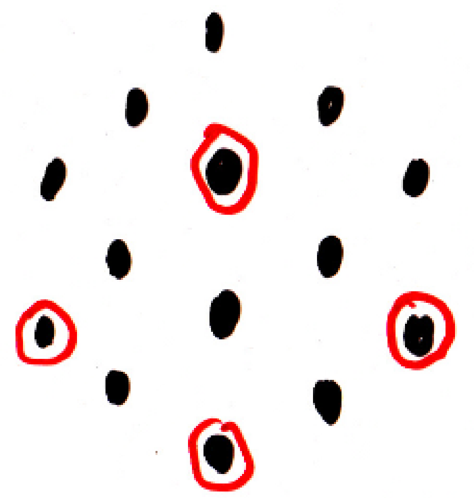


Ni(111), E_{prim} = 205 eV

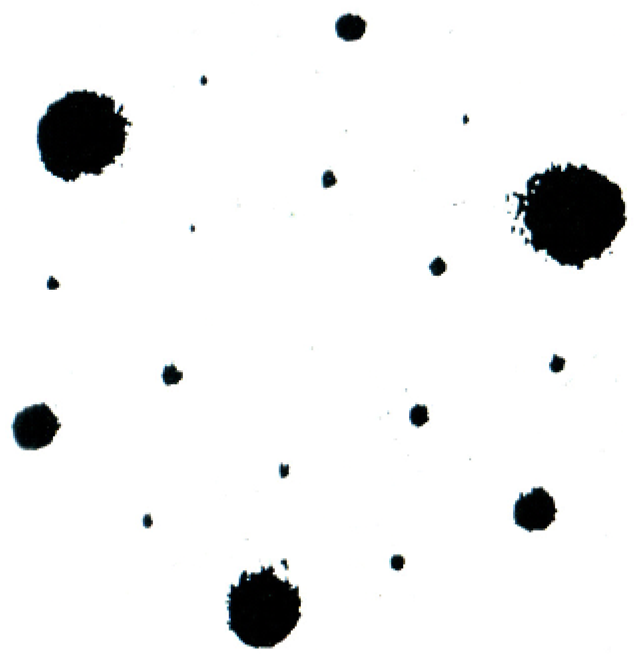
Ni(111) + H_2

Wo sitzt der Wasserstoff?

Da!

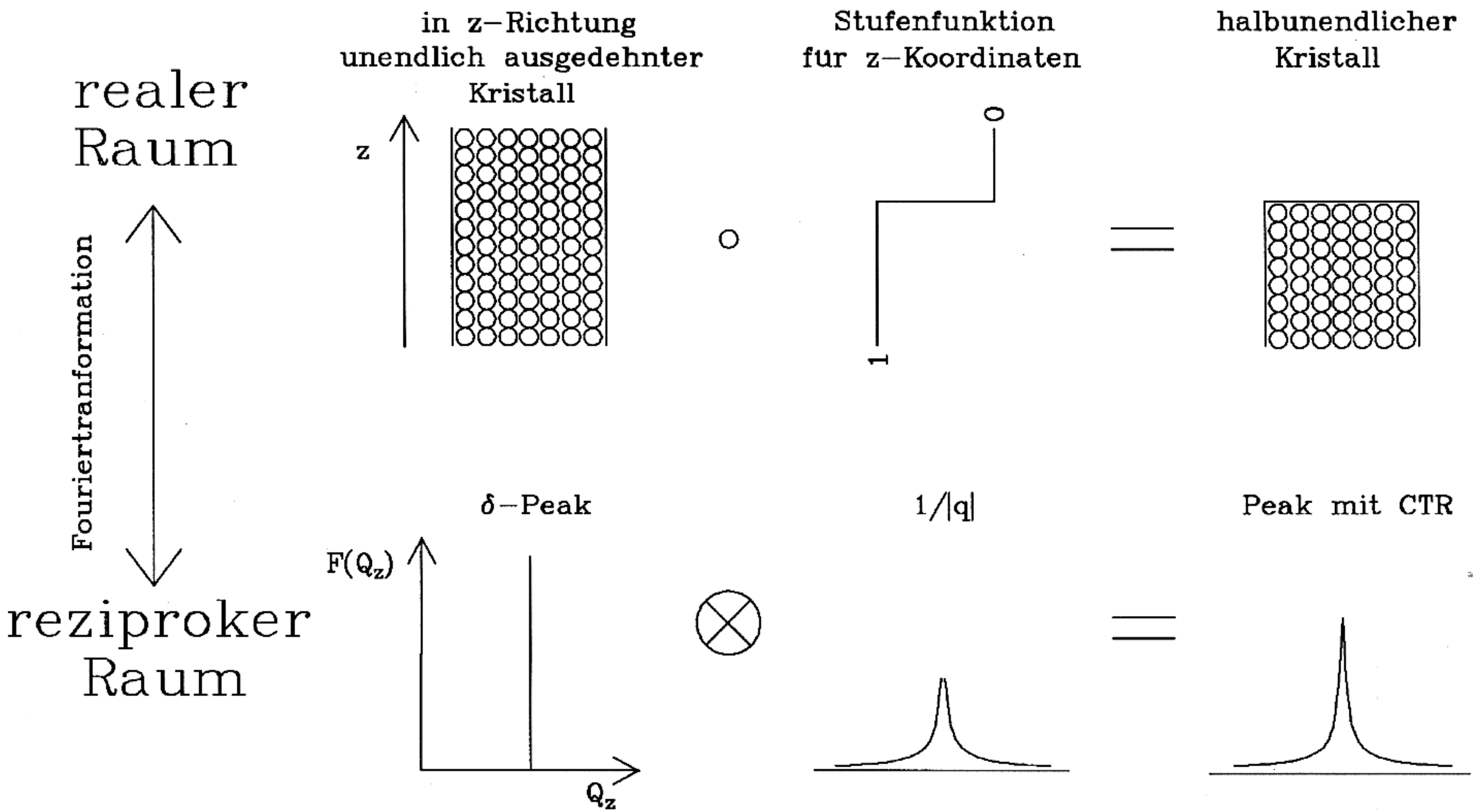


$Ni(111) + H_2$



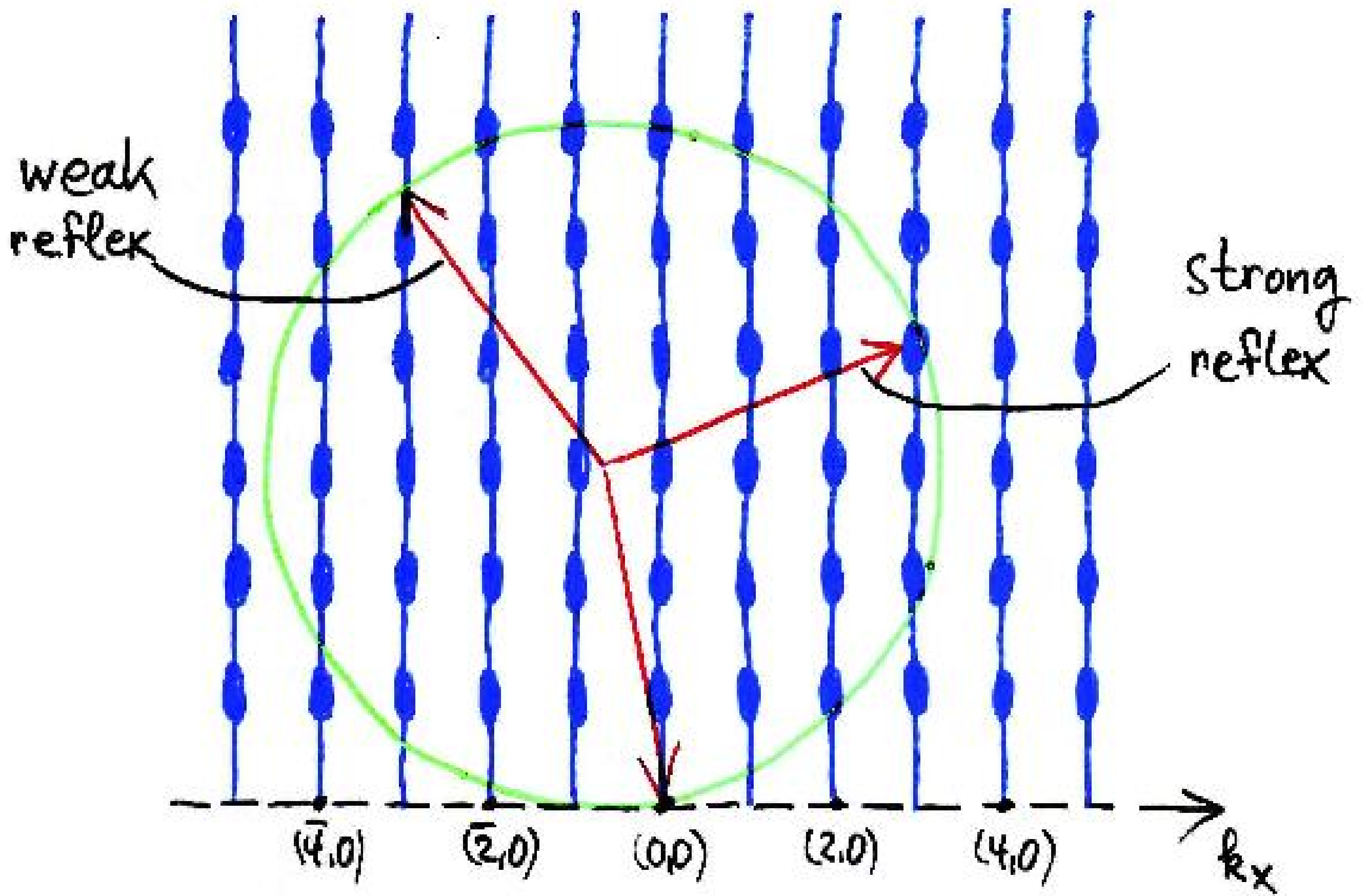
Aber das sieht man nicht an diesem LEED-Bild

Peakform (in der Röntgenbeugung)



(crystal truncation rod)

Finite penetration depth and LEED spots



"Dynamical LEED": I-V Curves

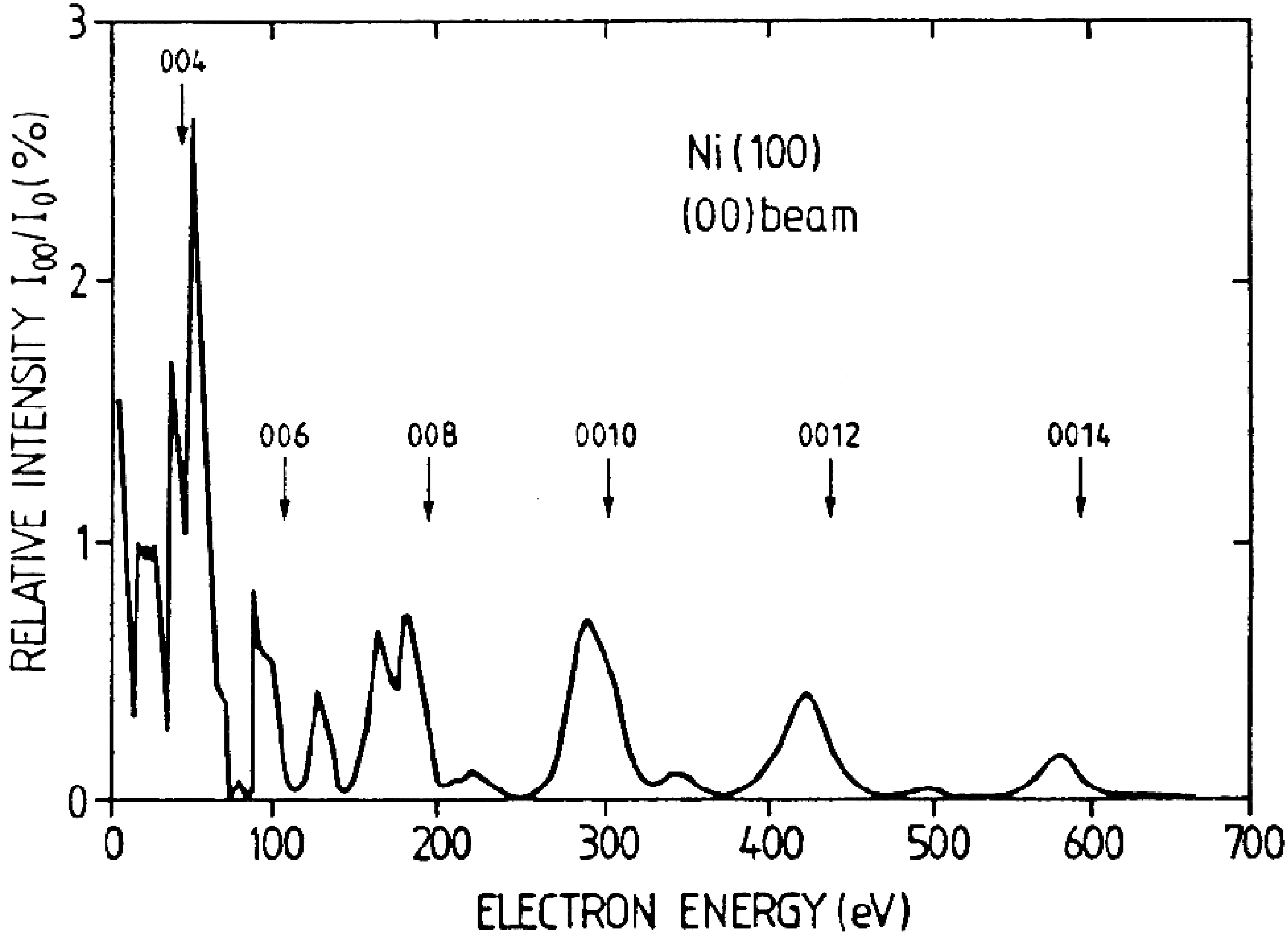


Fig. 4.5. Intensity versus voltage (I-V) curve for the (00) beam from a clean Ni(100) surface. The diffracted intensity I_{00} is referred to the intensity of the primary beam I_0 [4.4]

Domänen

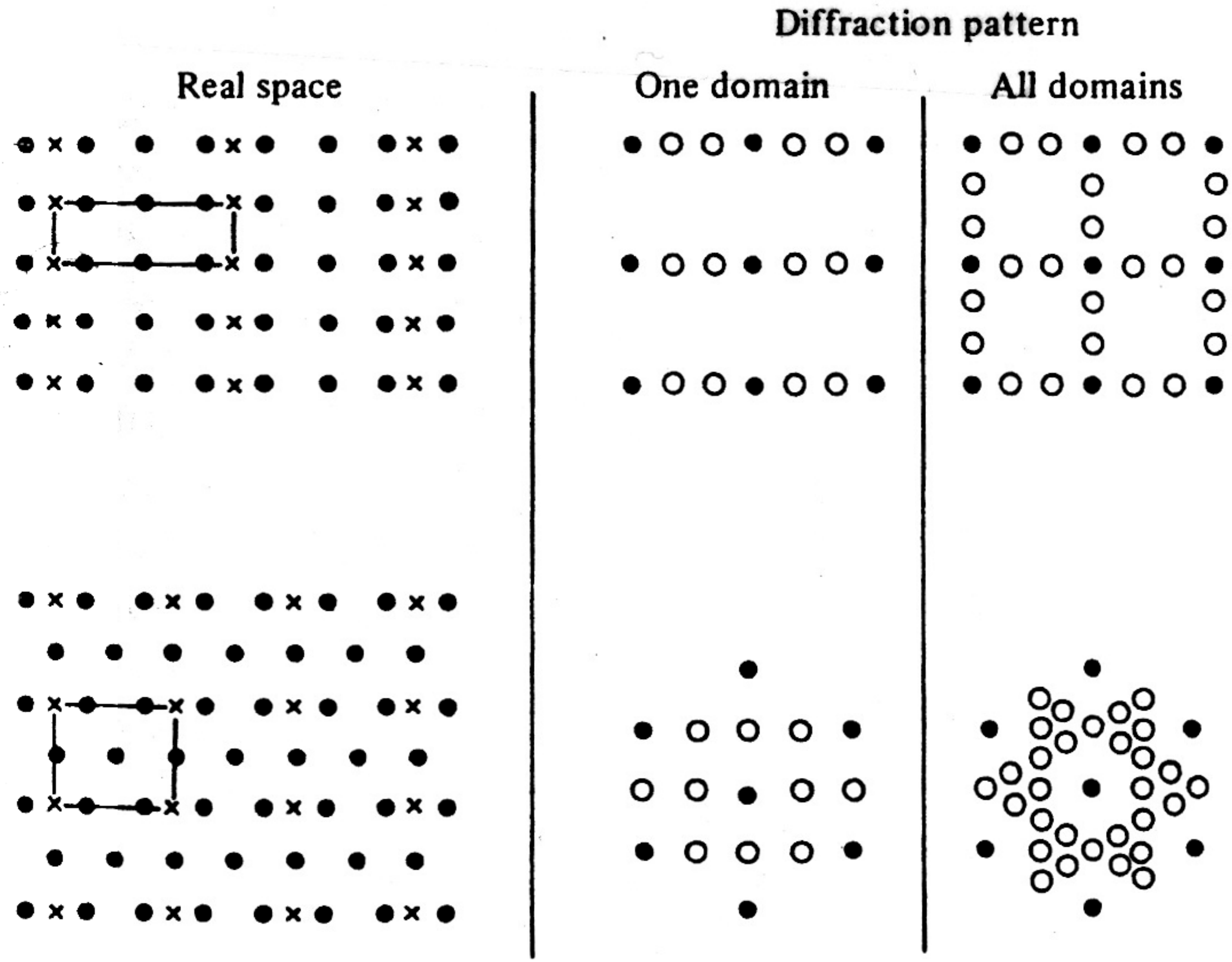


Fig. 2.9 Two examples of the effects of multiple domains on a resultant LEED pattern. In each case the real space surface structure, the single domain diffraction pattern and the sum of all equivalent domain diffraction patterns is shown. The upper example of a rectangular mesh on a square substrate involves two domain types. In the lower example three domains of a rectangular mesh on the hexagonal substrate contribute to the final pattern.

Domänen II: etwas trickreicher

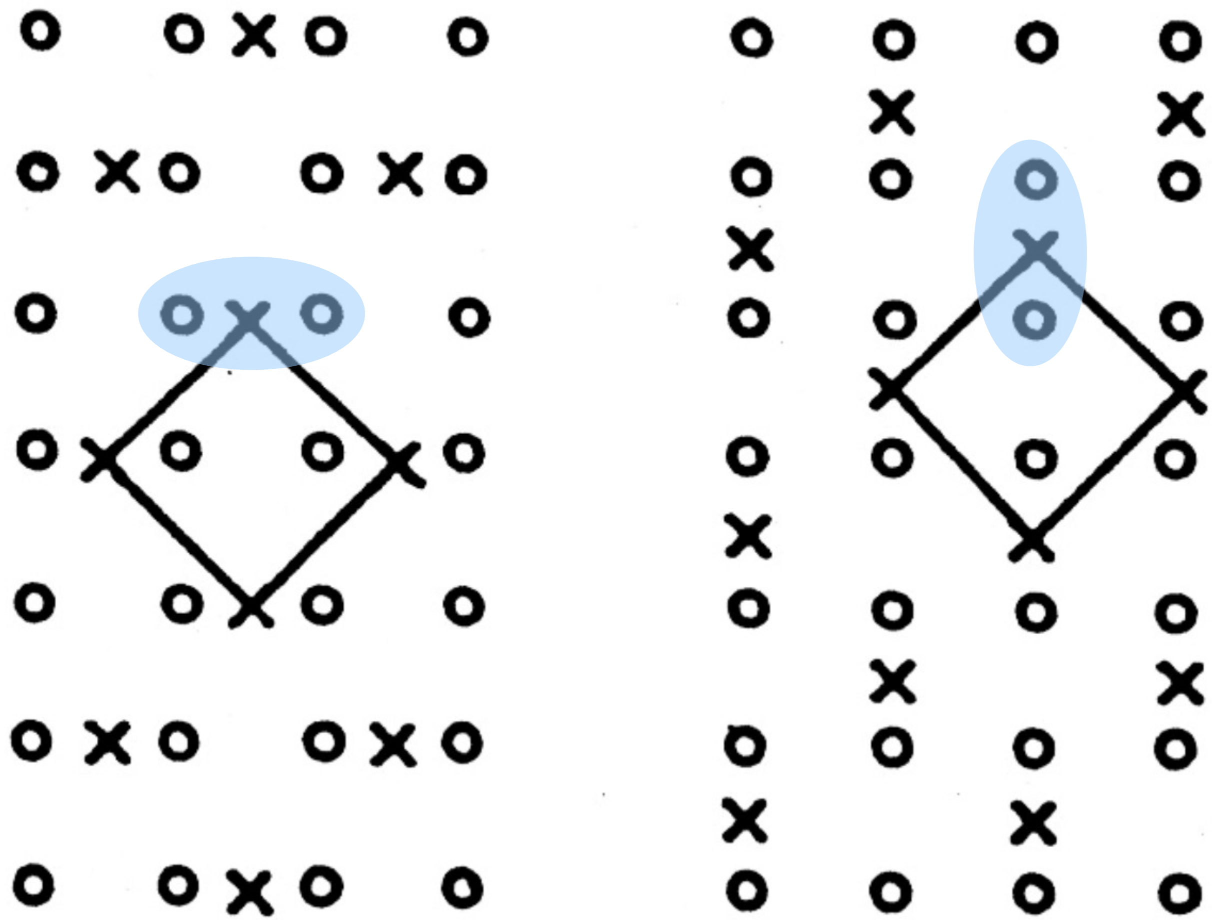
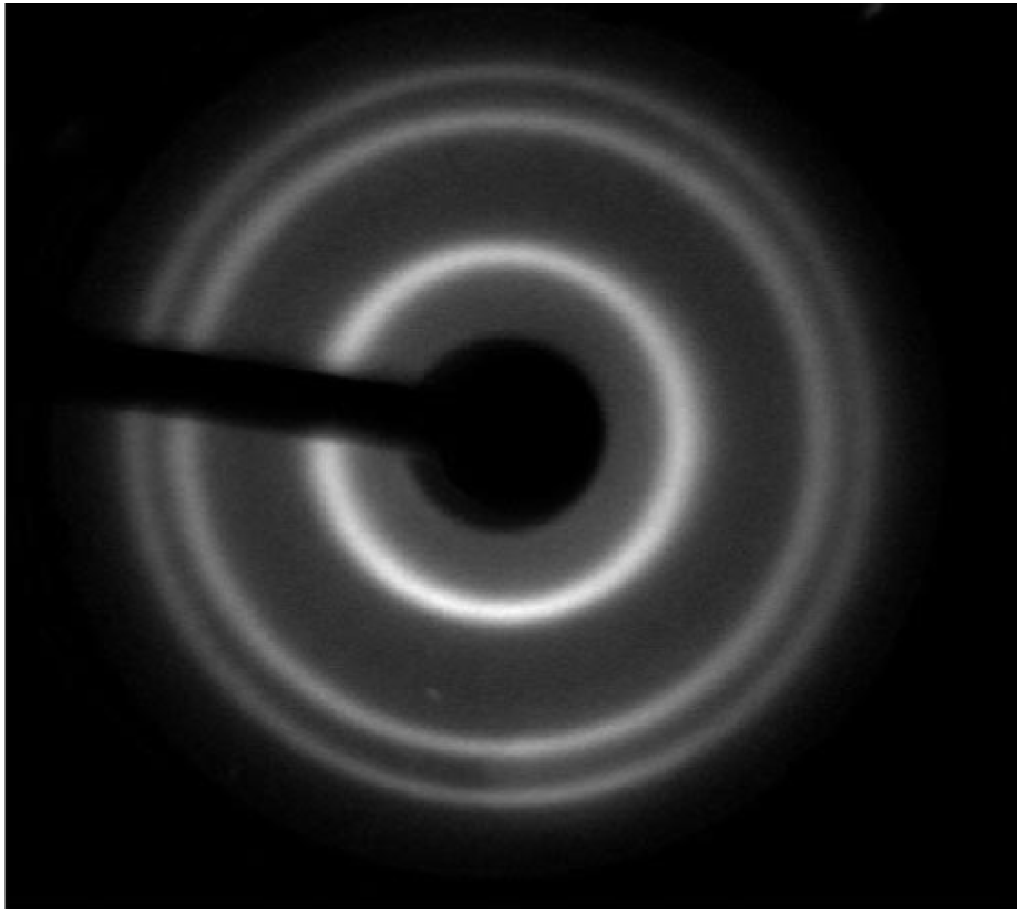


Fig. 2.10 Schematic diagram of two domains of a $(\sqrt{2} \times \sqrt{2})R45°$ (c(2 × 2)) structure formed by adsorption at the cross sites onto a square mesh substrate (open circles). The two domains are symmetrically equivalent relative to the substrate and lead to diffracted beams in the same locations, but because the adsorbate–substrate coordination symmetry (two-fold) is lower than that of the substrate (four-fold) the diffracted beam intensities will differ. A sum of the two domains, however, will lead to a diffraction pattern showing four-fold symmetry.

LEED pattern of HOPG



What is a possible real space structure?

N. Ferralis *et al.*, Phys. Rev. B **70**, 245407 (2004).

Stufen

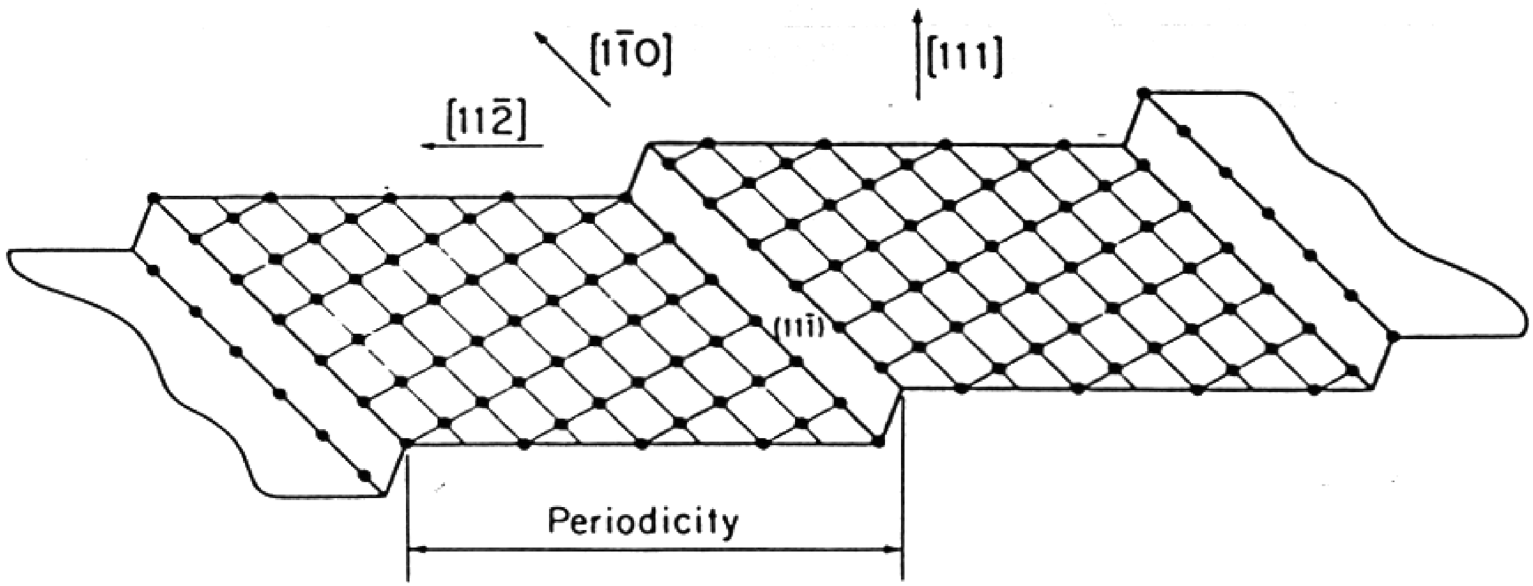
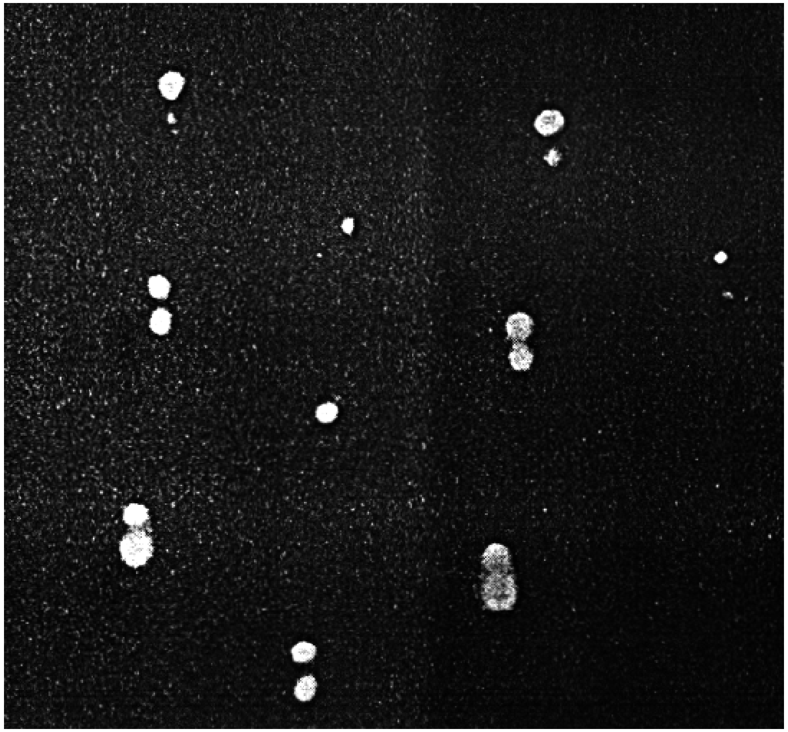
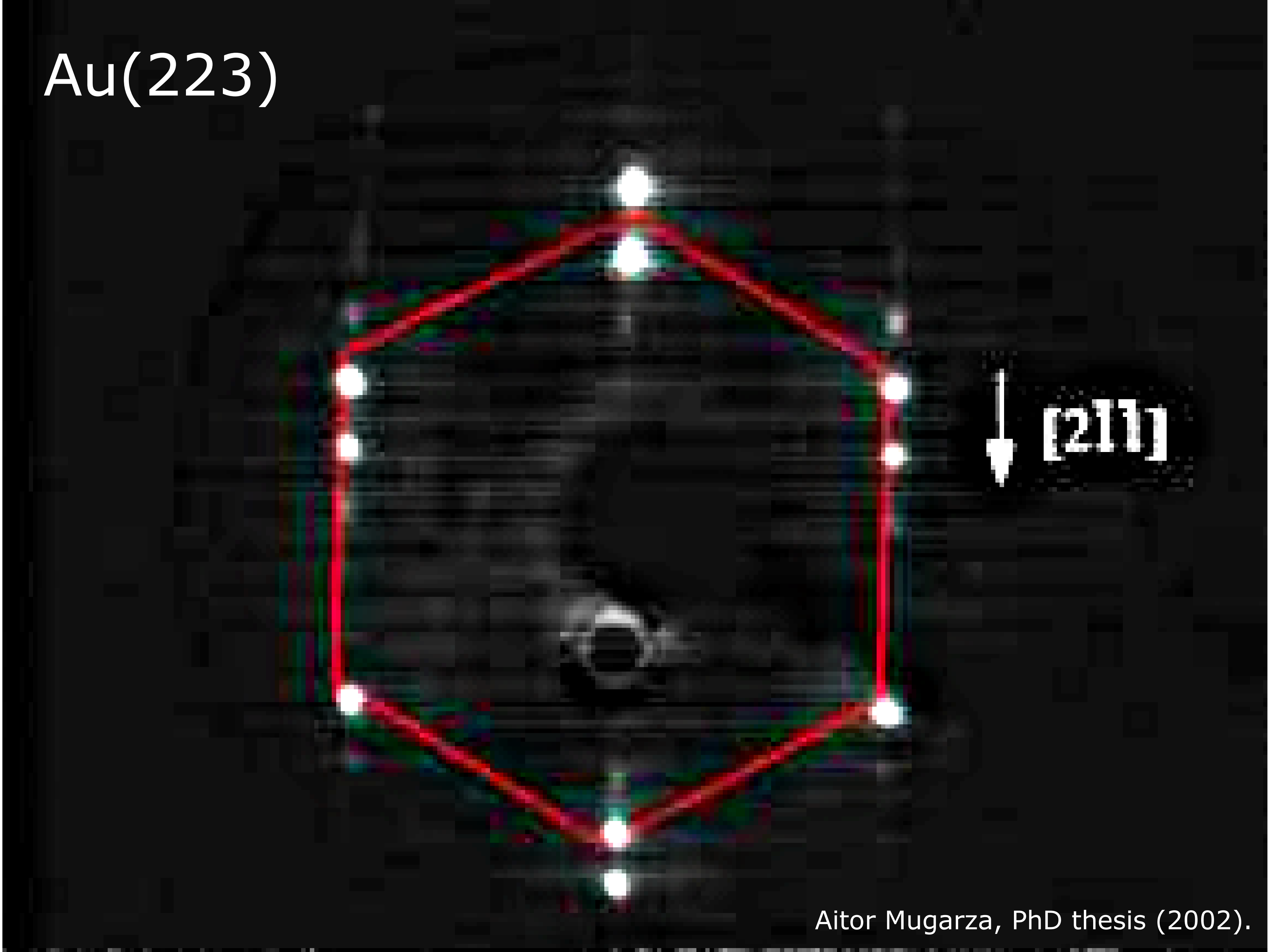


Figure 1.36. Diffraction pattern and schematic representation of a stepped surface that was cut 6.5° from the (111) crystal face. The notation to identify this surface is PtS) − [9(111) × (111)]. (Reproduced by permission of North Holland Physics Publishing from Baron *et al.*[63])

Wie sähe (111) LEED aus? Wie das der Vizinalfläche?

PtS) − [9(111) × (111)]




Au(223)
[211]
Aitor Mugarza, PhD thesis (2002).

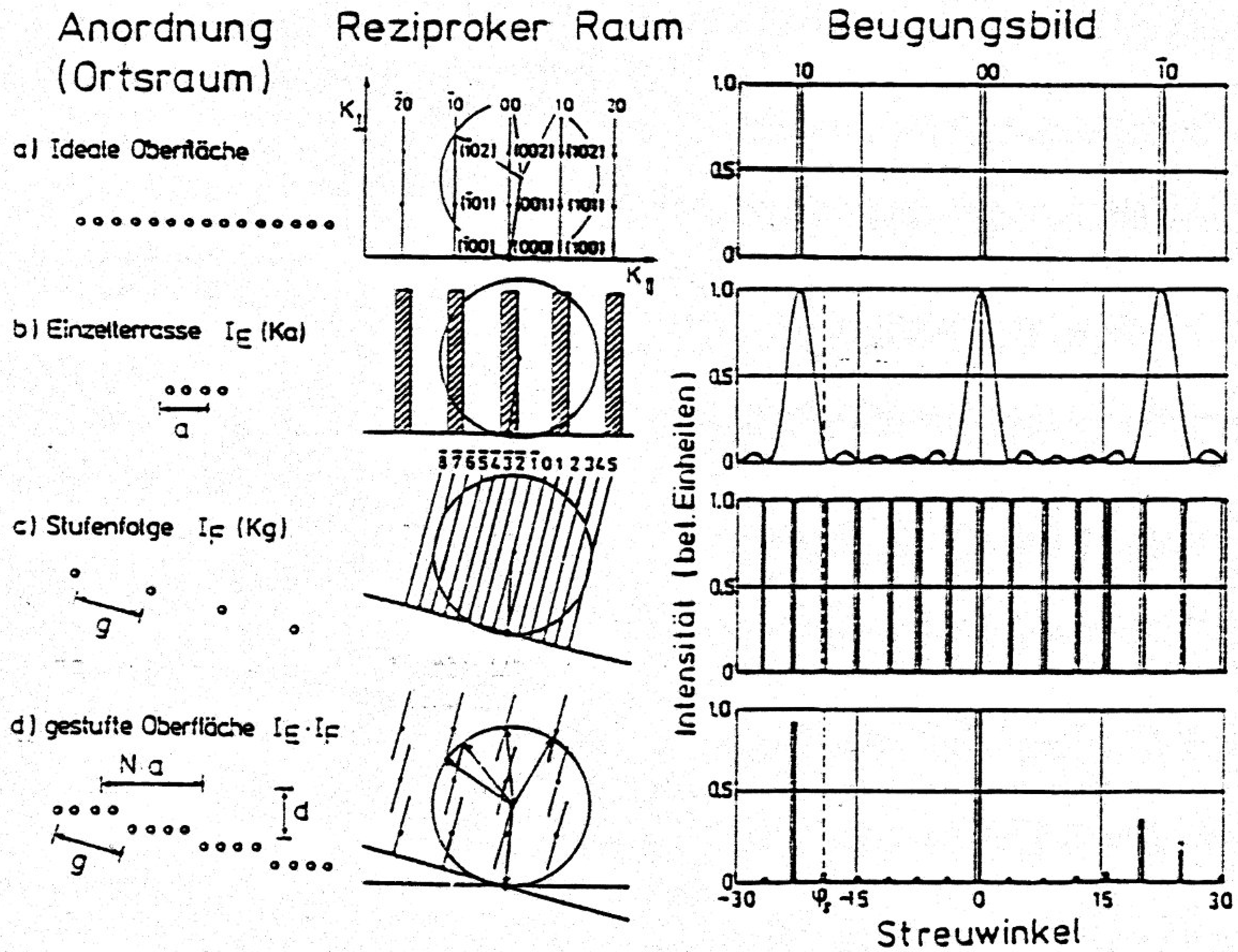


Abb. 3.8.3
Konstruktion des Beugungsbildes einer regelmäßig gestuften Fläche aus Einzelterrasse und Stufenfolge. Das im rechten Teilbild gezeigte Beugungsbild ergibt sich für die Energie, die der eingezeichneten Ewald-Kugel entspricht.

More SPALEED: Islands