INTERNATIONAL ATOMIC ENERGY AGENCY
UNITED NATIONS EDUCATIONAL, SCIENTIFIC AND CULTURAL ORGANIZATION

INTERNATIONAL CENTRE FOR THEORETICAL PHYSICS
34100 TRIESTE (ITALY) - P.O.B. 586 - MIRAMARE - STRADA COSTIERA 11 - TELEPHONE: 2240-1
CABLE: CENTRATOM - TELEX 460392 - I

SMR/388- 16

SPRING COLLEGE IN MATERIALS SCIENCE ON 'CERAMICS AND COMPOSITE MATERIALS'
(17 April - 26 May 1989)

ELECTRON, MICROSCOPY (transmission, scanning, Auger)
Lectures IX and X

M.J. GORINGE
University of Oxford
Dp.Metallurgy-Sc.Materials
Parks Road
Oxford OX1 3PH
United Kingdom

Scanning Electron Microscopy Equations

M. J. Goringe

$D_1 = D_0 \times V_1 / U_1$ (1)

Beam diameter, $D = D_1 \times V_2 / U_2 = D_1 \times WD / U_2$ (2)

Beam current, $I = I_1 \times (\alpha_2 / \alpha_1)^2$ (3)

Specimen pixel side (diameter), $p = 100\mu m / M$ (4)

Depth of field, $H = 2 \times p / 2\alpha$ (5)

or $\Delta H = \pm p / 2\alpha = \pm 50\mu m / M\alpha$ (6)

where Beam convergence $\alpha = A / 2 \times WD$ (7)

So $\Delta H = \pm 100\mu m \times WD / A \times M$ (8)

Spherical aberration minimum $D_S = \frac{1}{2} C_s \alpha^3$ (9)

Aperture diffraction limit $D_\alpha = 1.22 \lambda / \alpha$ (10)

So a theoretical probe diameter D_t from eqn (2) becomes a real probe diameter $D = (D_s^2 + D_\alpha^2 + D_t^2)^{1/2}$ (11)

Minimum value for $D_t = 0$ is $D_{min} = 1.29 \lambda^{3/4} C_s^{1/4}$ (12)

For a thermionic emission filament probe diameter D and beam current I obey $D = D_{min} \times 7.92 \left[\left(\frac{IT}{j}\right) \times 10^9 + 1 \right]^{(3/8)}$ (13)

where T = filament temperature and j = current density from filament surface

Natural contrast, $C = (S_{max} - S)/S_{max} = \Delta S / S_{max}$ (14)

Rose equation for seeing a difference $S > 5N$ or $\Delta S > 5\sqrt{\bar{n}}$ (15)

$\therefore$ minimum detectable contrast $C_{min} = 5/\sqrt{\bar{n}}$ (16)

or minimum signal level $\bar{n}_{min} = (5/c)^2$ (17)

Pixel dwell-time for frame time F is $F \times 10^{-6}$. Hence no. of electrons per pixel is $n_0 = It/e = IF \times 10^{-6}/e$ (18)

No. of electrons detected is $n = q n_0$ where q is efficiency (19)

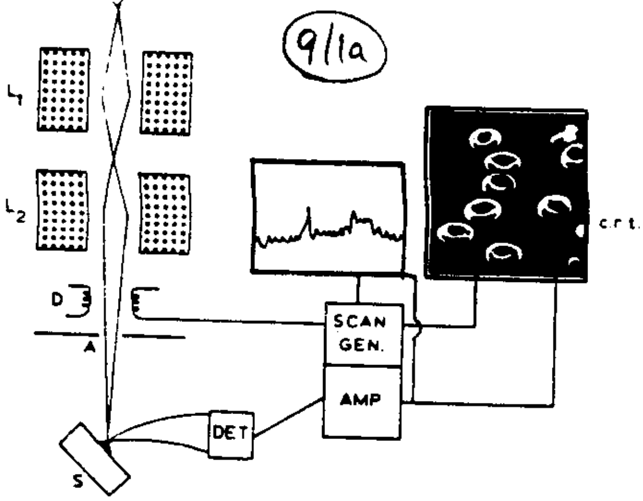
Hence critical current, $I_c > (4 \times 10^{-12})/(q F C^2)$ Amp (20)

Secondary emission coefficient, $\sigma = \sigma_0 \sec \phi$ (21)

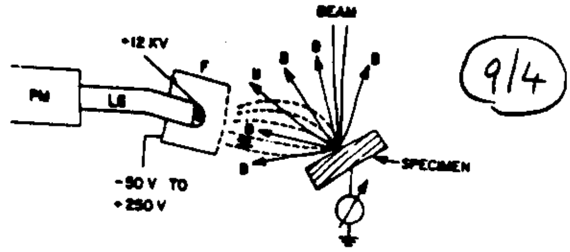
Backscattering coefficient, $\eta = -0.254 + 0.016 Z - 1.86 \times 10^{-4} Z^2 + 8.3 \times 10^{-7} Z^3$ (22)

Atomic number contrast $C_Z = (\eta_1 - \eta_2)/\eta_1$ (23)

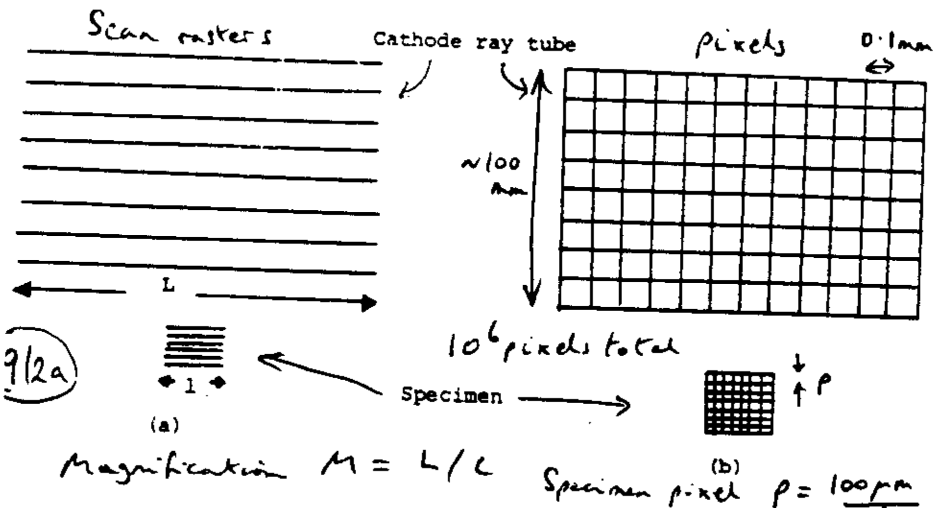
9-1



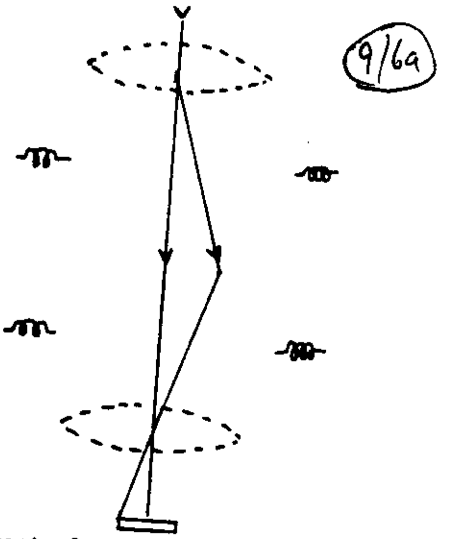
Schematic diagram of an SEM.



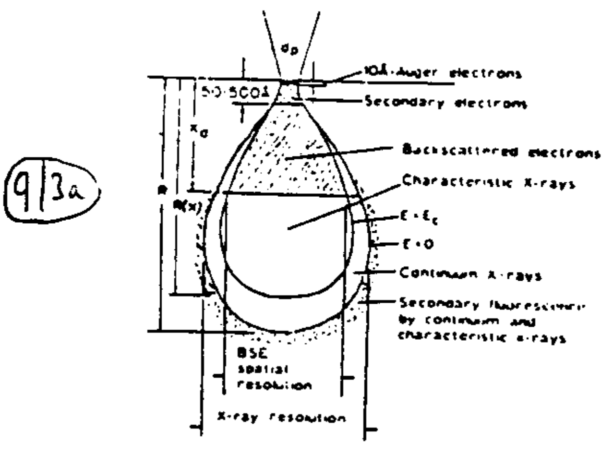
The Everhart Thornley secondary electron detector.



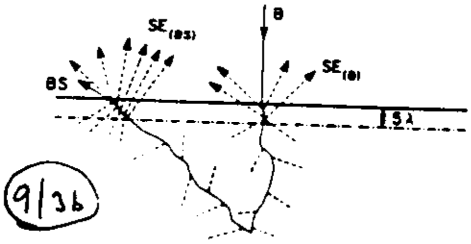
a) The rasters on the specimen and c.r.t. b) The equivalent pixels.



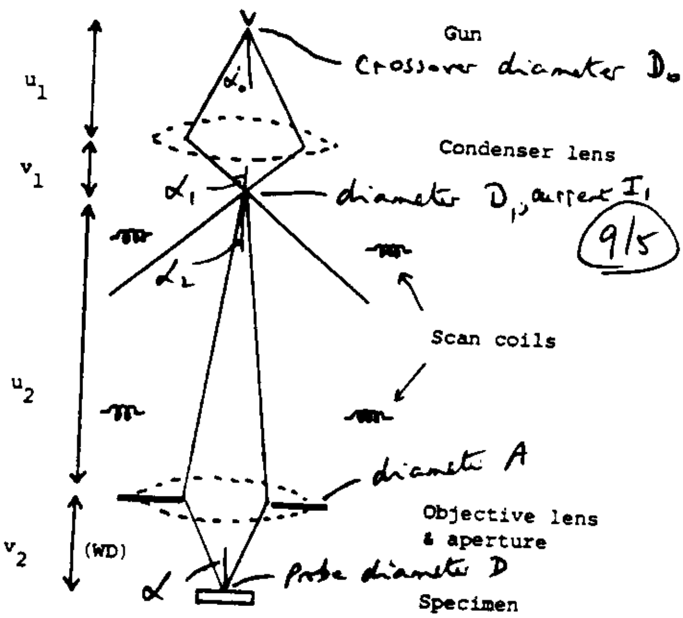
Movement of the axial ray during scanning.



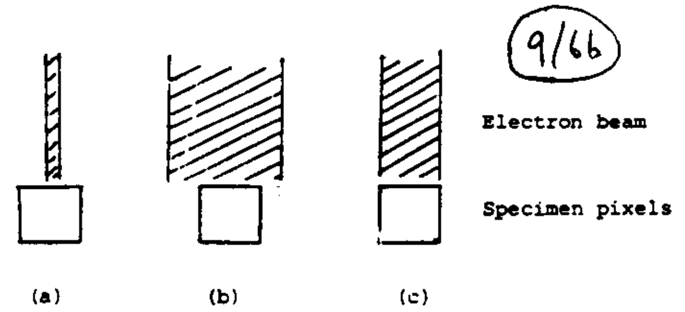
Interaction and sampling volumes for some radiations.



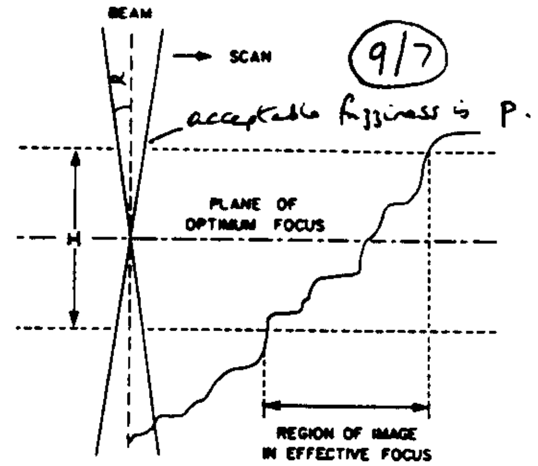
Secondary electron generation.



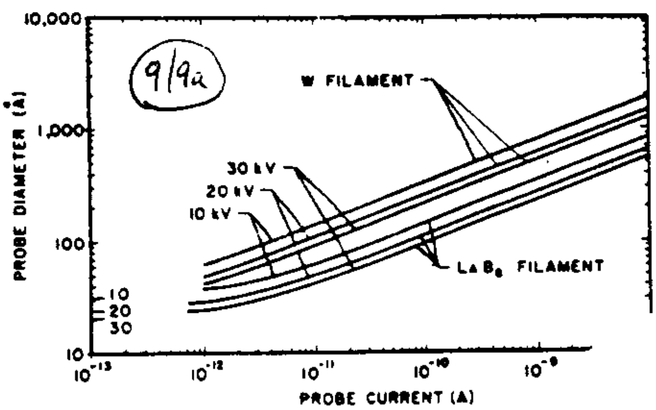
Ray diagram of SEM



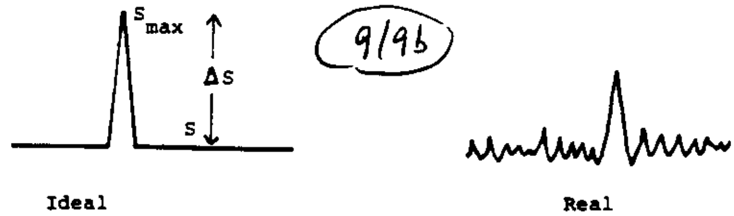
Relationship of specimen pixel size and probe size.



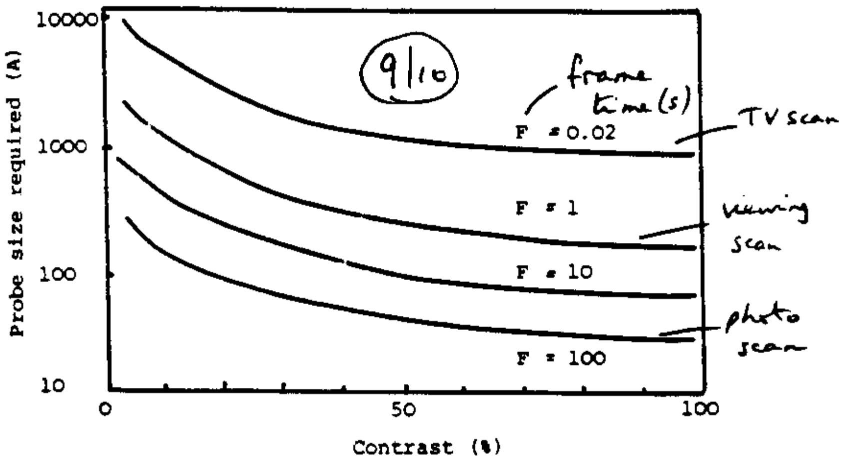
Depth of field in the SEM.



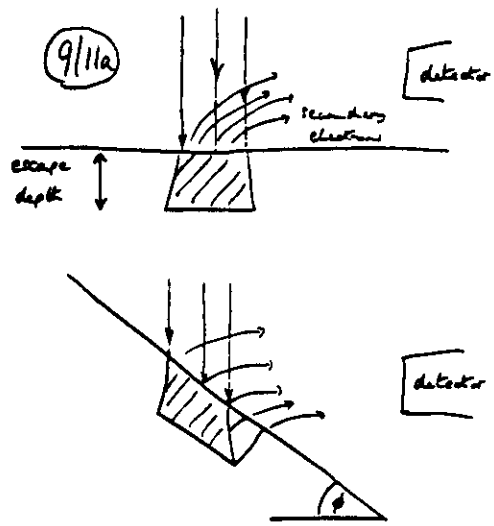
Relation between probe current and diameter.



The effect of noise on the signal.

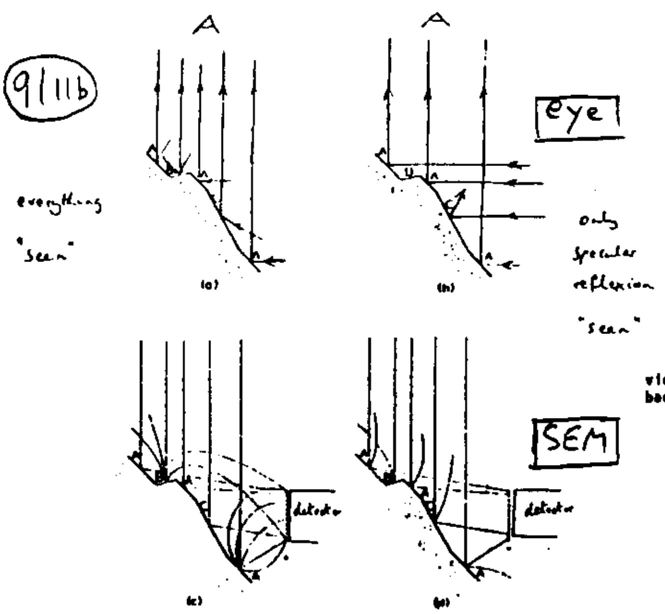


Minimum useable probe size as function of contrast and scan rate.



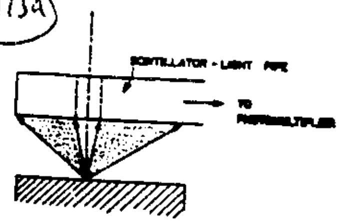
Secondary electron coefficient δ depends on angle ϕ approximately as

$$\delta = \delta_0 \sec\phi \qquad (21)$$



The analogy between the eye and the SEM. a) Diffuse illumination, viewed by eye. b) direct illumination viewed by eye. c) secondary electrons. d) backscattered electrons.

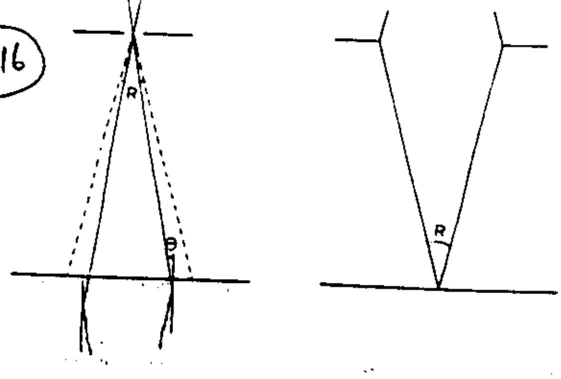
9/13a



Robinson

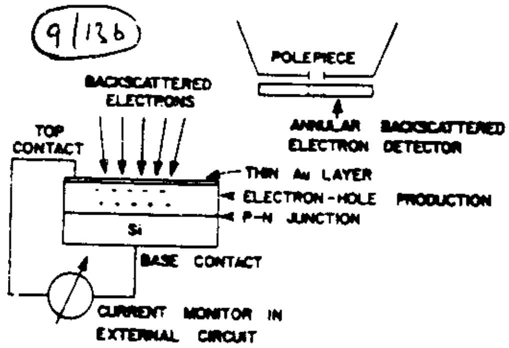
Scintillator backscattered detector

9/16



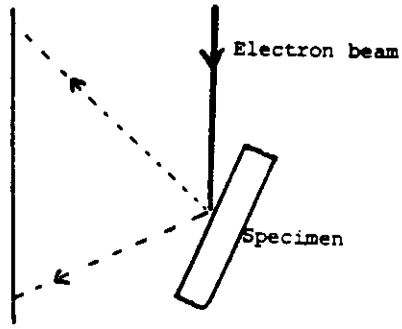
Method of obtaining selected area channelling patterns.

9/13b



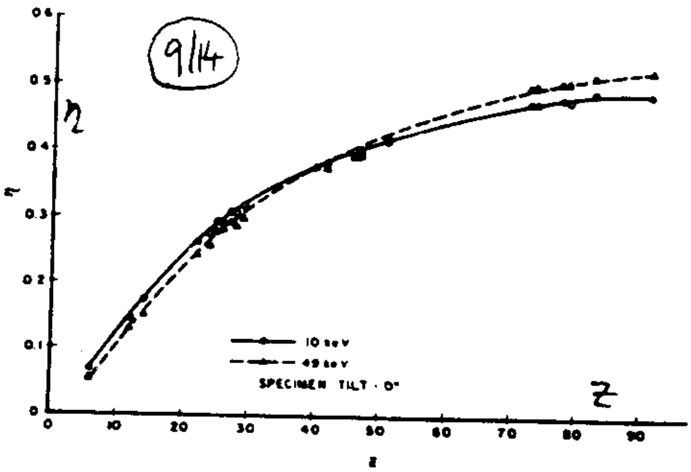
Solid state backscattered electron detector.

9/17



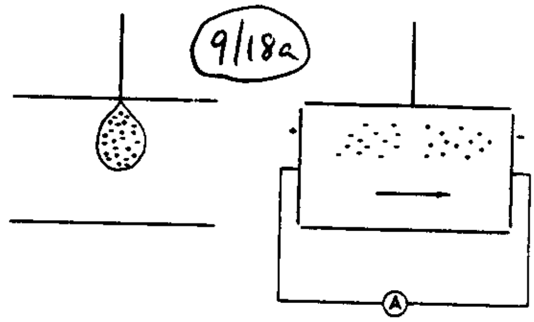
Method of obtaining Electron backscatter patterns.

9/14



Variation of backscattered coefficient with atomic number.

9/18a

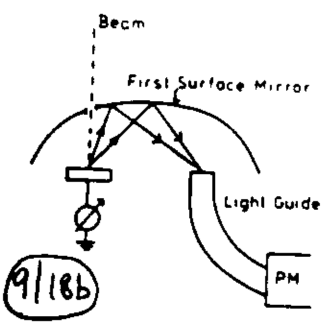


Charge collection current mode.

Table 1 gives some examples of atomic number contrast calculated from equation 22

9/15 TABLE 1 ATOMIC NUMBER CONTRAST

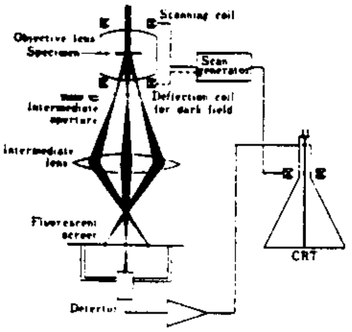
Phase 1	Z1	Phase 2	Z2	1	2	Contrast %	Resolution degradation (nm)
Al	13	Mg	12	0.153	0.141	7.6	19
Al	13	Cu	29	0.153	0.304	49.4	5
Al	13	Pt	78	0.153	0.485	68.4	4
Cu	29	Zn	30	0.304	0.310	2.3	47
brass	29.35	brass	29.45	0.305	0.306	0.2	264



9/18b

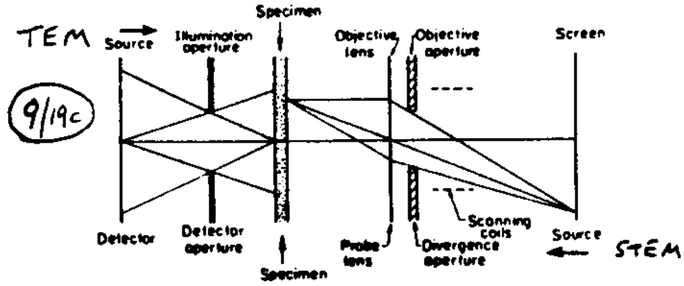
Ellipsoidal mirror for CL detection.

9/19a



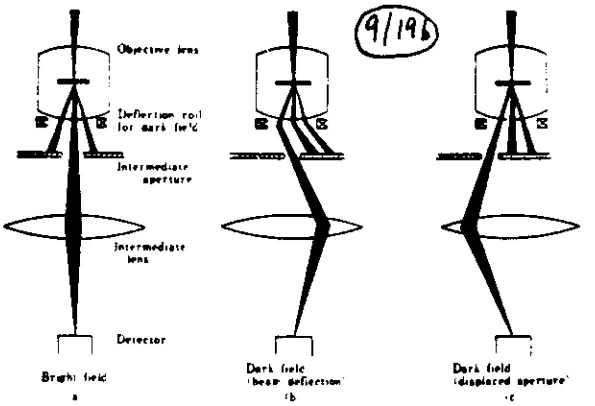
Ray diagram of formation of STEM image and micro-microdiffraction pattern.

9/19c



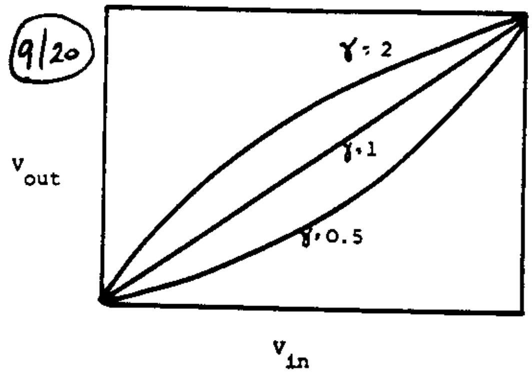
Schematic ray diagram illustrating the reciprocity between TEM (upper row, read left to right) and STEM (lower row, read right to left).

9/19b

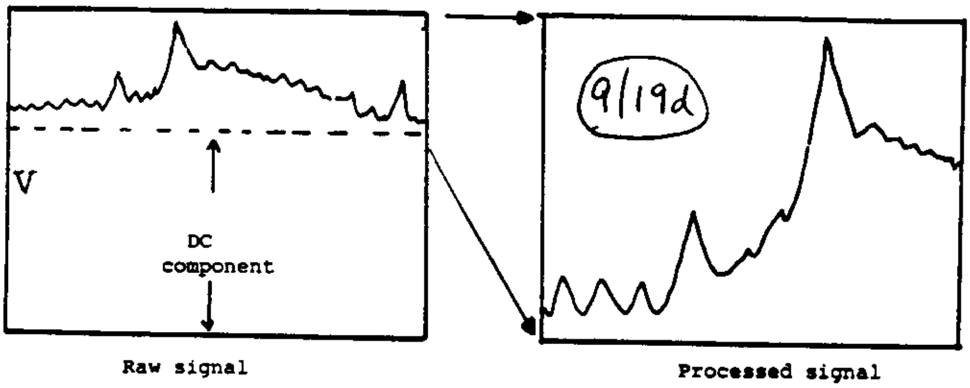


Ray diagrams of formation of bright and dark field images in STEM.

9/20



Gamma processing.



Optimising a signal using contrast and brightness controls.

I am endebted to Prof F. J. Humphreys for much of the material in lectures 9 & 10.