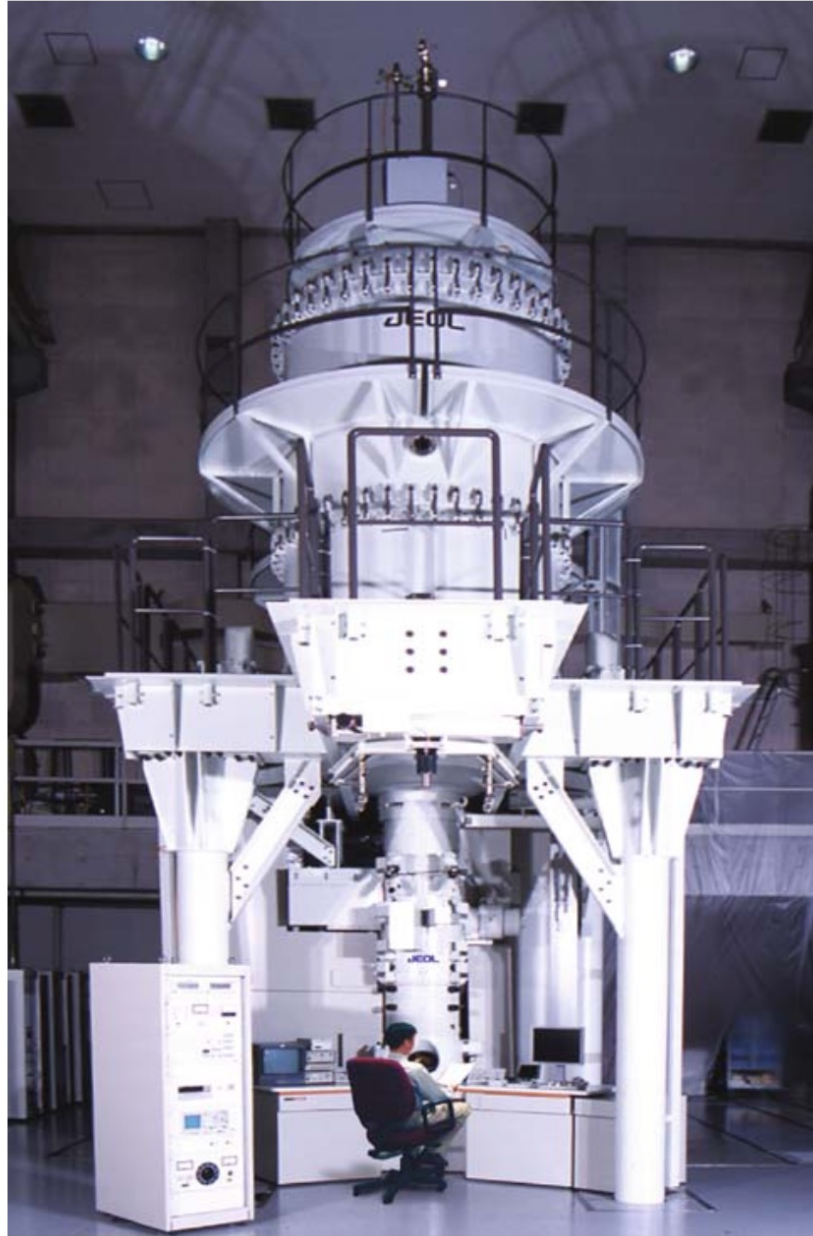


Elements of Electron Diffraction

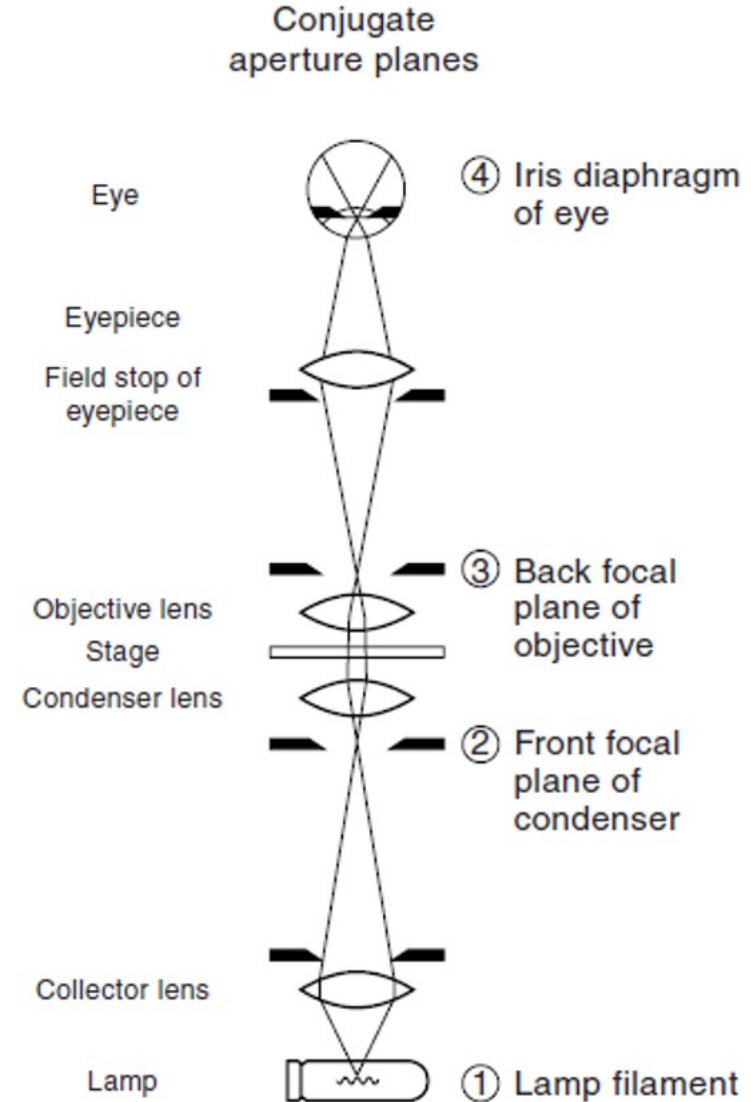
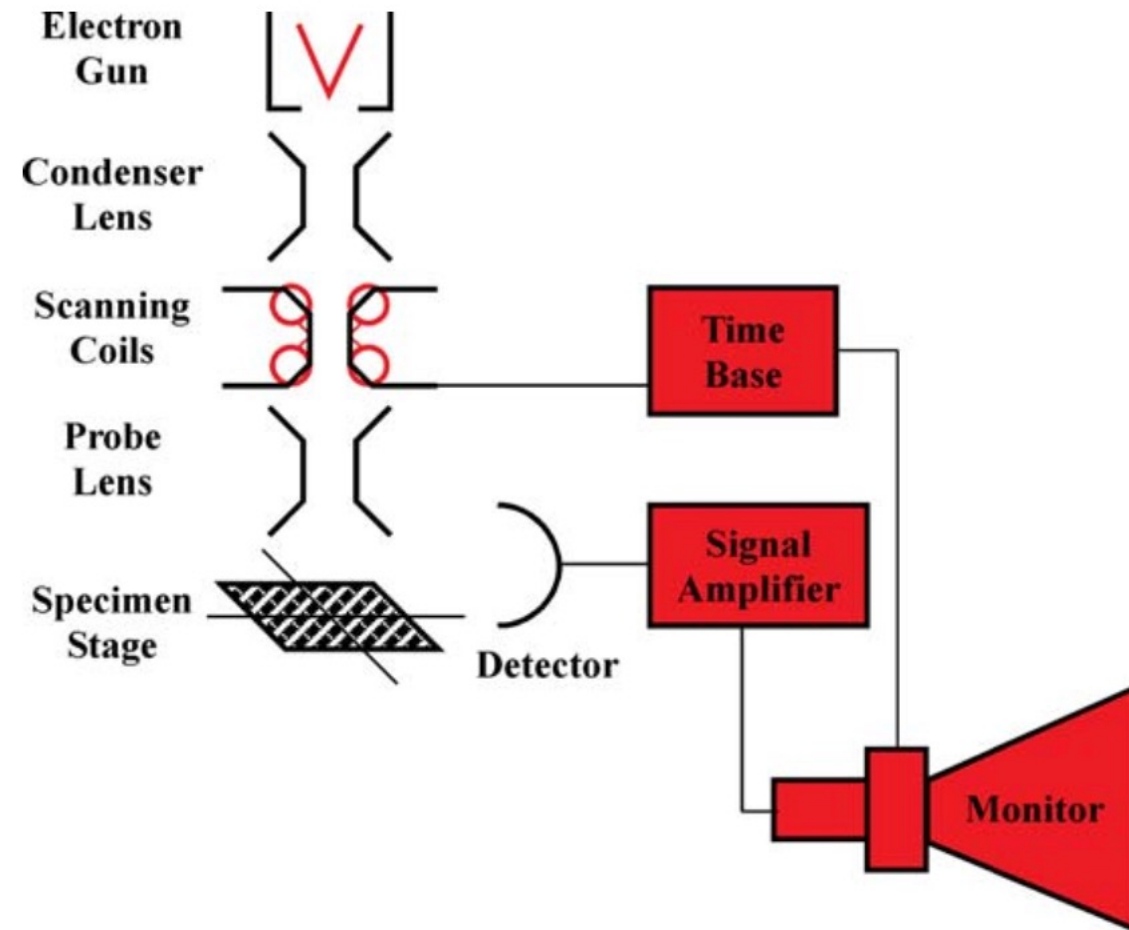
(A)



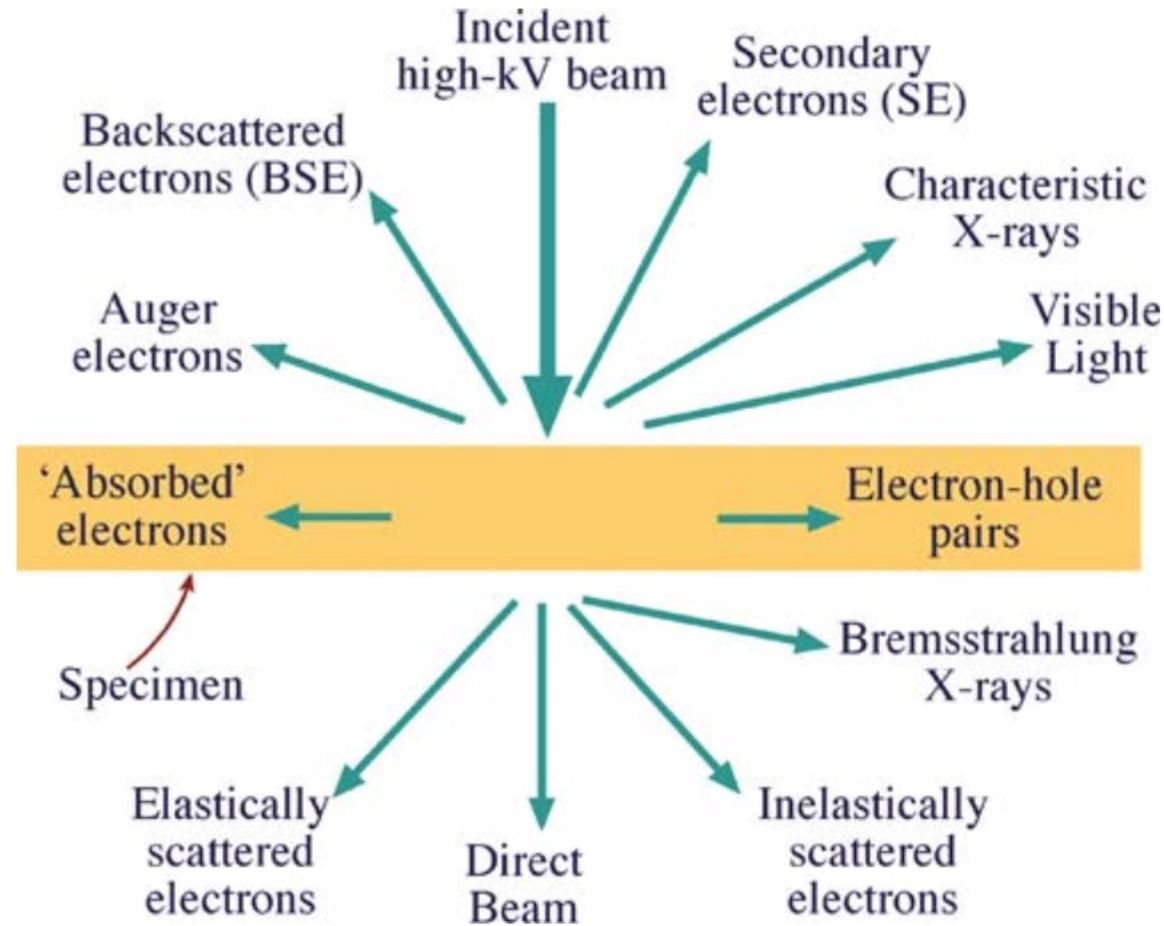
(B)



Different microscopes



Electron beam interaction with materials



Electron wavelengths

$$\lambda = \frac{h}{(2m_0eV)^{1/2}}$$

TABLE 1.2 Electron Properties as a Function of Accelerating Voltage

Accelerating voltage (kV)	Non-relativistic wavelength (nm)	Relativistic wavelength (nm)	Mass ($\times m_0$)	Velocity ($\times 10^8$ m/s)
100	0.00386	0.00370	1.196	1.644
120	0.00352	0.00335	1.235	1.759
200	0.00273	0.00251	1.391	2.086
300	0.00223	0.00197	1.587	2.330
400	0.00193	0.00164	1.783	2.484
1000	0.00122	0.00087	2.957	2.823

Compare this with those that you know:

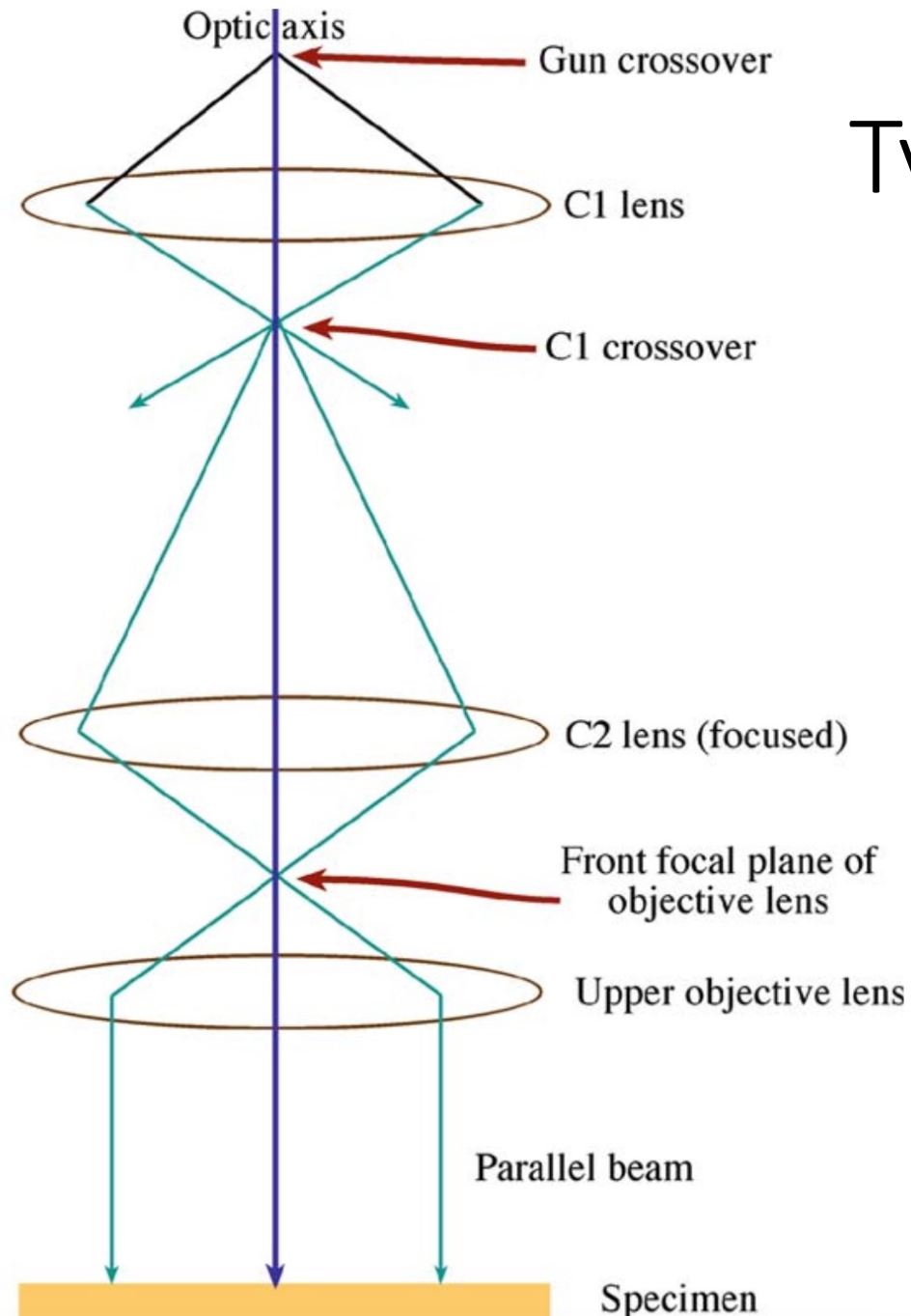
Wavelength of visible light = 400 – 700 nm

Wavelength of X-Rays = 0.154 nm

Why do you want to do electron diffraction ?

- X-Ray diffraction is very good for powdered polycrystalline samples.
- For single crystals and oriented growth, it becomes progressively difficult
 - The plane normal and the incident and diffracted rays should be in the same plane! If it's a single crystal, the plane normal is very hard to find!

(B)

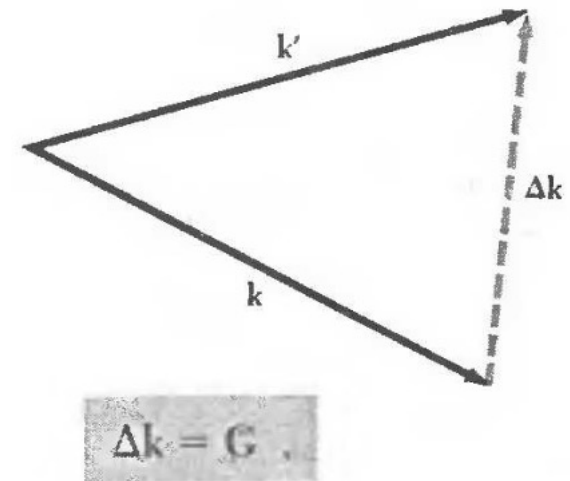
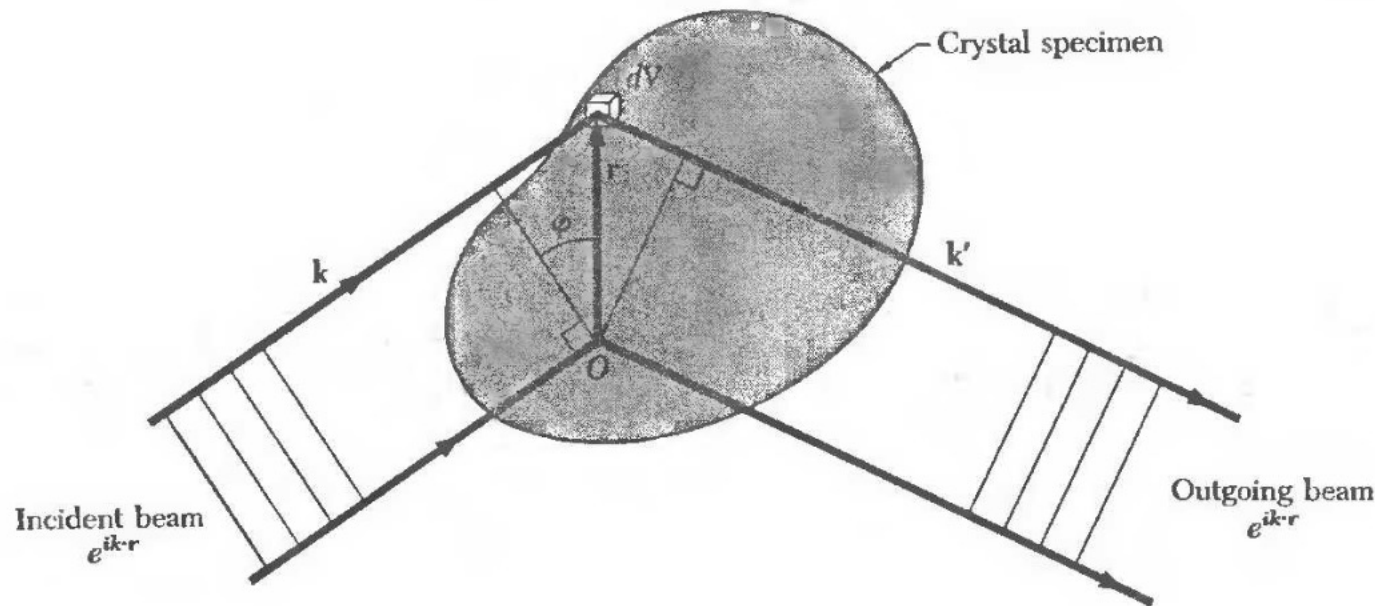


Typical arrangement in a TEM

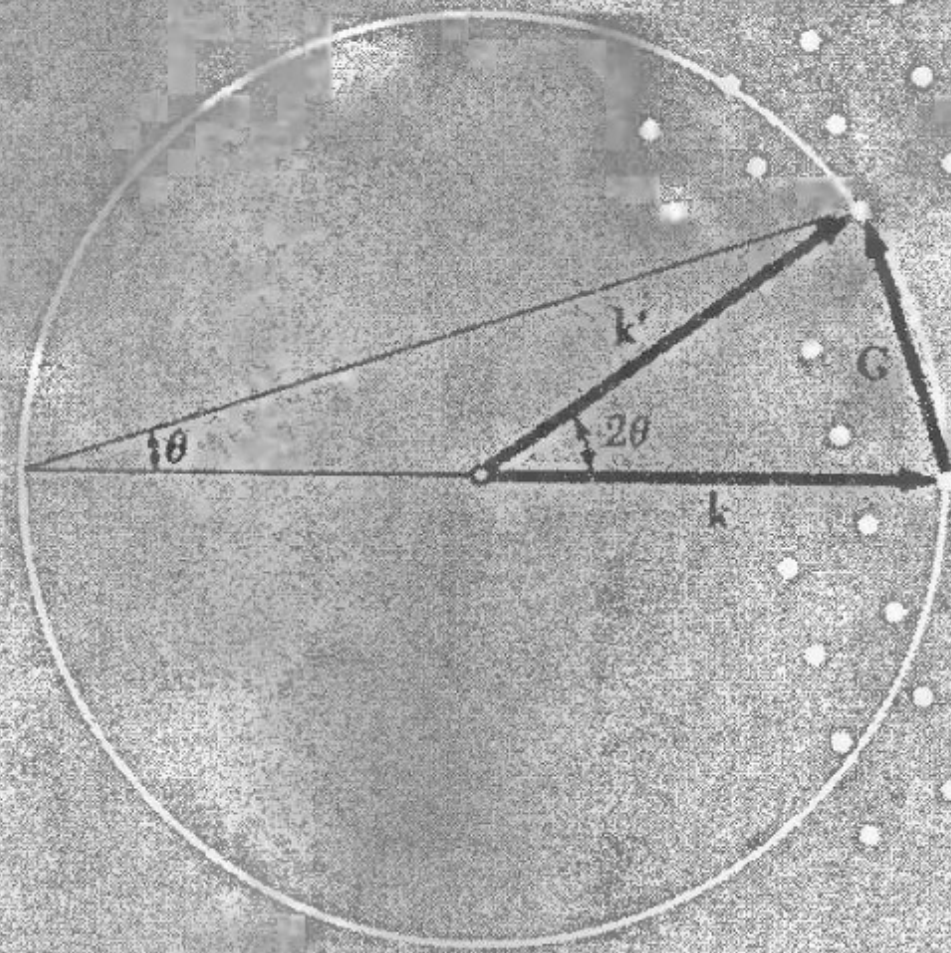
- A collimated beam of electrons are made to incident on the sample
- The wavelength of electrons is smaller than the lattice constants!
- This leads to strongly diffracting beams of electrons.
- What beams diffract, how many diffract, how many planes interact ?

For doing diffraction in transmission:

- Bragg's reflection description is not very helpful for a TEM
- We need to look at the Laue formalism: Via reciprocal lattice!



ΔG is a reciprocal lattice vector



Condition for diffraction (Ewald Sphere)

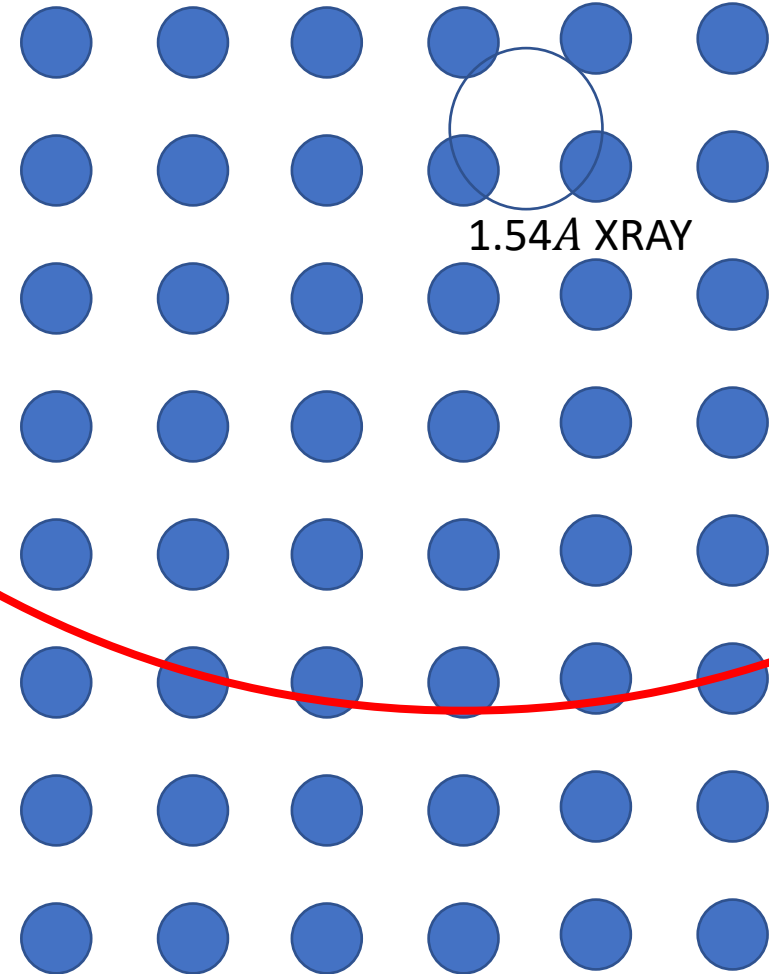
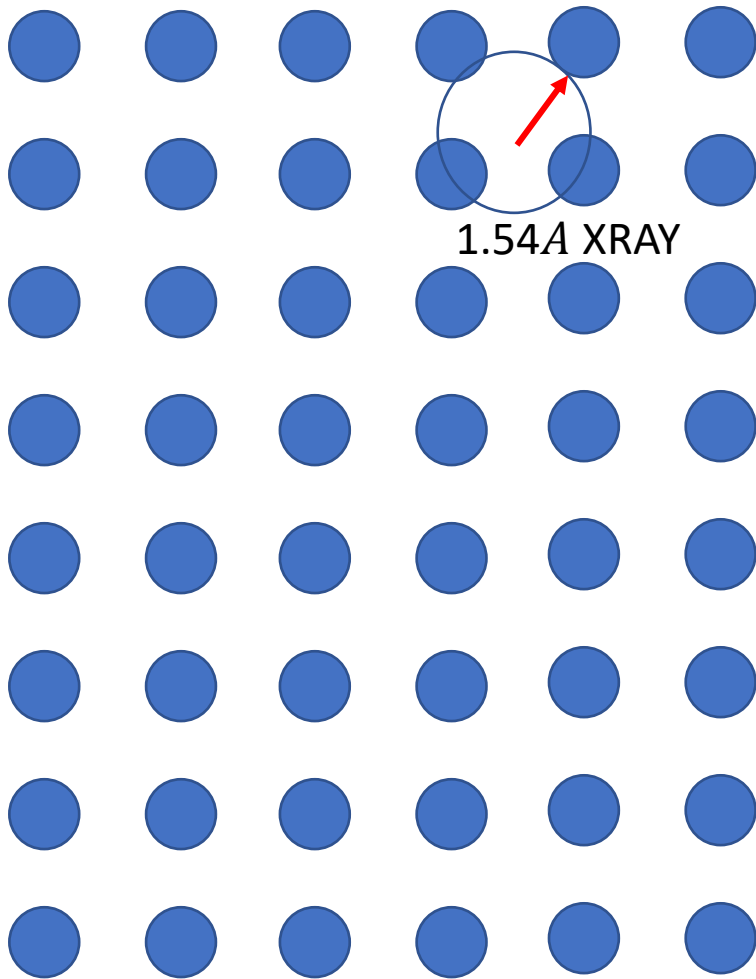
- If the radiation has wavelength λ , draw a sphere of radius $2\pi/\lambda$
- Such that, atleast one point in the reciprocal lattice is coincident
- If, the circle meets another point, then there is diffraction from the set of planes connecting the two lattice points.

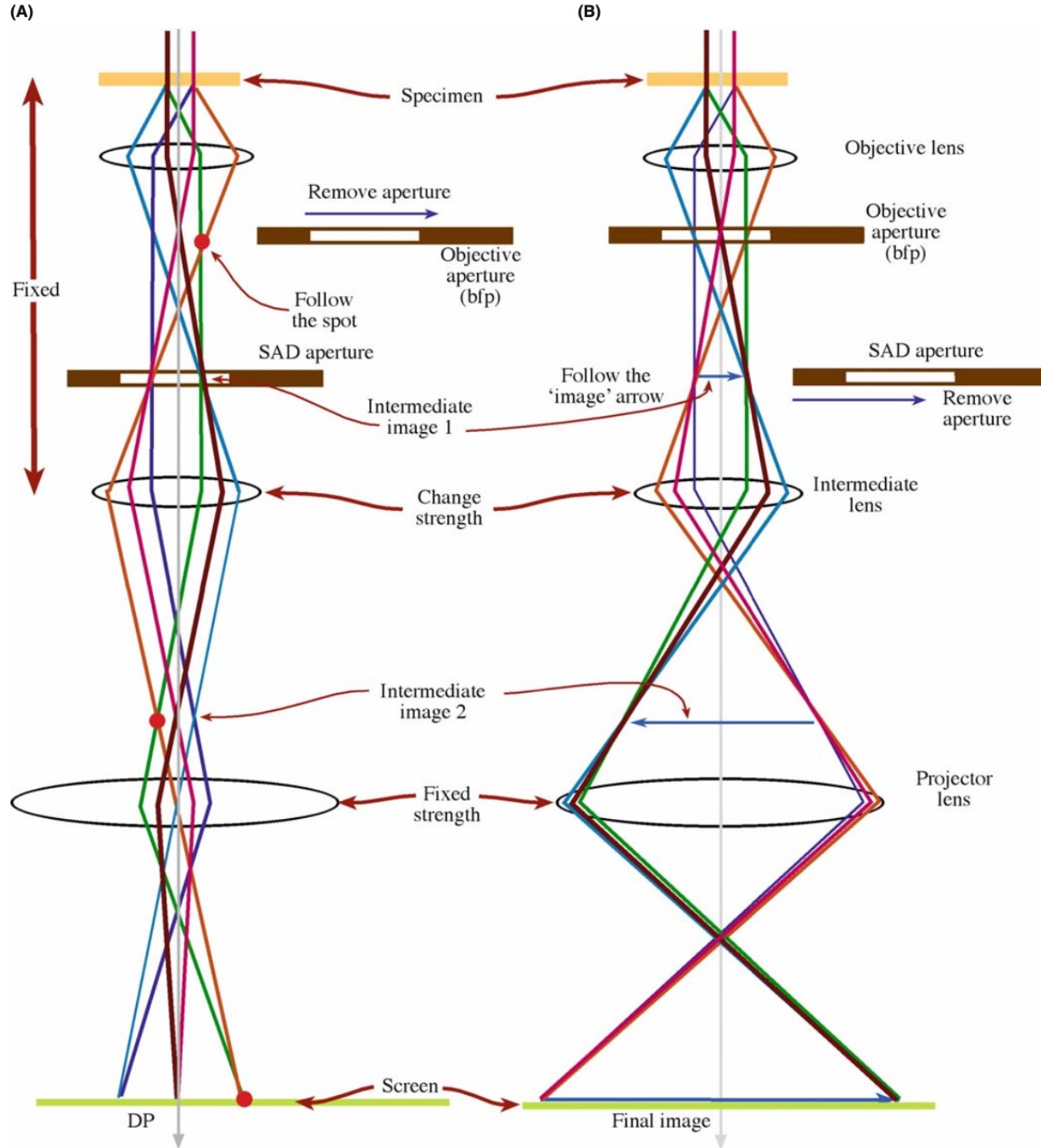
Bottom line:

1. On the Ewald's sphere, atleast two reciprocal lattice points should lie for diffraction
2. The vector joining the two points, gives you a set of planes that diffract!
3. More the number of points on Ewald's surface, more set of planes diffract simulataneously.

Now it is easy to see, why electron diffraction is great!

Ewald sphere for a electron beam $R_{electron} = R_{XRAY} * 10$

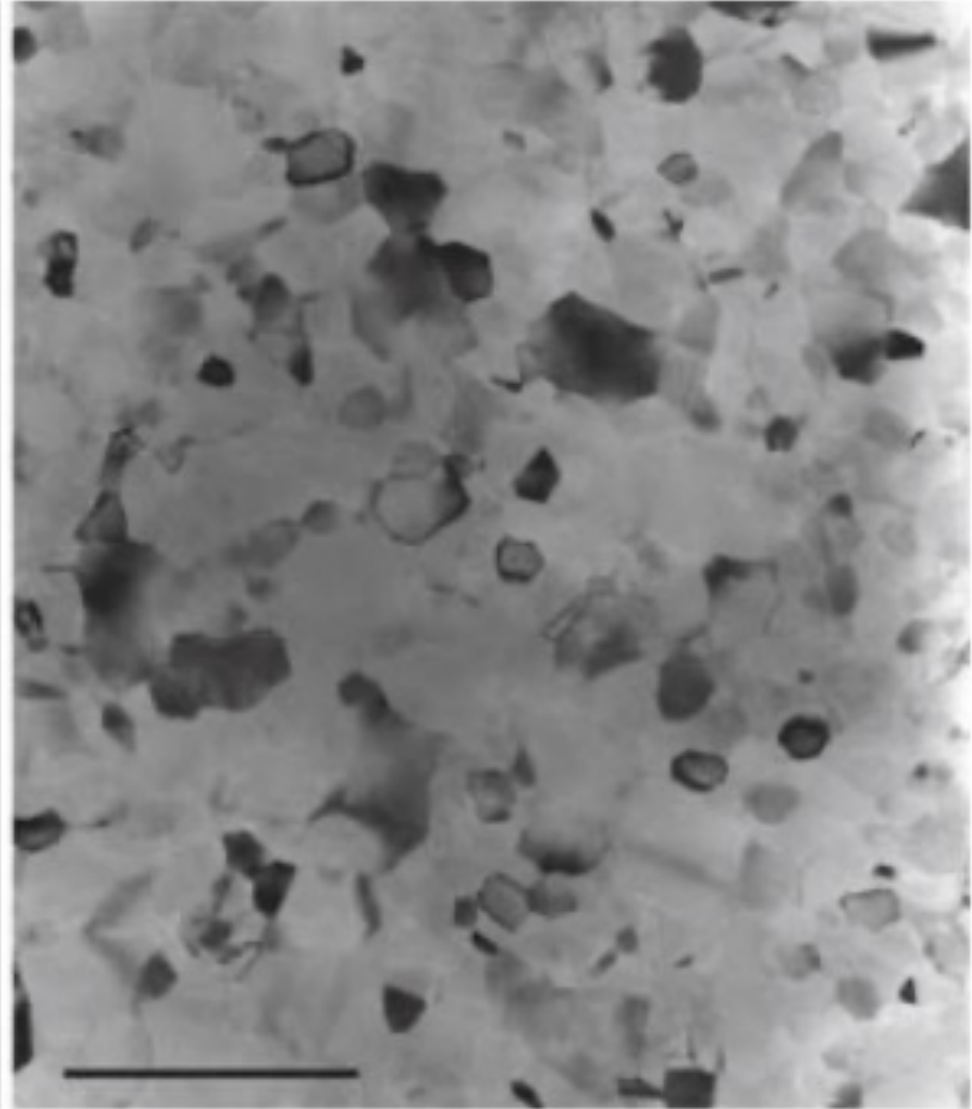




Two Imaging Techniques

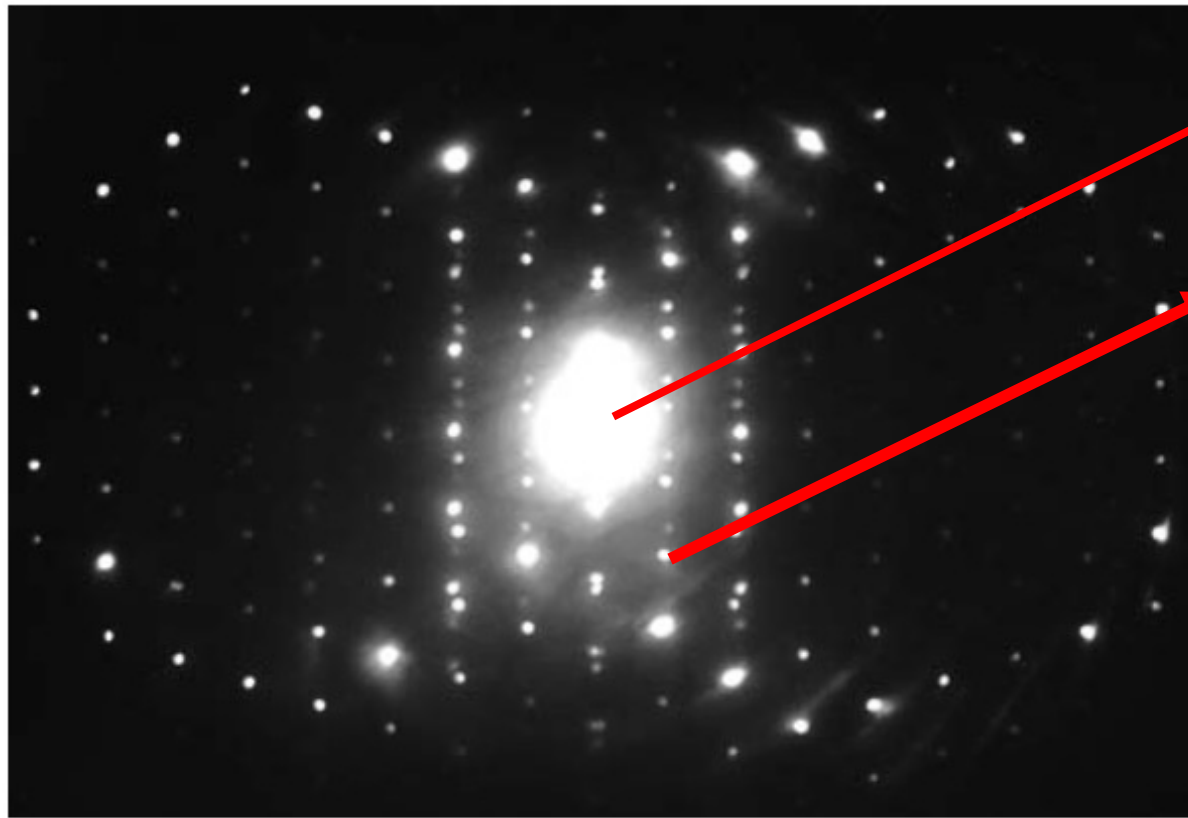
1. Image the diffraction patterns
2. Image the sample

Image formation



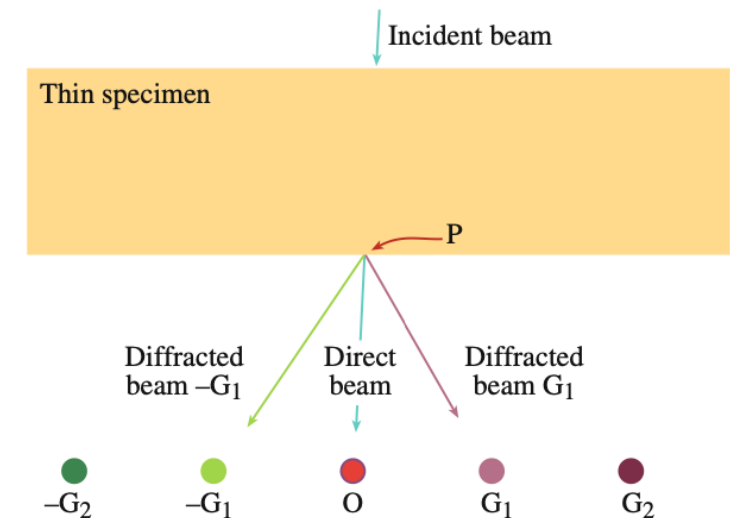
What are the bright and the dark regions ?

- What are bright and dark regions in the diffraction image ?

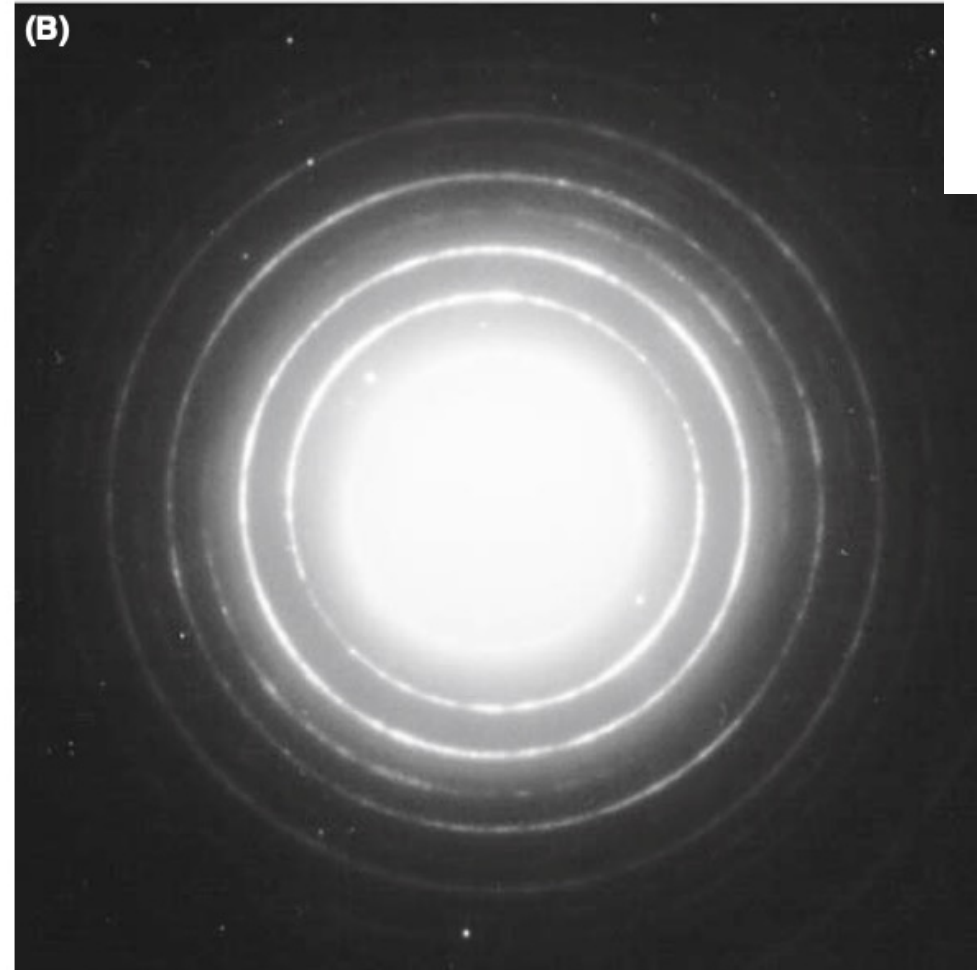
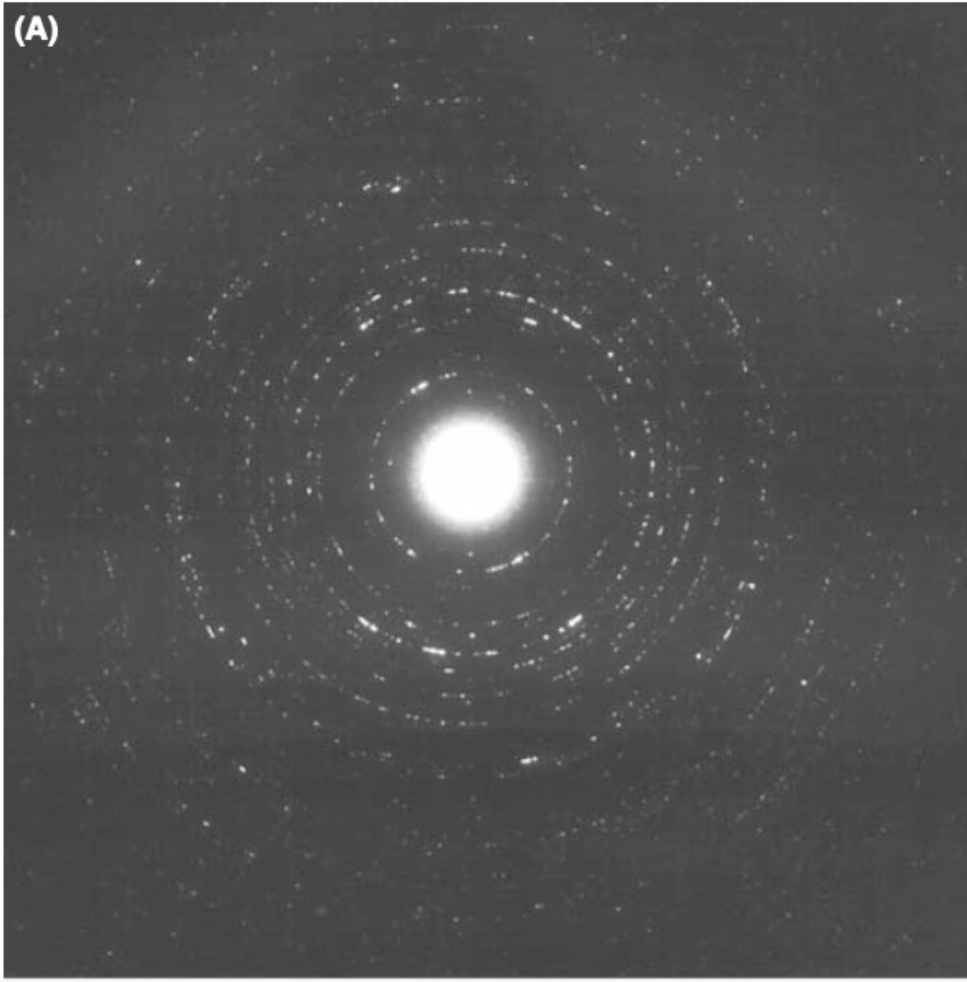


Central direct beam

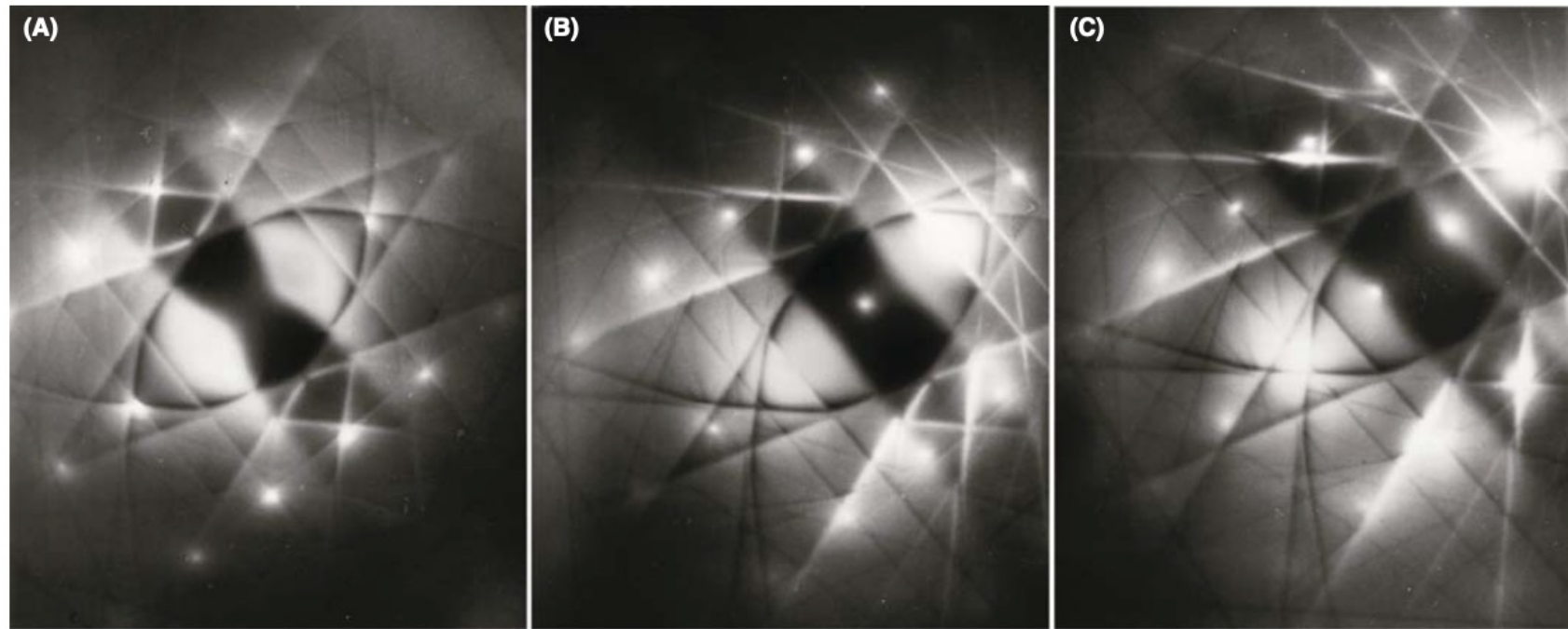
Diffracted beams



Diffraction measurements as a measure ρ^f crystallinity



Kikuchi lines



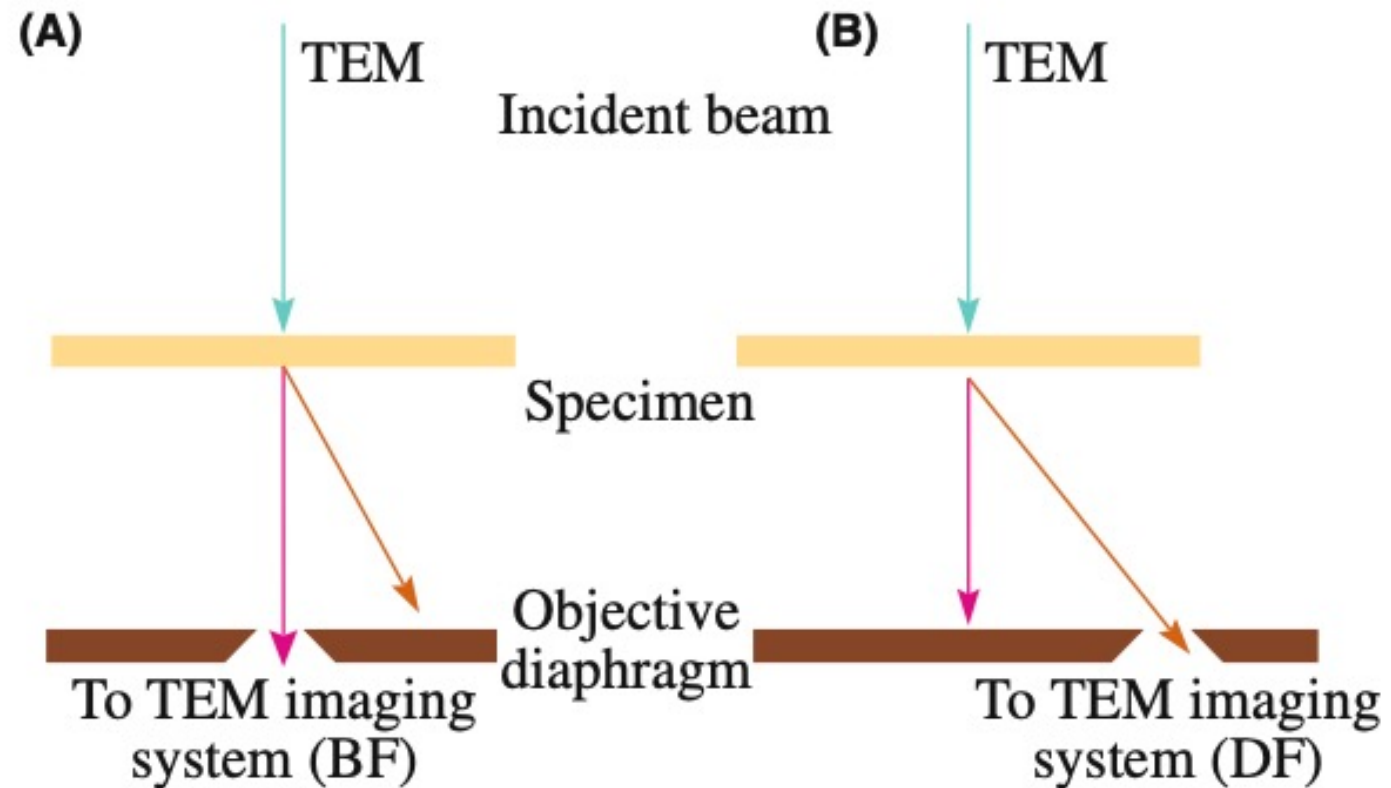
- In thick specimens, inelastically scattered electrons form secondary diffraction patterns.
- The scattered electrons can then again be diffracted, giving streaks of lines

Imaging in TEM

- Bright and dark field imaging:

If the direct beam is imaged, you have the bright field

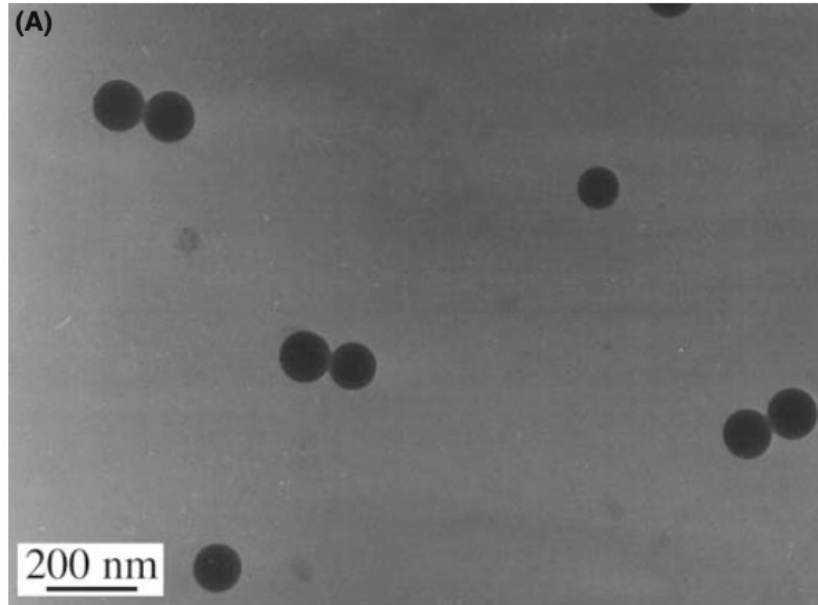
If a diffracted beam is imaged, you have a dark field imaging. (from selected area)



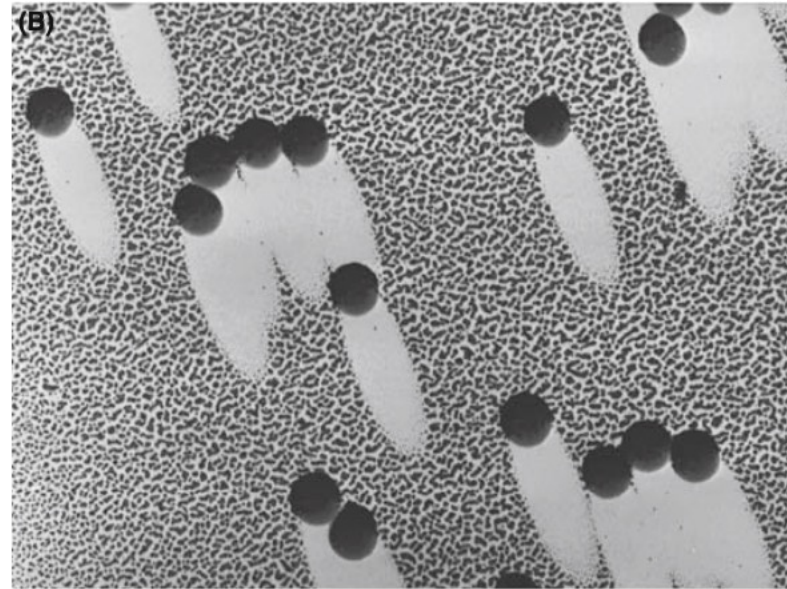
Origin of contrast

- Mass-thickness contrast
- Z-contrast
- Diffraction contrast
- Phase contrast

Thickness and Z contrast contrast in TEM



Latex on carbon grid

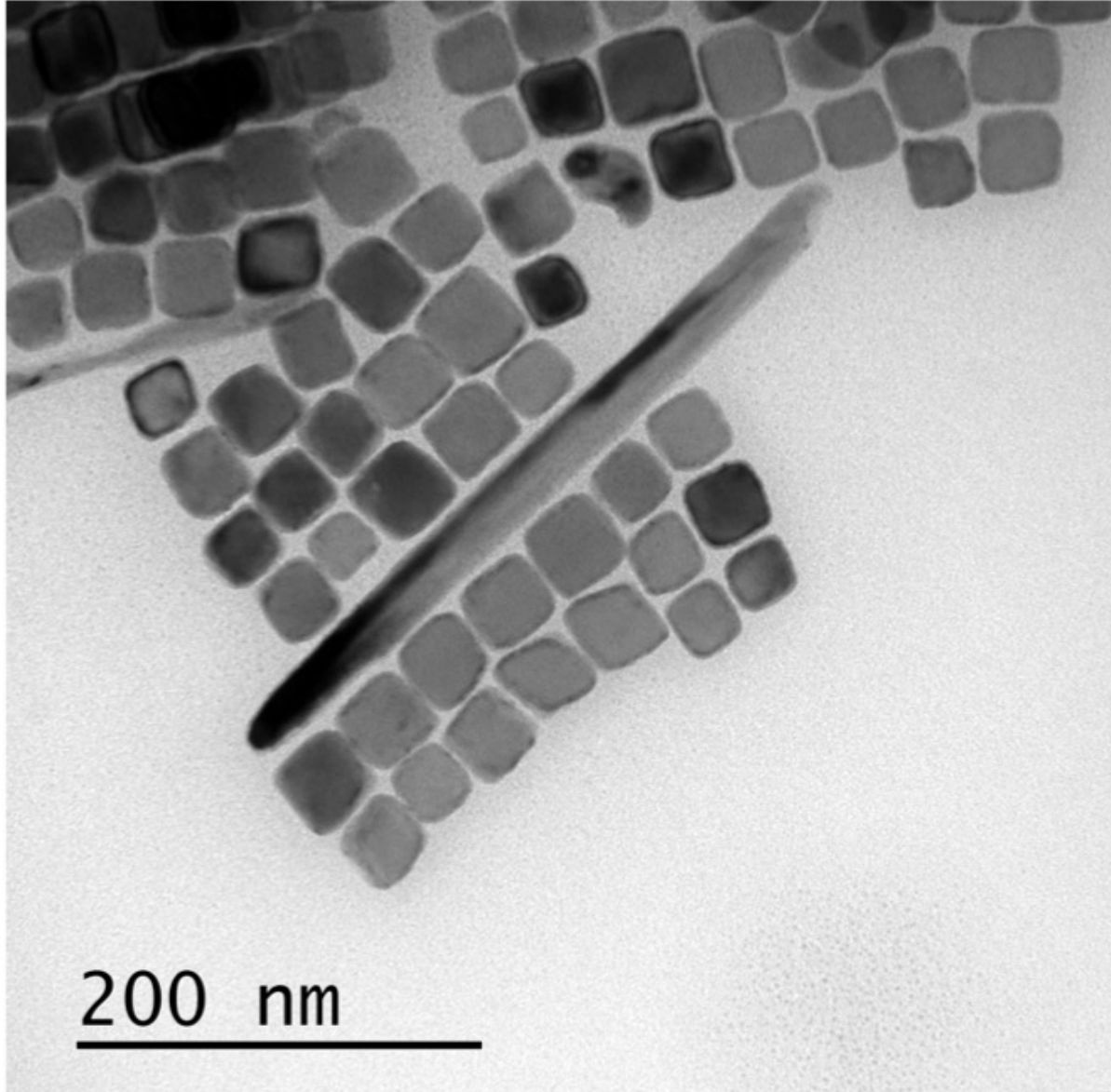


Latex on carbon grid with shadow coated Au

Shadow is coated by using a very thin metal coated at oblique angles

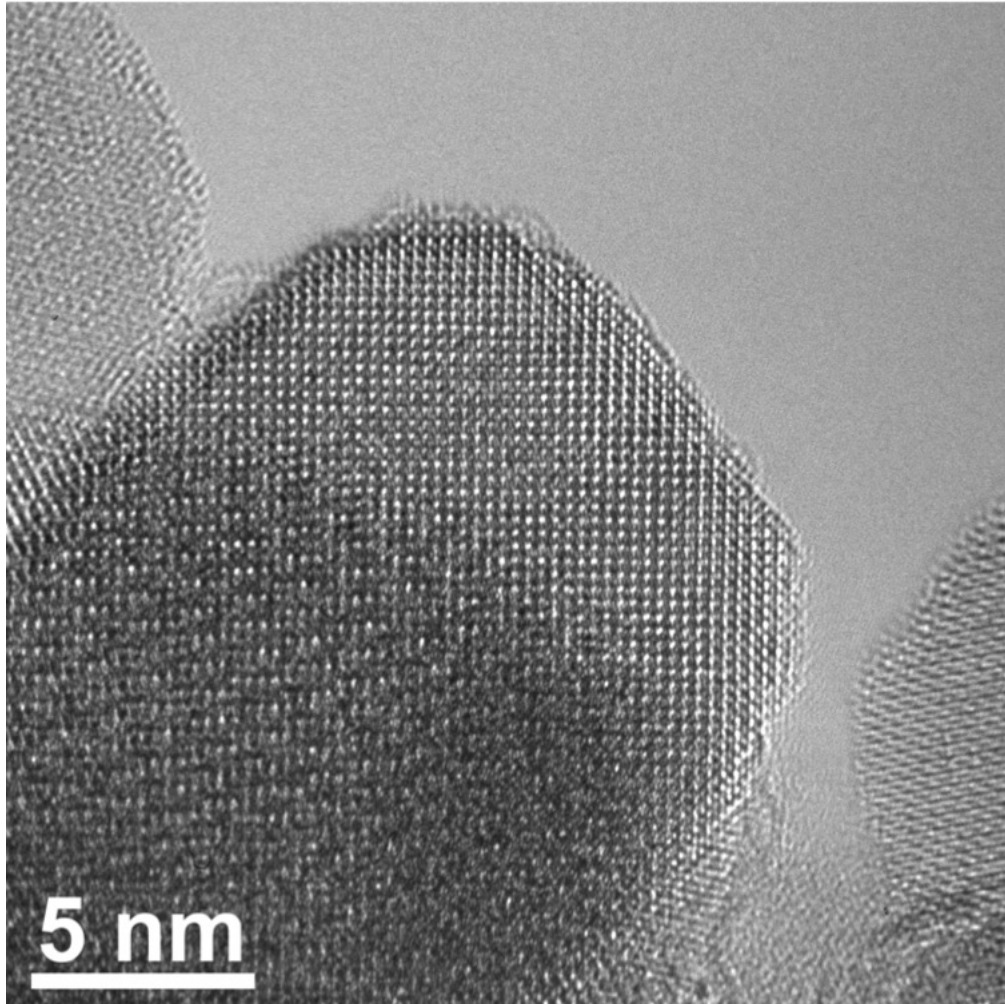
Why is the shadow appearing bright ?

Cubes of crystalline Cu



- Why are Cu appearing dark ?

Phase Contrast (HR TEM)



lattice fringes in iron oxide nanoparticles

- Moire fringes are obtained, when scattered beam interferes with the original beam!
- Scattered beam is phase modulated due to the lattice periodicity
- Two phase modulated beam gives Moire fringes.
- The bright/dark spots are not atoms! They only correspond to the periodicity !

Many more things to do In TEM

- Selected area electron diffraction
- Converged beam electron diffraction
- Scanning transmission electron microscope
- Electron energy loss spectroscopy

Indexing a diffraction pattern

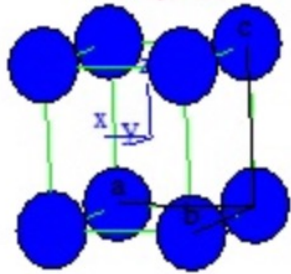
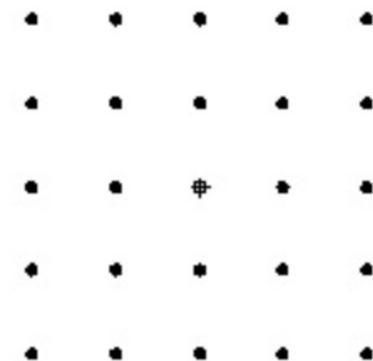
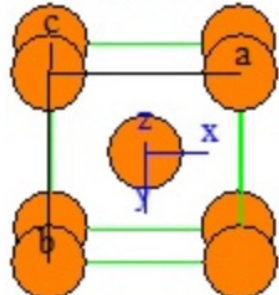
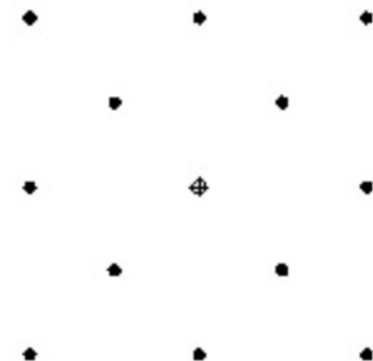
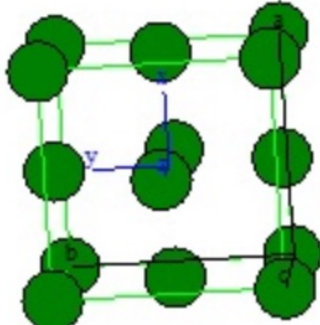
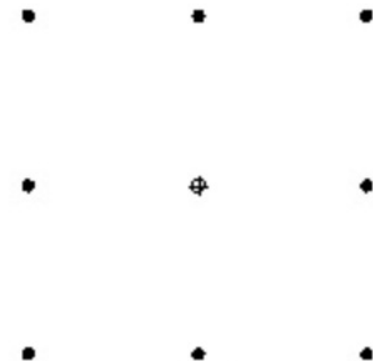
- Systemic absences

$$F_{hkl} = \sum_i f_i e^{2\pi i(hx_i + ky_i + lz_i)}$$

For any atom 'i' in the unit cell

For BCC,

$$F = f \left\{ 1 + e^{\pi i(h+k+l)} \right\} \quad \begin{array}{l} F = 2f \text{ if } h + k + l \text{ is even,} \\ F = 0 \text{ if } h + k + l \text{ is odd.} \end{array}$$

S. No.	Crystal / image	Selection Rule	Reciprocal Lattice for [001] zone axis
1.	Simple Cubic 	All permitted	
2.	Body Centered Cubic 	$(h+k+l) = \text{even}$	
3.	Face Centered Cubic 	$(h,k,l) \rightarrow$ all odd or all even	

Sample grid and holders

