Instructor: Dr. C.Wang

EMA 6518 Course Presentation

Lenses and Apertures of A TEM

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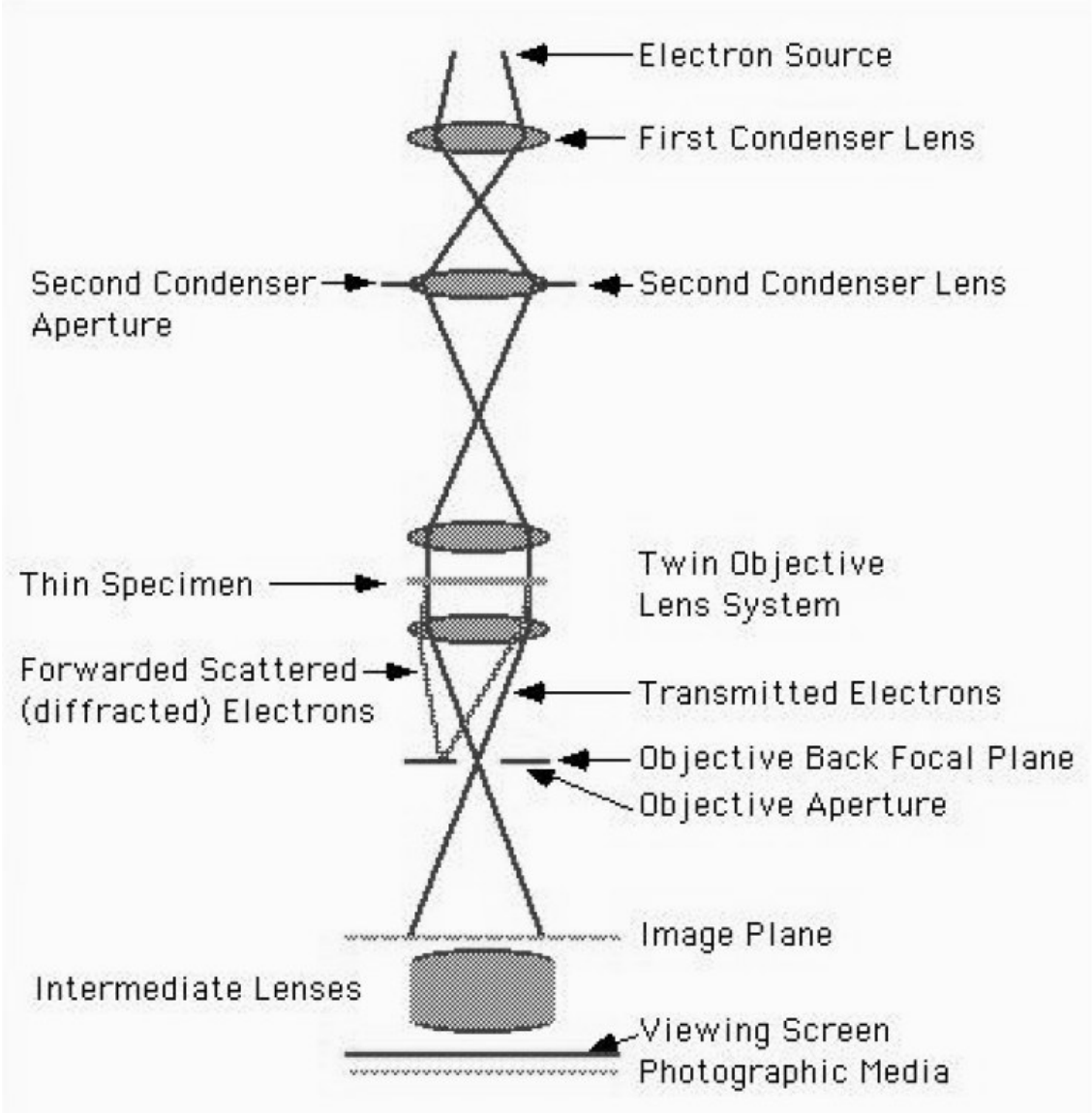
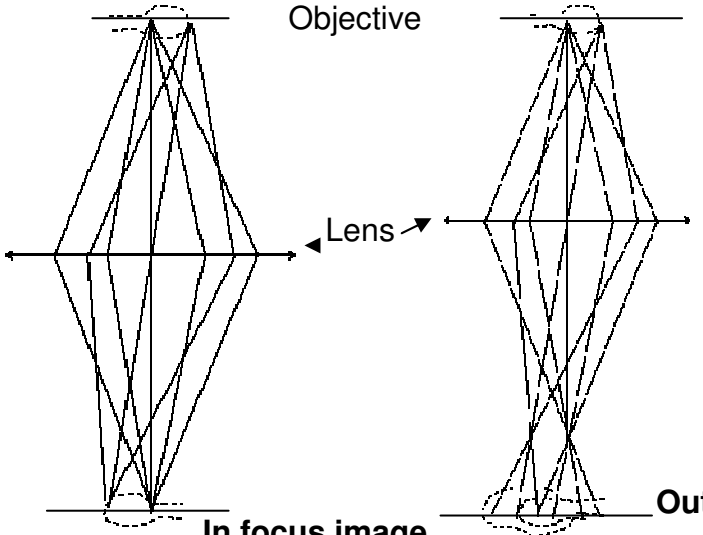
Outline

- Electron Optics of A TEM
- The Lenses in a TEM
- Condenser Lenses and Aperture
- Objective Lens and Aperture
- Intermediate lens
- Projector Lens

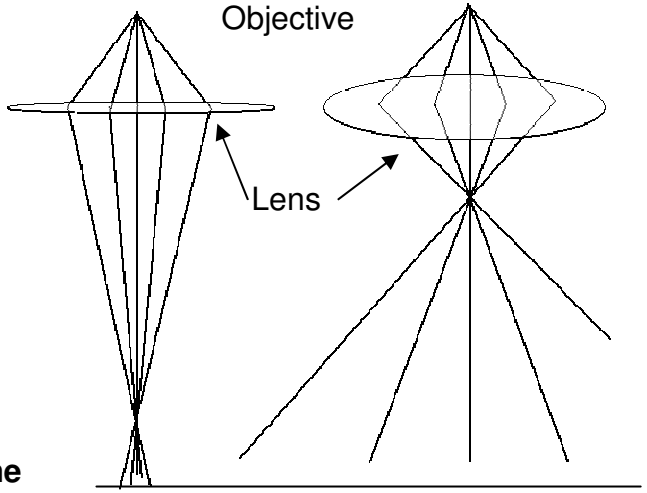
Electron Optics of A TEM



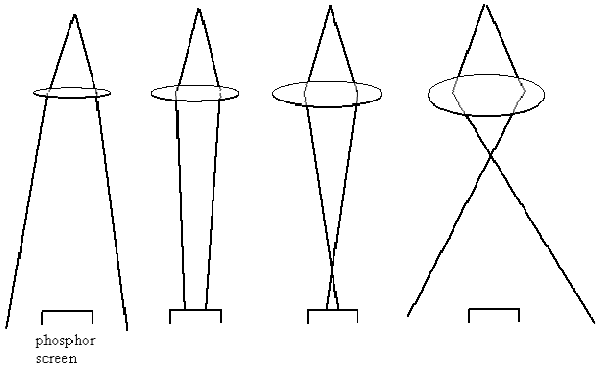
Lens



In focus image **Out of focus image**



Thin lens **Thick lens**

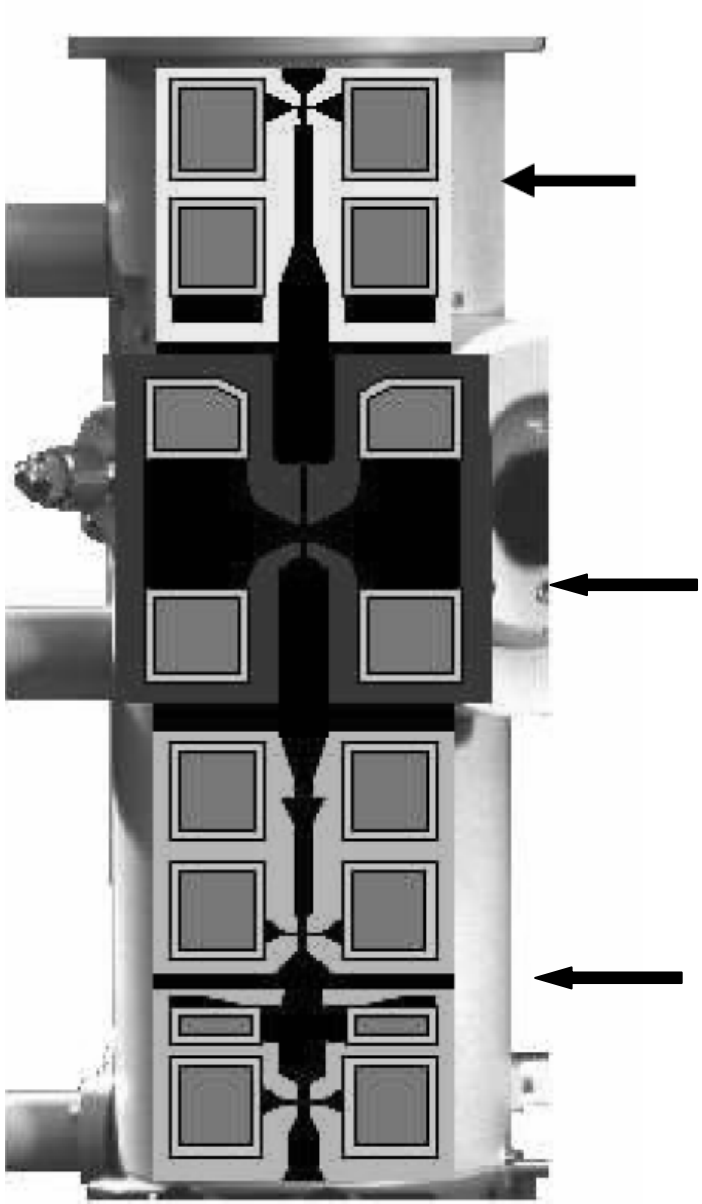


Under focus **over focus**

The source (or object) is in the same position relative to both lenses, but note that the strong lens focuses the beams into a cross-over at a point much ***closer*** to the lens. A ***strong*** lens has a ***short*** focal length.

When an electron lens is turned up (knob turned clockwise) above the focal position, it is said to be '***over- focussed***'; when it is turned down it is said to be '***under- focussed***'.

The Lenses in a TEM



Condenser lenses(two)-control how strongly beam is focused (condensed) onto specimen. At low Mag. Spread beam to illuminate a large area, at high Mag. strongly condense beam.

Objective lens-focus image (image formation) and contribute most to the magnification of the image.

Four lenses form magnification system-determine the magnification of the microscope. Whenever the magnification is changed, the currents through these lenses change.

Electromagnetic Lenses

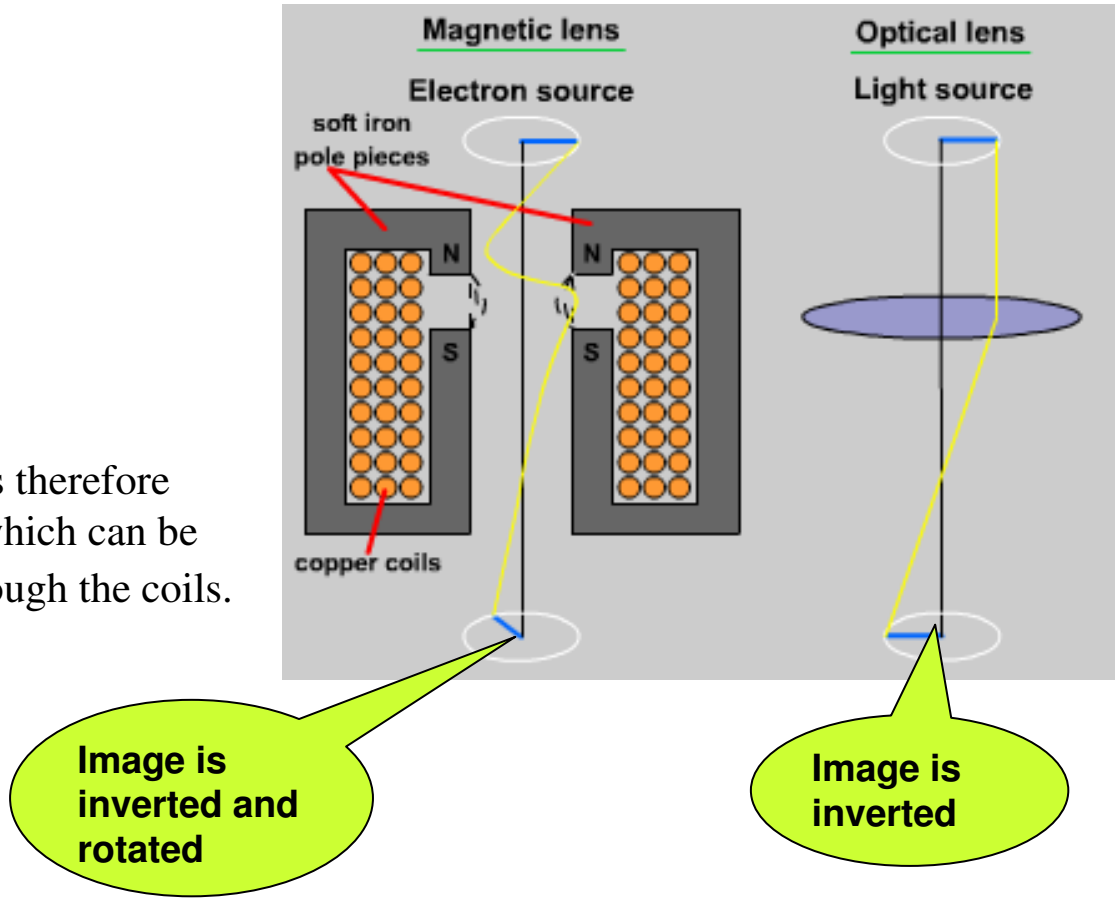
Electron lenses are the **magnetic equivalent** of the glass lenses in an optical microscope and to a large extent, we can draw comparisons between the two. A strong magnetic field is generated by *passing a* **current through a set of windings**. This field acts as a convex lens, bringing off axis rays back to focus. The image is rotated, to a degree that depends on the strength of the lens. Focal length can be altered by changing the strength of the current.

$$\mathbf{F} = -e\,(E + \mathbf{v} \times \mathbf{B})$$
$$|\mathbf{F}| = ev\mathbf{B}\sin(\mathbf{v},\mathbf{B})$$

E: strength of electric field
B: strength of magnetic field

e/v: charge/velocity of electrons

The focusing effect of a magnetic lens therefore increases with the magnetic field B, which can be controlled via the current flowing through the coils.

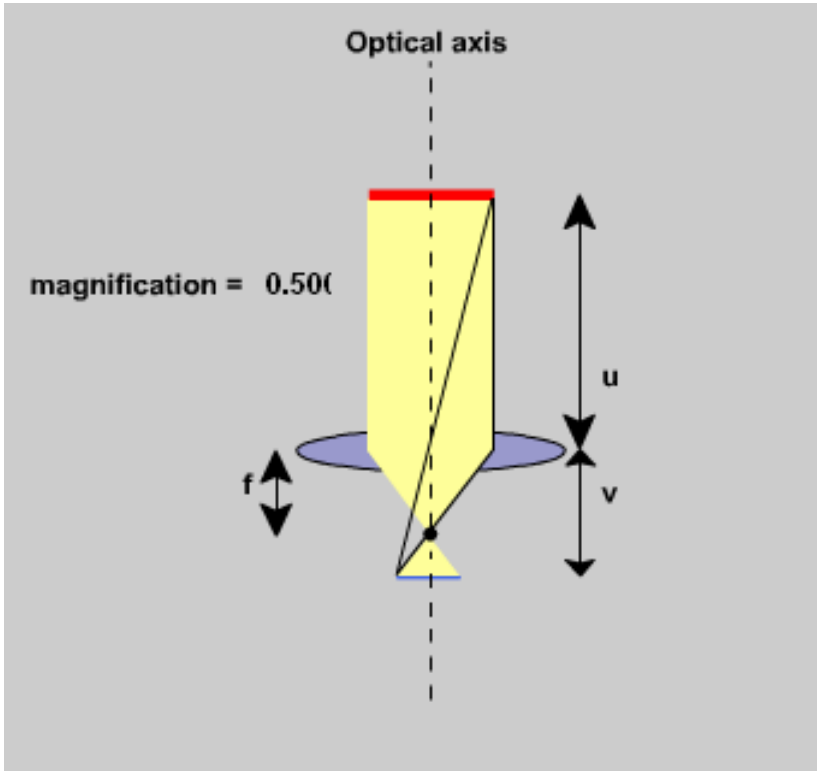


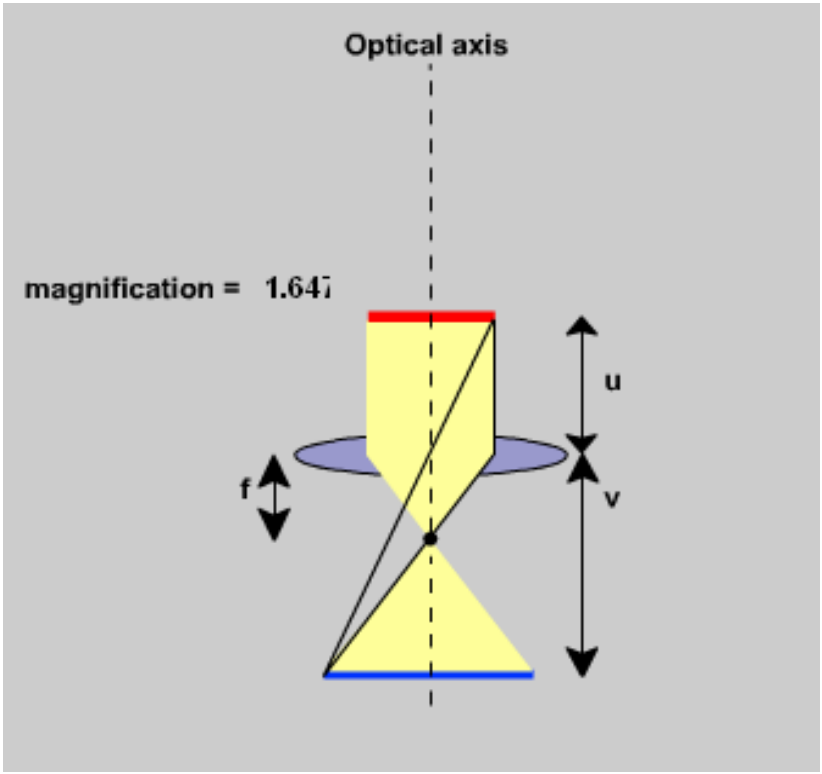
Condenser lenses

- This lens is used to form the beam and limit the amount of current in the beam and it is also used to control the diameter of the electron beam.
- The purpose of the condenser lens is to focus the light onto the specimen. The stream is condensed by the condenser lens (usually controlled by the "coarse probe current knob").
- If the condenser current increases, the beam focuses well above the aperture and a large part of the beam is intercepted by the aperture and hence the current is reduced.
- It works in conjunction with the condenser aperture to eliminate the high-angle electrons from the beam.
- Condenser lenses are most useful at the highest powers (400X and above).

Condensing Optics

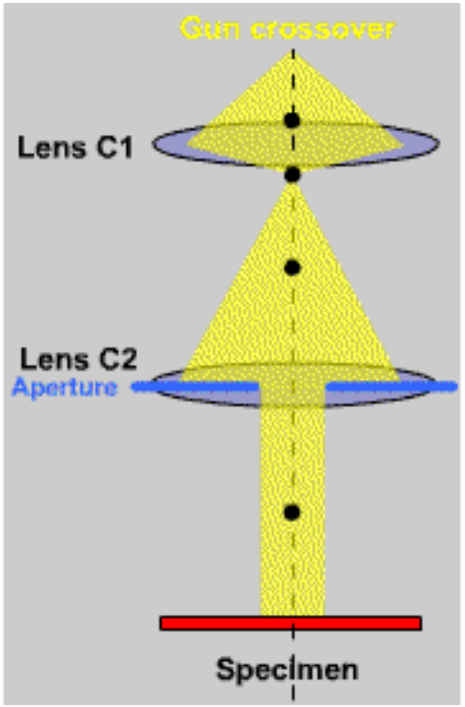
In microscopy, lenses are often used to demagnify (make smaller) the diameter of the beam. In this case it is more appropriate to draw the ray diagram.





Double Condenser Lens

- The double condenser system or illumination system consists of two or more lenses and an aperture. It is used in both SEM and TEM. Its function is to control spot size and beam convergence.
- Two or more lenses can act together and their ray diagrams can be constructed using the thin lens approximation for each of them.
- The diagram below shows the ray diagram for the double condenser system. The black dots represent the focal point of each lens.



Advantage of Double Condenser Lens

- Illumination of smaller areas reduces irradiation of specimen areas outside the field of view which acts to cut down on the background scattering from such areas, and also reduces the total accumulation of contamination on the specimen.

- Since C1 is closer to the source than C2 it has a larger acceptance angle (aperture) and therefore collects more electrons from the source than C2 alone. The higher efficiency of the double condenser system means that the brightness of the gun can be reduced with consequent increase in filament life. If C1 is highly excited (to produce a very small illuminating beam when C2 is focused) than a large proportion of the electrons focused by C1 fall outside the aperture of C2. This loss of illuminating beam intensity may consequently force the operator to increase the gun brightness (shortening filament lifetime) to achieve satisfactory working conditions.

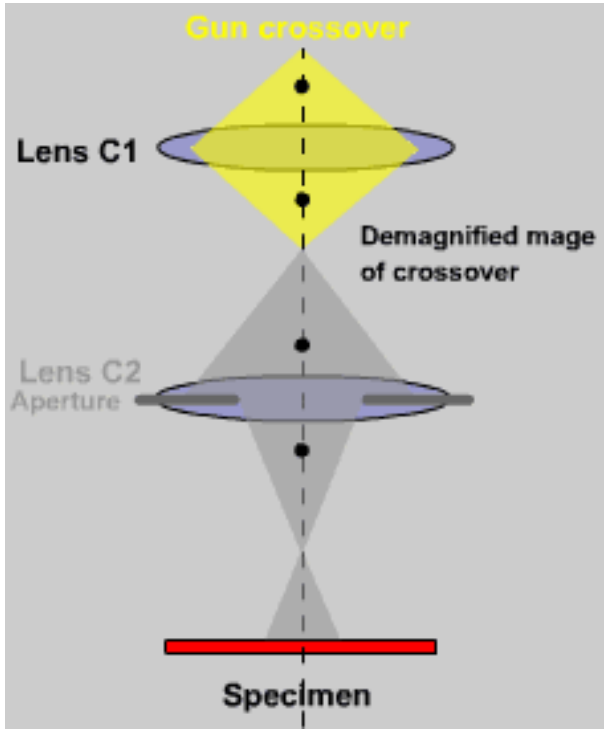
- Image contrast is improved as a result of the increased coherence of the effectively smaller electron source.

First condenser lens (C1)

C1, the first condenser lens, is shown highlighted in the diagram below.

Its function is to:

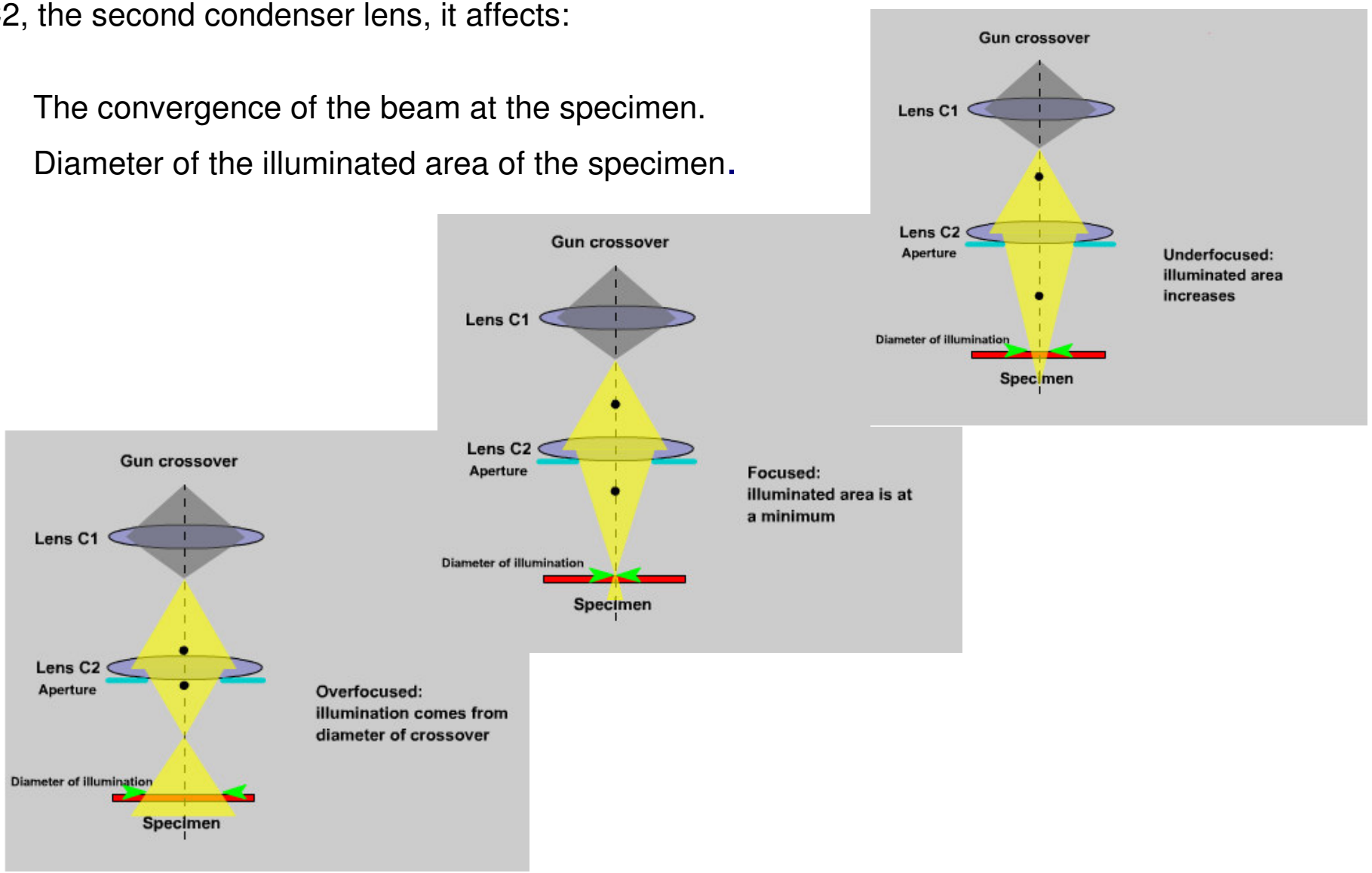
- Create a demagnified image of the gun crossover
- Control the minimum spot size obtainable in the rest of the condenser system.



Second condenser lens (C2)

C2, the second condenser lens, it affects:

- The convergence of the beam at the specimen.
- Diameter of the illuminated area of the specimen.



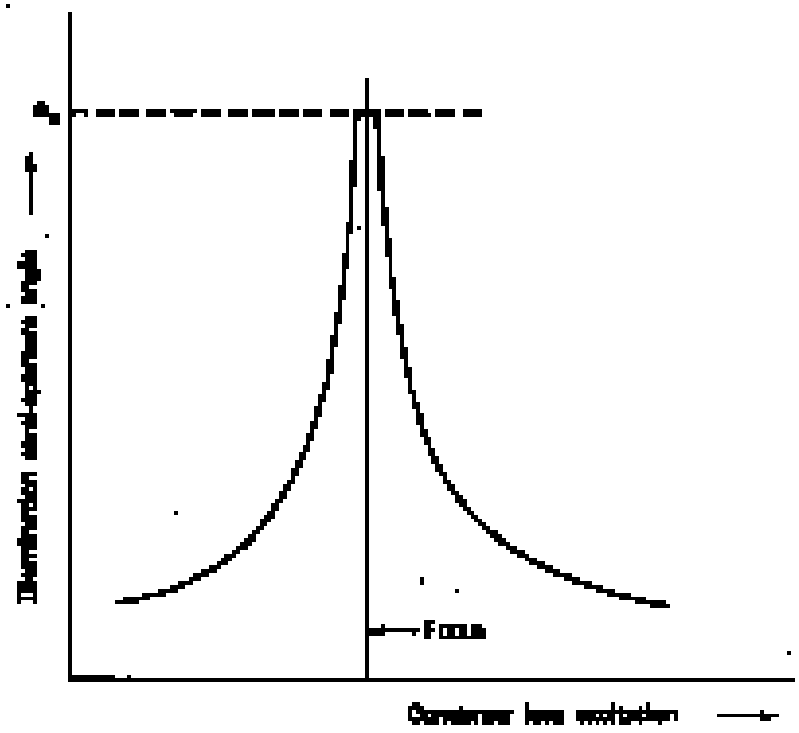
Condenser Aperature

- Apertures in each lens limit the amount of electrons striking the specimen (protecting it from excessive irradiation) and limit the number of x-rays generated from electrons hitting parts of the microscope column. The size of the C2 aperture determines the maximum semi-angular aperture of the illumination, ac, as viewed from the specimen. When crossover is focused by the condenser lens on or near the object plane, ac is a maximum and decreases for smaller or larger condenser currents.

- The larger the aperture angle, the greater the maximum illumination intensity, but in general the poorer the image quality. When C2 is defocused, the semi-angular angle is defined not by the size of the condenser aperture but by the size of the crossover image and its distance from the specimen.

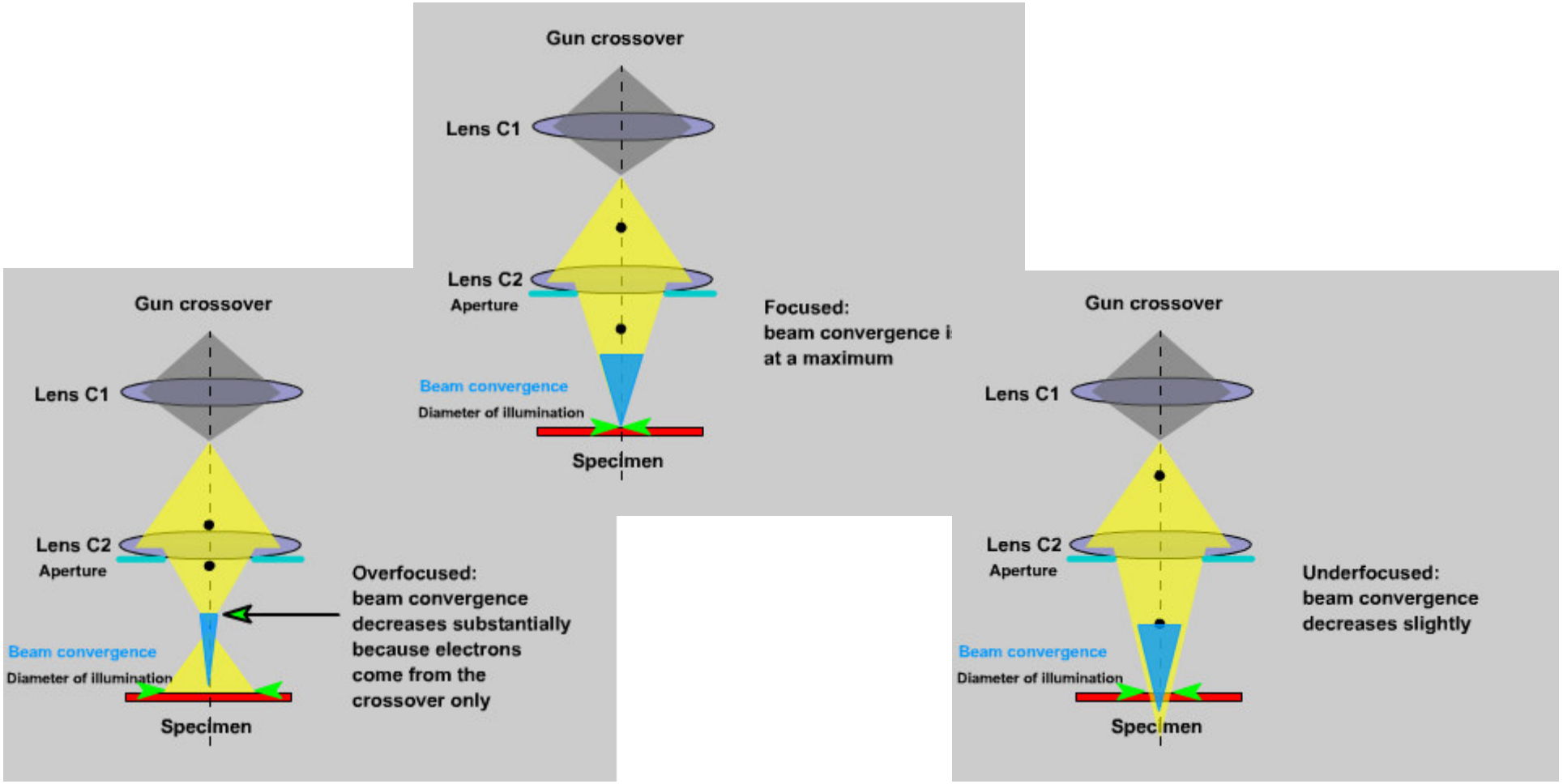
Variation in aperture angle with respect to the C2 lens excitation

- C1 often has a fixed aperture and C2 a variable aperture (with centering controls). As the strength of C1 increases more electrons are lost outside the C2 aperture. In practice, the focal length of C1 is usually set to give a particular minimum spot size and the focal length of C2 is adjusted to vary the beam spread at the specimen.



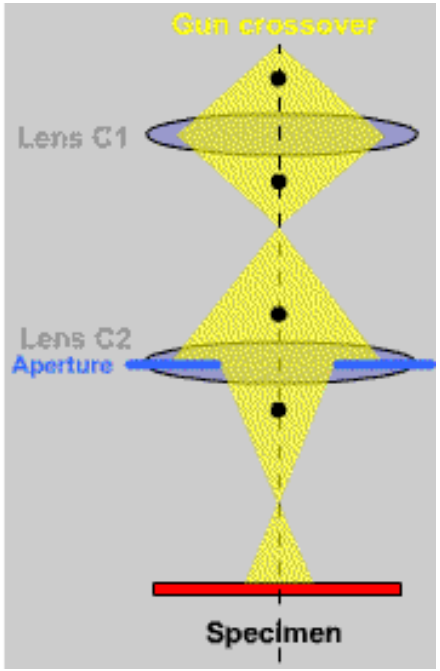
Beam convergence

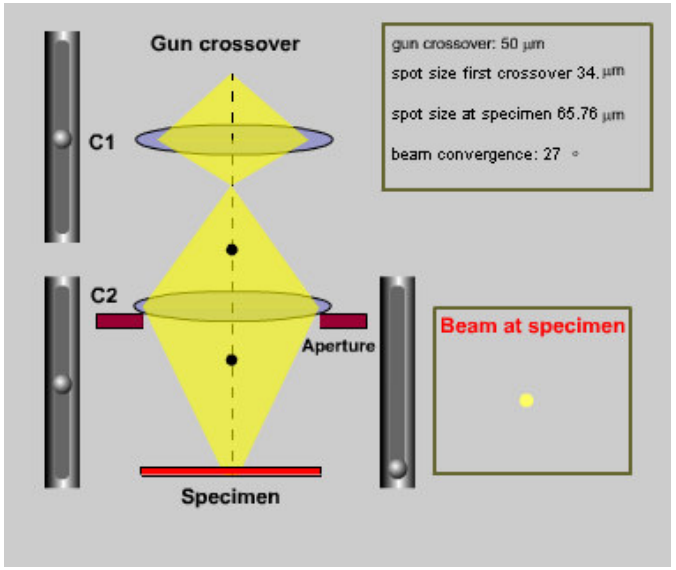
- The state of focus makes a big difference to the beam convergence at any point on the specimen.
- The convergence is defined as the angular range from which the electrons incident on a point appear to come. This is shaded blue in the diagram.

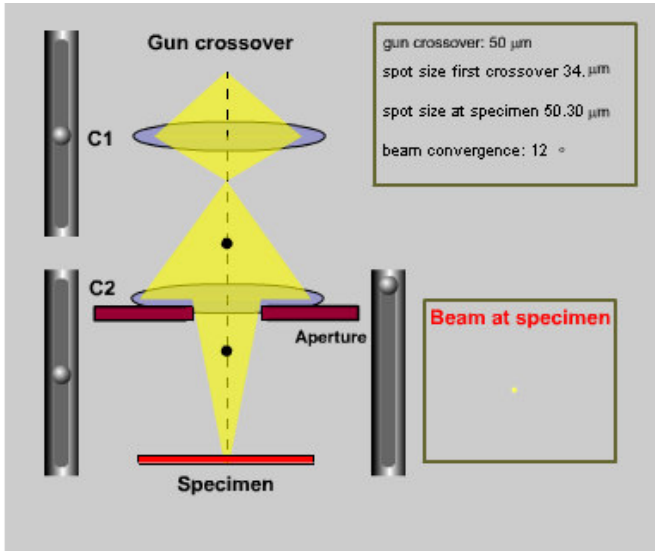


Condenser Aperture

- The condenser aperture controls the fraction of the beam which is allowed to hit the specimen. It therefore helps to control the intensity of illumination, and in the SEM, the depth of field.







Objective lens & Aperture

- This is the first lens of a microscope and it is closest to the specimen being observed.
- The objective lens is designed asymmetrically and is therefore different from the axially symmetrical construction of the condenser lens.
- In the electron microscopy it is not possible to move the position of the lenses, so it is necessary to change the focal length of the objective lens, to focus the specimen. This is done by varying the current through the windings of the electromagnet that makes up the objective lens.

Objective Aperture

The objective aperture can be inserted here. Its function is to:

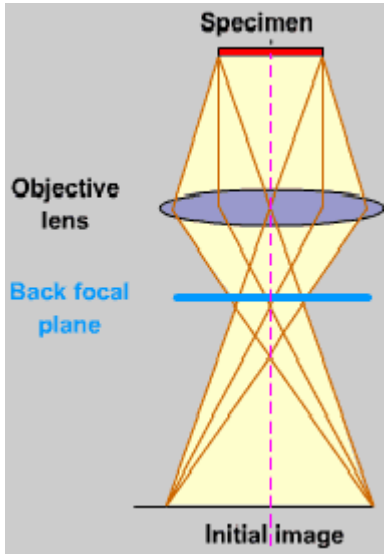
- Select those electrons which will contribute to the image, and thereby affect the appearance of the image
- Improve the contrast of the final image.

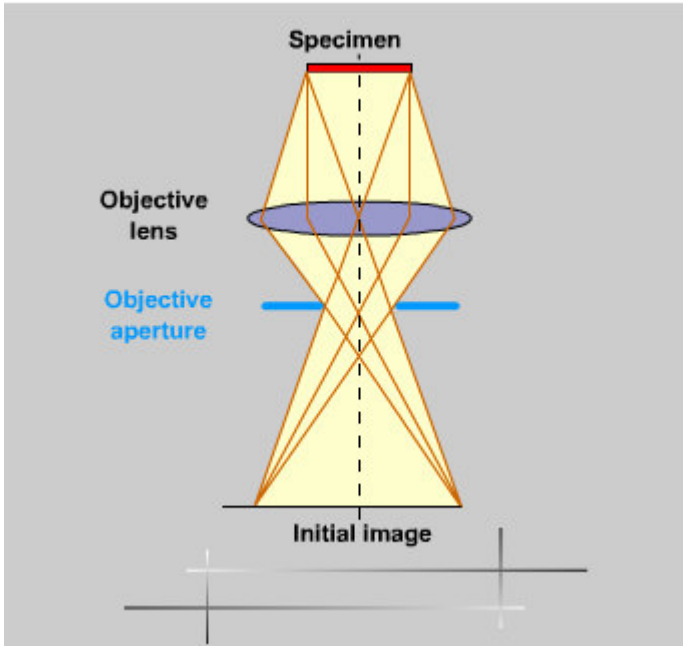
By inserting the aperture or tilting the beam, different types of images can be formed. The most common conditions are:

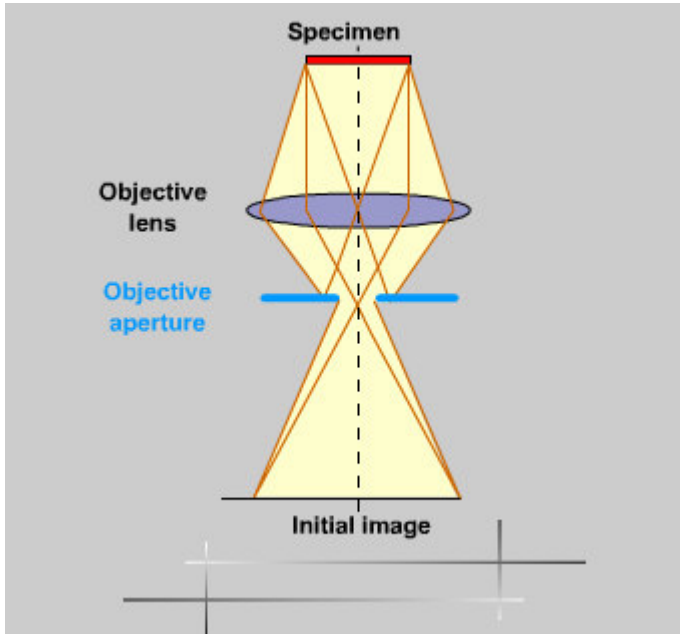
- No aperture - the diffraction pattern is centered on the optical axis.
- Aperture is centered on the optical axis.
- Aperture displaced, selecting a diffracted beam.
- Beam is tilted so that the diffracted beam is on the optical axis.

Objective lens & Aperture

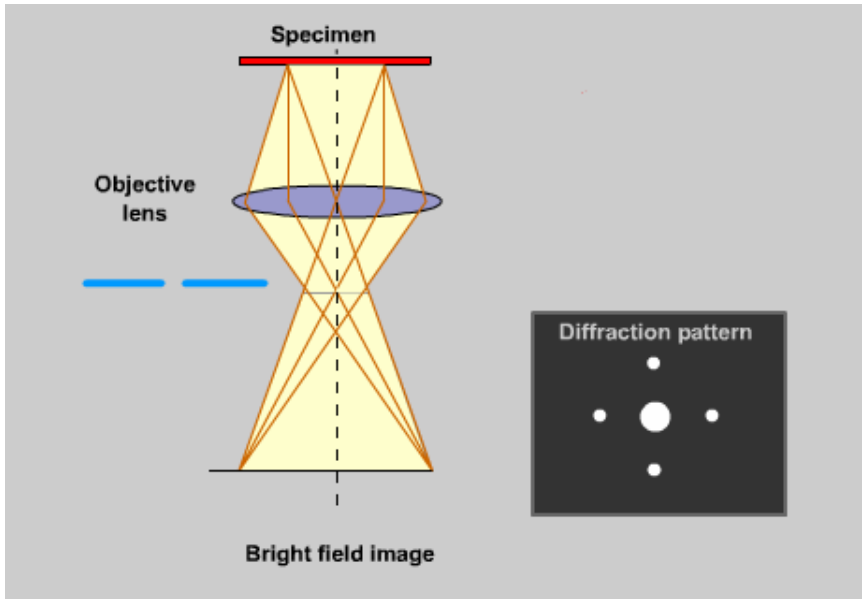
Most important lens in the microscope since it generates the first intermediate image, the quality of which determines the resolution of the final image. The objective lens forms an inverted initial image, which is subsequently magnified. In the back focal plane of the objective lens diffraction pattern is formed. The objective aperture can be inserted here.

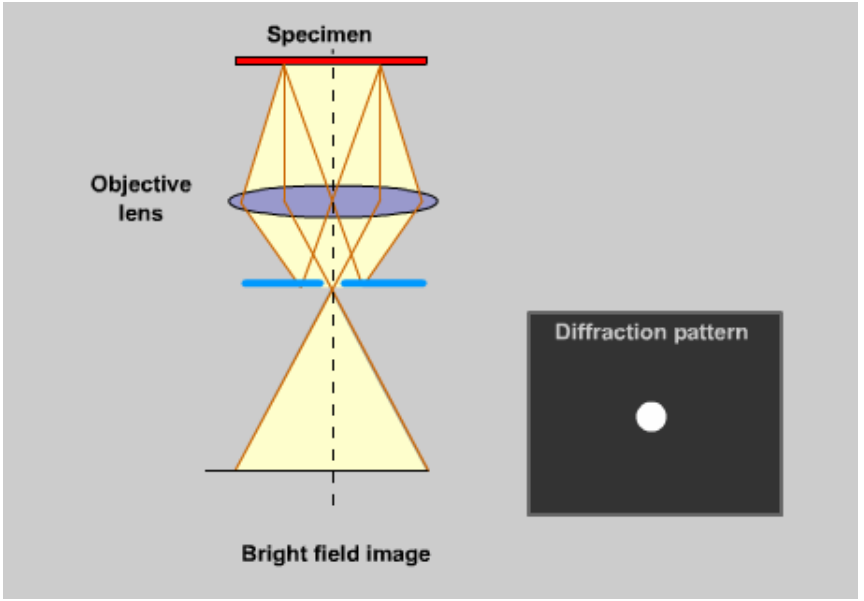


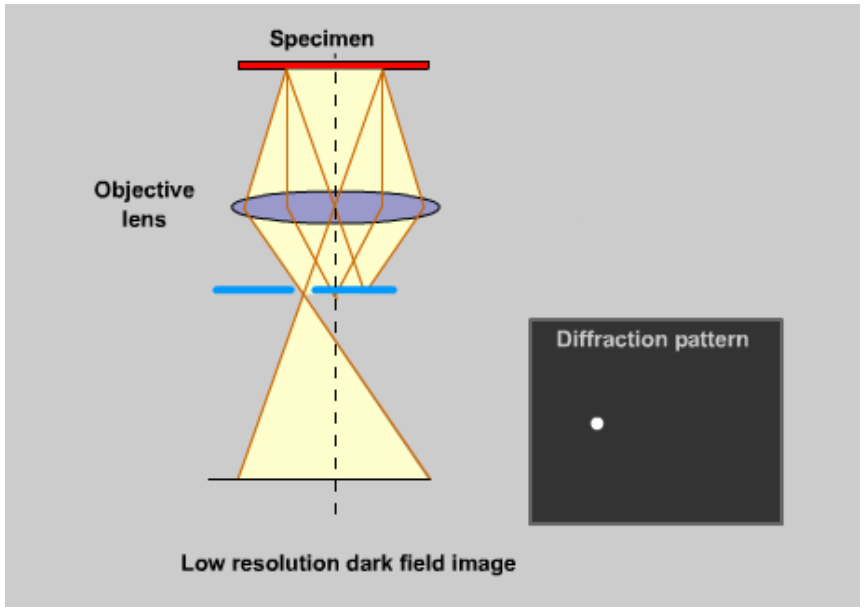


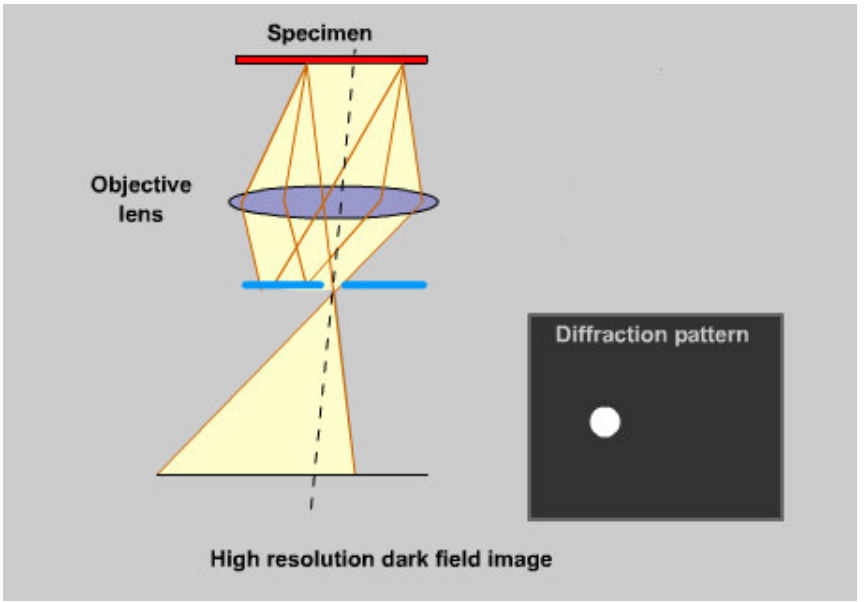


Objective lens & Aperture









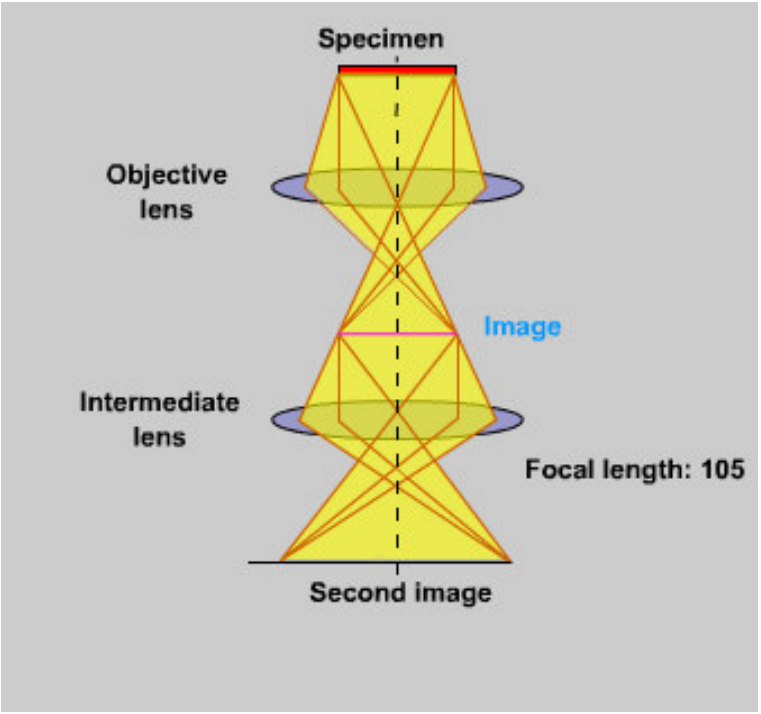
Intermediate lens

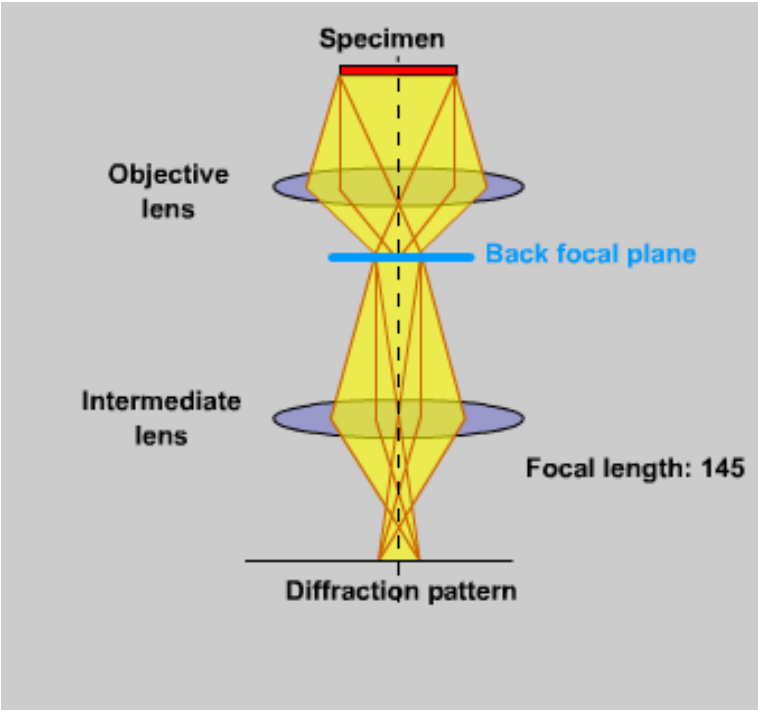
The first intermediate lens magnifies the initial image that is formed by the objective lens:

The lens can be focused on:

- Initial image formed by the objective lens, or
- Diffraction pattern formed in the back focal plane of the objective lens.

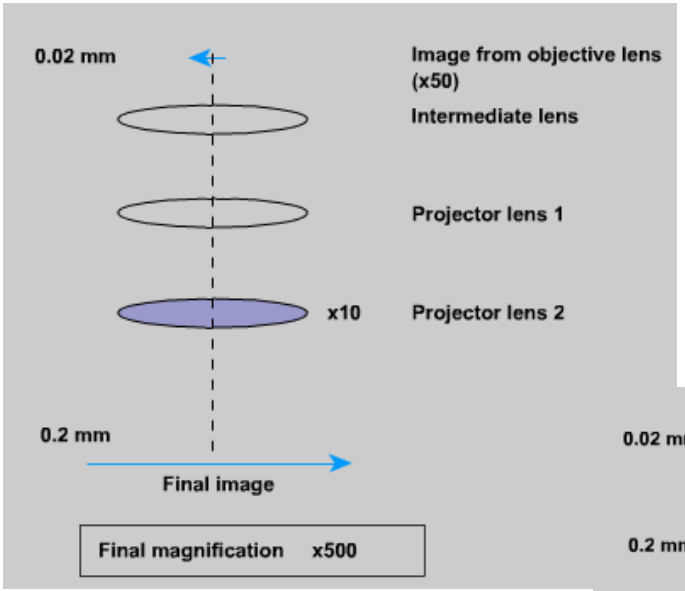
This determines whether the viewing screen of the microscope shows a diffraction pattern or an image.

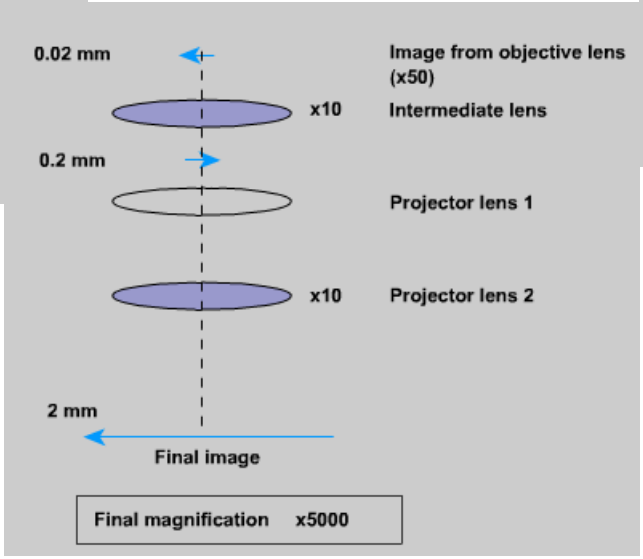


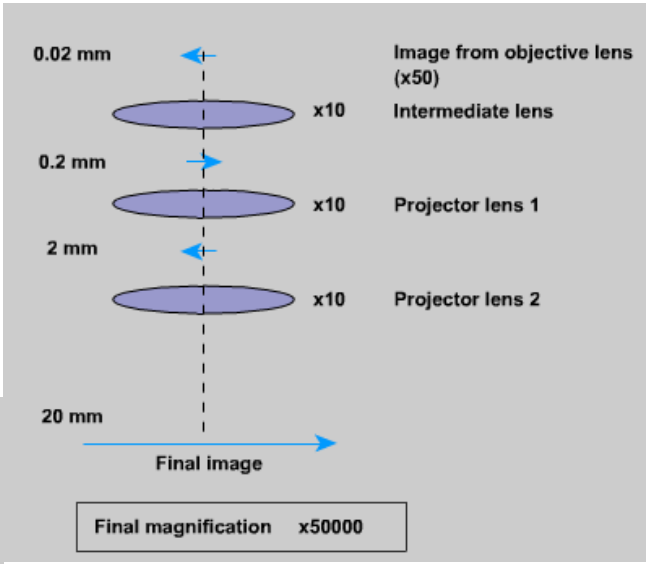


Projector Lens

- Magnification in the electron microscope can be varied from hundreds to several hundred thousands of times.
- This is done by varying the strength of the projector and intermediate lenses. Not all lenses will necessarily be used at lower magnifications.







Reference:

- Transmission Electron Microscopy (I), David B. Williams and C. Barry Carter, Plenum Press, 1996\

- http://www.matter.org.uk/tem/default.htm

Thanks