Chapter 1. Basic Electron Optics

• Basic concepts of microscope
• Fundamental properties of electrons
• Sample preparation
Basic conceptions of microscope

- Ray diagram
- Magnification
- Resolution
- Depth of field and depth of focus
- Aberration of optical system
Projection image (or shadow) ray diagram
One-stage microscope ray diagram with two rays

Object plane

Object

u

f

f

Back focal plane

v

Image plane

Lens formula: \( \frac{1}{f} = \frac{1}{u} + \frac{1}{v} \)

HW#1: prove it. Due day: 09/03/08

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One-stage microscope ray diagram

- $u < f$, no real image can form.
One-stage microscope ray diagram with more rays

Ray leaving object as parallel rays (0 ray, transmission in TEM)

Ray leaving object at some angle (g ray, diffraction in TEM)

Aperture to select the rays in TEM

Object plane

Image Plane

f

Back focal plane (BFP)
Optical system of projection microscope with transmission illumination

- Illumination source (light, or electron gun) from behind of object
- Object is transparent for illumination source (e.g. biology sample)
- Analogy to TEM
Optical system of projection microscope with reflected illumination

- Illumination source (light, or electron gun) using reflection source
- Surface of object is examined (e.g. metallographic sample)
- Analogy to SEM

Object A
- Objective lens
- Objective aperture
- Condenser lens
- Condenser aperture
- Half-silvered mirror

Image B
- Illumination source

Image C
- Projector lens

Objectives:
- f1
- f2
- BFP
Magnification $M$:

- For single lens: $M_1 = \frac{BB'}{AA'} = \frac{v_1}{u_1}$, or $M_1 = \frac{f_1}{(u_1 - f_1)} = \frac{(v_1 - f_1)}{f_1}$
  
  $M_2 = \frac{CC'}{BB'}$, or $M_2 = \frac{(v_2 - f_2)}{f_2}$

- For two-stage lens: $M = \frac{CC'}{AA'}$
  
  $M = \frac{(v_1 - f_1)(v_2 - f_2)}{f_1 f_2} = M_1 \times M_2$

We cannot continuously add project lens to enhance magnification due to resolution of microscope.
When light or electron beam passes through an aperture, diffraction occurs so that a parallel beam of light (which would be seen as a spot) is transformed into a series of cones, which are seen as circles and known as **Airy’s rings**.
\[
d \propto \frac{1}{d_{\text{aperature}}} \]

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Rayleigh Criterion:

\[ r = \frac{d}{2} = \frac{0.61 \lambda}{\mu \sin \alpha} \]

Resolution of the Human Eye \(~ 0.1 \text{ mm}\)

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The resolution (or strictly resolving power) is defined as the closest spacing of two points which can be clearly seen through the microscope to be separate entities.
**Microscope Resolution:**

The minimum resolvable distance between the image of two point objects using a perfect lens.

Resolution of an imaging system (Raleigh criterion or Abbe's equation)

\[ r = \frac{0.61 \lambda}{\mu \sin(\alpha)} \]

- \( \lambda \): wavelength of the imaging radiation
- \( \eta \): index of refraction of the lens
- \( \alpha \): illumination semi-angle
**Light vs. Electrons**

<table>
<thead>
<tr>
<th>Light Microscope</th>
<th>Electron Microscope</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\lambda = 0.5 , \mu m$</td>
<td>$\lambda = \sqrt{\frac{150}{V_0}} = 0.055 , \text{Å} (@50 , \text{kv})$</td>
</tr>
<tr>
<td>$\mu = 1.5$ (glass)</td>
<td>$\mu = 1.0$ (vacuum)</td>
</tr>
<tr>
<td>$\alpha = 70^\circ$</td>
<td>$\alpha = 1^\circ$</td>
</tr>
<tr>
<td>$r = 0.2 , \mu m = 200 , \text{Å}$</td>
<td>$\rho = 0.00016 , \mu m = 1.6 , \text{Å}$</td>
</tr>
</tbody>
</table>

**Why electron microscope?**
Optical Microscopy vs. TEM

Optical Polarization Microscopy
Light Source (Halogen)
\[ \lambda = 550 \text{ nm} \]
Optimal Resolution
420 nm – 440 nm
Leica, Planachromat (Oil)
Zeiss, Achromate (Oil)
Magnification x2000

Detector
Ocular
Analyzer
Objective
Sample (25 micron)
Condenser
Polarizer
Light Source
Resolution \( r \):

\[
    r = \frac{d}{2} = \frac{0.61\lambda}{\mu \sin \alpha}
\]

\( \lambda \): wavelength of light, 
\( \mu \): refractive index of medium 
\( \alpha \): aperture semi-angle

\( \lambda = 1.8 \text{ pm} \)

\( \lambda = 2.9 \text{ pm} \)
Depth of field and depth of focus

Plane of optimum focus

Depth of field

\[ h = \frac{r}{\tan \alpha} = \frac{0.61 \lambda}{\mu \sin \alpha \tan \alpha} \]

Depth of focus

\[ \frac{dv}{du} = -\frac{v^2}{u^2} = -M^2 \]

HW#2

A TEM sample is 100 nm thick. If we only need 1 nm detail in image, what is the aperture size (semiangle of collection) we should choose?
NEXT lecture:

- Lens aberration
- Electron properties
- Electron properties
- Electron scattering
- TEM structure