According to Abbe’s simple criterion for estimating the resolving power of an optical instrument, the smallest object spacings (or details) one can expect to resolve with the instrument are about \( XXX \) the wavelength of the radiation used to form images.

A. one tenth the size of
B. one half the size of
C. the same size as
D. two times the size of
E. ten times the size of
Multiple Choice Question

Which dimension in the following list is largest?

A. $0.0191 \, \mu m$
B. $19.0 \, nm$
C. $190 \, \text{Å}$
D. $1.91 \, nm$
E. $1.92 \times 10^{-10} \, m$
The angular aperture typically used in electron optics is much smaller than what is used in light optics.

A. True
B. False
Announcements for Jan 15, 2013

Reading assignment for Thursday: Lecture notes pp.65-72

‘Virtual homework’: always check web site for new updates

Recitation session: Friday Jan 18; York 4080A; 5-6:00 pm

TEM facility tour: Jan 28,29 (check web site)

Reminders:

   Keep your *p-Flasher* sheets readily available during class

   Powerpoint lectures posted on Web site will include additional
   (‘hidden’) slides not shown during class
Recitation session **THIS** Friday, Jan 18, 2013
5:00 – 6:00 PM

Will include a laser diffraction demo, showing the relationship between simple objects and their diffraction patterns
TEM Facility Tour

Where: 1510 Bonner Hall basement

When: Aiming for Jan 28, 29th

Check class web site for details on dates, times, and directions to facility

Attendance is optional but 5 pts extra credit towards final grade will be awarded

To reserve and guarantee a time slot, email nholson@ucsd.edu

First come, first served.
CHEM 165,265 / BIMM 162 / BGGN 262 - 3D Electron Microscopy of Macromolecules
Winter Quarter 2013

Syllabus (PDF)

Book list (PDF)

Reference list (PDF)

The Bottom Line (PDF) -- Key concepts from daily lectures through January 10, 2013

Virtual Homework - Practice Questions for Section 1 (PDF) Updated January 10, 2013 (Password protected)

Lecture Notes

- Sec. IA. Principles of the transmission electron microscope (9.2 MB)
- Sec. IB. Design of the transmission electron microscope (3.5 MB)

Powerpoint® presentations from lecture (PDFs)

- Introduction to the course January 8, 2013 (48 MB)
- Lecture #1. January 8, 2013 (15.5 MB)
- Lecture #2. January 10, 2013 (4.3 MB)
I.A PRINCIPLES OF TRANSMISSION EM

KEY CONCEPTS FROM LECTURE #2

- **Coherence**: defines variance in $\lambda$ and phase of component waves

- **Instrument resolving power**: limited by $\lambda$ of radiation; at best $= 1/2 \lambda$

- **Image resolution**: always $\leq$ resolving power of instrument

- **Electron waves**: potential to resolve finer object details than can photons

- **Rayleigh Criterion**: gives more realistic estimate of instrument resolving power for TEM (compared to Abbe’s simple $1/2$ wavelength rule) primarily because it accounts for effects of lens aperture.

- **Geometrical (Ideal) Optics**: Ray paths through lenses and apertures

- **Physical (Real) Optics**: Accounts for diffraction and interference effects
I.A PRINCIPLES OF TRANSMISSION EM
MORE KEY CONCEPTS FROM LECTURE #2

- Ideal vs. Real Lenses

- Ray Diagrams

- Converging / Diverging Lenses; Real / Virtual Images

- Thin Lens Equation: 
  \[
  \frac{1}{f} = \left(\frac{1}{o}\right) + \left(\frac{1}{i}\right)
  \]

- Magnification: 
  \[
  M = \left|\frac{i}{o}\right|
  \]

- Lens Aperture: determines amount of radiation arriving from object that can be focused to form an image

- High Magnification Imaging: generally requires 3-4 lenses
I.A.4 Optics (Lens Theory)

I.A.4.h Magnification

For a converging lens:

- If object is $> 2f$ in front of the lens, the image formed is real, inverted, and smaller than the object ($M < 1$)

- If object is exactly $2f$ in front of the lens, image is real, inverted, and the same size as the object ($M = 1$)

- If object is between $f$ and $2f$, image is real, inverted, and larger than the object ($M > 1$)

- If object is $< f$, image is virtual, erect, and larger than the object ($M > 1$)
Resolution (d)

- Low ↔ High
- Poor ↔ Good
- Coarse detail ↔ Fine detail
- Large number ↔ Small number
Resolution (d)

200 Å

50 Å
Resolution (d)

Resolution: 25 Å

Scale: 200 Å
Resolution (d)

5 Å

200 Å
Resolution \( (d) \)

\[ 5 \text{ Å} \]

*Thermus thermophilus* 70S ribosome
Resolution (d)

Low

50 Å

25 Å

10 Å

5 Å

High

Thermus thermophilus 70S ribosome
Resolution (d)

Low

50 Å

25 Å

10 Å

5 Å

High

Thermus thermophilus 70S ribosome
§ I: The Microscope

I.A Principles of TEM

I.A.5 Electron Optics / Electron Lenses

(pp.25-37 of lecture notes)
NEW CONCEPTS

- Thermionic emission creates a source of beam electrons
- Charged objects produce an electric field
- Path of an electron passing through an electric field or a magnetic field is bent or refracted
- Focal length of electromagnetic lens determined by field strength and electron speed
Thermionic Emission

Process by which thermal energy is supplied to loosely bound e\(^-\) in a metal to form a source of ‘free’ e\(^-\)

Simplest form of an electron gun filament is a thin tungsten wire

Wire is heated by passing an electric current through it

Electron gun tungsten filament (cathode)
Take home message of next several slides:

Electromagnetic lenses produce strong magnetic fields

These refract (bend) moving electrons and therefore allow them to be focused into electron images
I.A.5 Electron Optics / Electron Lenses
I.A.5.a Electron Emission

**FACT**: Electrons accelerate in an applied electric field

From Sjostrand, Fig. II.15, p.26
FACT: Electrons accelerate in an applied electric field

A strong electrostatic field applied in a vacuum between a wire [cathode], at negative potential, and an anode, at positive potential, causes e⁻ to accelerate away from the wire towards the anode.
Speed of the moving e- depends on strength of the electrostatic field (voltage) between the cathode and anode.

\[ v = \sqrt{\frac{2eV}{m}} \]

From Sjostrand, Fig. II.15, p.26
I.A.5 Electron Optics / Electron Lenses

I.A.5.a Electron Emission

**Speed** of the moving e- depends on **strength** of the electrostatic field (voltage) between the cathode and anode.

**Number** of e⁻ that leave the wire depends on the **temperature** to which the wire is heated, which depends on the **filament current**

From Sjostrand, Fig. II.15, p.26
Path of an electron between two parallel plates of opposite charge

From Sjostrand, Fig. II.22, p.33
- Electrons traveling in a direction parallel to the plates are affected by the force directed perpendicular to the plates.

- Electrons are attracted toward the positive plate.

- Path changes in a series of gradual steps at the equipotential surfaces.

**RESULT:** Fundamentally same as given by Snell's Law of refraction (light optics). Curved equipotential surfaces exhibit the properties of a lens.
The path of a moving electron is bent when the electron encounters an electric field.

What happens if a moving electron encounters a magnetic field?
Magnetic field: An electric current passing through a conductor gives rise to a magnetic field.

From Sjostrand, Fig. II.26, p.35
Flux density depends on the properties of the material surrounding the conductor.

Iron induces a higher flux density than air or a vacuum.

*Magnetic flux density* = number of lines per unit area

Direction in which magnetic field lines point = North

From Sjostrand, Fig. II.26, p.35
Flux density is greatest at the center of the loop.
I.A.5 Electron Optics / Electron Lenses

I.A.5.e Magnetic Fields and Magnetic Lenses

Flux density even higher if solenoid has an iron core

From Sjostrand, Fig. II.31, p.40
I.A.5 Electron Optics / Electron Lenses

I.A.5.e Magnetic Fields and Magnetic Lenses

However...

Use of iron leads to a problem: lens hysteresis

Lens strength depends to some extent on the magnetic history of the lens

Read about lens hysteresis and lens normalization (p.32, lecture notes)
I.A.5 Electron Optics / Electron Lenses

I.A.5.f The Electromagnetic Lens

From Wischnitzer, 2nd ed., Fig. 35, p.33
I.A.5 Electron Optics / Electron Lenses

I.A.5.f The Electromagnetic Lens

Forces Acting on a Current in a Magnetic field

Thompson’s experiment

From Wischnitzer, Fig. 25, p.25

From Sjostrand, Fig. II.35-36, p.43
I.A.5 Electron Optics / Electron Lenses

I.A.5.f The Electromagnetic Lens

Path of Electron Through an Electromagnetic Lens

Electron starting at point A on axis and at an angle to it follows a spiral path, returning to the axis at point B

**BOTTOM LINE:** Action is *similar* to a *converging* glass lens

From Meek, 1st ed., Fig. 1.3, p.8
Spiral path of single electron through the electromagnetic lens. **Note:** this is a highly exaggerated schematic diagram, since the path does not include multiple, full rotations.

Schematic diagram of the paths of many different electrons through the electromagnetic lens, scattered from a single point in the specimen.

From Bozzola, 1st Ed., Figs. 6-11 and 6-12, p.142
Geometrical optics for a magnetic lens is the SAME as that for a glass lens, except e⁻ travel in spiral paths through a magnetic lens.

From Agar, Fig. 1.4, p.5
Any axially-symmetric magnetic field has the properties of an ideal lens

- All formulas for the ideal lens may be applied

- Magnetic lenses are always convergent (i.e. positive)
Determined by two factors:

**Field strength** in the lens gap **AND**

**Speed of the e**⁻ (depends on accelerating voltage)

\[
f = \frac{KV_r}{(N \cdot I)^2}
\]

- \(f\)  = focal length of the lens
- \(K\)  = a constant
- \(V_r\) = accelerating voltage (relativistically corrected)
- \(N\)  = # of turns in the excitation coils
- \(I\)  = current (in amps)
How does one focus an electron image in the TEM?

Varying the current in the OBJECTIVE lens of the TEM

- Changes magnetic field strength and alters lens focal length

\[ f = \frac{KV_r}{(N \cdot I)^2} \]
I.A.5 Electron Optics / Electron Lenses

I.A.5.f The Electromagnetic Lens

**Magnetic Lens Focal Length** \((f)\)

\[
f = \frac{KV_r}{(N \cdot I)^2}
\]

How does one focus an electron image in the TEM?

**Varying** the **current** in the **OBJECTIVE** lens of the TEM

- Changes magnetic field strength and alters lens focal length

- If TEM voltage is **increased** (e⁻ velocity increases), lens current must be increased to **keep the focal length constant**
Objective Lens Design

- **Typical construction:**
  
  Strong field of short axial extent \( (f = 1.5-3 \text{ mm}) \) needed to form images at high magnification

- **Specimen** sits inside the magnetic field of the objective lens

From Agar, Fig. 2.11, p.51
A few take home messages:

- "Refractive index" changes gradually in electromagnetic lenses.

- Electrons travel spiral paths through electromagnetic lenses.

- Magnetic lens focal length determined by field strength of the lens \AND by speed of electrons in the imaging beam.

\[ f = \frac{KV_r}{(N \cdot I)^2} \]
§ I: The Microscope

I.A Principles of TEM

I.B Design of the TEM

(pp.39-72 of lecture notes)
TOPICS

- Principles of TEM
  Electrons, lenses and optics

- Design of TEM
  Components top to bottom

- Contrast and image formation
  Electron scattering from object

- Optimizing TEM performance
  Alignment assures ‘best’ images

- Operation of TEM
  “What do all these buttons do?”

- Other modes of TEM
  Many ways to ‘observe’ specimens

- Specimen preparation for TEM
  Getting specimen ready

- Radiation damage
  Less is better

- 3D reconstruction
  Specimen 3D structure from 2D images

Have I learned ANYthing yet?
I.B DESIGN OF THE TEM

The TEM Top to Bottom:

- Electron gun
- Condenser lens(es)
- Lens aberrations
- Objective lens and specimen stage
- Projector lenses
- Camera and viewing system
- Vacuum system
- Electrical system
The TEM Top to Bottom:

- Electron gun: Produces beam of electrons
- Condenser lens(es): Focuses e\textsuperscript{-} beam onto specimen
- Lens aberrations: Electromagnetic lenses stink!
- Objective lens and specimen stage: Objective is most important lens
- Projector lenses: Magnify image formed by objective
- Camera and viewing system: View and record electron image
- Vacuum system: Enables beam to travel length of TEM
- Electrical system: Needed for virtually every part of the TEM
Philips EM 200

From Meek, Fig. 5.4b, p.99

Philips EM 300

From Agar, Fig. 2.2, p.40

Philips EM 400

From Philips brochure
§ I: The Microscope

I.B Design of the TEM

(pp.39-72 of lecture notes)
§ I: The Microscope

I.B Design of the TEM

I.B.1 Electron Gun

(pp.39-42 of lecture notes)
I.B DESIGN OF THE TEM

The TEM Top to Bottom:

- Electron gun
- Condenser lens(es)
- Lens aberrations
- Objective lens and specimen stage
- Projector lenses
- Camera and viewing system
- Vacuum system
- Electrical system
I.B.1 The Electron Gun

**KEY CONCEPT**

Gun creates source of high voltage electrons
I.B.1 The Electron Gun

I.B.1.a Gun Design

Gun in most TEMs consists of a tungsten wire (filament-cathode), bent into a hairpin ("V") shape and surrounded by a shield (gun cap, wehnelt cylinder) with a circular aperture (1-3 mm diameter) centered just below the filament tip.
I.A.5 Electron Optics / Electron Lenses

I.A.5.a Electron Emission

TEM Filaments

Tungsten filament
From Agar, Fig. 2.5, p.45

LaB$_6$ filament
From Bozzola, 1$^\text{st}$ Ed., Fig. 6-26, p.155

Tungsten, cold field-emitting tip
From Watt, Fig. A4.8, p.444

$3$

$1000$

$18,000$
I.B.1 The Electron Gun

I.B.1.a Gun Design

Electrons accelerated across large potential difference (~100,000 volts) between cathode and anode

Wehnelt shield controls beam shape and emission

Anode controls acceleration

Crossover considered the actual source of $e^-$ for the TEM

From Sjostrand, Fig. III.6, p.74
I.B DESIGN OF THE TEM

The TEM Top to Bottom:

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§ I: The Microscope

I.B Design of the TEM

I.B.2 Condenser Lens(es)

(pp.42-46 of lecture notes)
I.B.2 Condenser Lens(es)

**Bottom Line:**

Condenser lens system *focuses / concentrates* the electron beam onto the specimen to give optimal *illumination* for viewing and recording the image.
I.B.2 Condenser Lens(es)

I.B.2.a,b Single and Double Condenser Systems

From Agar, Fig. 1.16, p.22
I.B.2 Condenser Lens(es)
I.B.2.b Double Condenser System

ADVANTAGES (lots of them!):

- More flexible control of illumination
- Wider range of intensities
- Reduces area of object irradiated
- Reduces specimen contamination
- Improves image contrast (smaller e\(^{-}\) source produces a higher coherence beam)
- Higher efficiency of double condenser ==> gun brightness can be reduced (increases filament life)

From Agar, Fig. 1.16, p.22
I.B.2 Condenser Lens(es)

I.B.2.c Condenser Apertures

- **CA1** is often a **fixed** aperture

- **CA2** is generally **adjustable** with centering controls (aperture holder allows rapid exchange of 3 different size apertures).

From Agar, Fig. 1.16, p.22
I.B.2 Condenser Lens(es)

I.B.2.c Condenser Apertures

- **CA1** is often a **fixed** aperture

- **CA2** is generally **adjustable** with centering controls
  (aperture holder allows rapid exchange of 3 different size apertures).

From Agar, Fig. 1.16, p.22

From Meek, 1st ed., Fig. 5.2, p.95
I.B DESIGN OF THE TEM

The TEM Top to Bottom:
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§ I: The Microscope

I.B Design of the TEM

I.B.3 Lens Aberrations

(pp.47-54 of lecture notes)
I.B DESIGN OF THE TEM

I.B.3 Lens Aberrations

Lots and lots of them:

- Spherical aberration
- Distortion
- Chromatic aberration
- Lens asymmetry
- Lens current fluctuations
- Curvature of field
- Coma and anisotropic coma
- Space charge distortion
I.B DESIGN OF THE TEM

I.B.3 Lens Aberrations

Lots and lots of them:

- Spherical aberration
- Distortion
- Chromatic aberration
- Lens asymmetry
- Lens current fluctuations
- Curvature of field
- Coma and anisotropic coma
- Space charge distortion
I.B.3 Lens Aberrations

**Bottom Line:**
Electromagnetic lenses are ‘crummy’

They are the reason why resolving power in TEM is **much worse** than estimated by the simple Abbe $1/2 \lambda$ criterion.

To reduce aberrations, the **semi-angular aperture** ($\alpha$) of the **objective** lens is made **VERY small** (recall Abbe’s equation?)

$$d = \frac{0.612\lambda}{n \cdot \sin \alpha}$$
I.B.3 Lens Aberrations

I.B.3.b Spherical Aberration

**Bottom Line:**

Spherical aberration is main culprit

Spherical aberration in TEM electromagnetic lenses is the **principal factor** that limits TEM **resolving power**
I.B.3 Lens Aberrations

I.B.3.b Spherical Aberration

**Recall:** For an **IDEAL** lens, all rays entering lens parallel to the optic axis are focused behind the lens on the axis at a **single point**, the focal point.
I.B.3 Lens Aberrations

I.B.3.b Spherical Aberration

For a **REAL** lens (esp. electromagnetic), rays entering different parts of the lens experience **different lens (or field) strength** and hence are not focused at a single point on the optic axis.

**Marginal rays** are **focused more strongly** than the **paraxial rays**.
I.B.3 Lens Aberrations

I.B.3.b Spherical Aberration

For a **REAL** lens (esp. electromagnetic), rays entering different parts of the lens experience **different lens (or field) strength** and hence are **not focused at a single point** on the optic axis.

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I.B.3 Lens Aberrations

I.B.3.b Spherical Aberration

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I.B.3 Lens Aberrations

I.B.3.b Spherical Aberration

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**Marginal rays** are **focused more strongly** than the paraxial rays.

Circle of least confusion
(practical focus point)
I.B.3 Lens Aberrations

I.B.3.b Spherical Aberration

IDEAL lens
Region of focus where the marginal and paraxial rays is smallest is the *disc of least confusion* with diameter of disc, $d_{sa}$, given by:

$$d_{sa} = \frac{C_s \alpha^3}{2}$$

$\alpha$ = semi-angle of illumination

$C_s$ = spherical aberration coefficient of objective lens

So, to **improve resolution** (*i.e.* get smaller $d_{sa}$), all one has to do is **reduce** the lens aperture (*i.e.* reduce $\alpha$).......all the way to zero???
I.B.3 Lens Aberrations

I.B.3.b Spherical Aberration

Life should be so simple...

SA can be minimized by ‘stopping down’ the lens with an aperture, but only so far because this worsens diffraction-limited resolution.

HENCE: Decreasing $\alpha$ to reduce spherical aberration must be balanced against loss of resolution caused by diffraction effects.

\[ d_{sa} = \frac{C_S \alpha^3}{2} \]

Resolution limit due to spherical aberration

\[ d_{di} = \frac{0.612\lambda}{n \cdot \sin \alpha} \]

Resolution limit due to diffraction (Abbe equation)

See Tables (p.48, lecture notes) listing values of $\alpha$ (for different $C_S$ values) that give ‘optimum’ resolution.
More thoughts about spherical aberration...

**Glass optics:**

Effects of SA **CAN be corrected** by judicious combination of converging (positive) and diverging (negative) lenses \([SA \text{ of one lens counteracts the } SA \text{ of the other lens}]\)

**Electron Optics:**

**NOT** generally possible since electromagnetic lenses only work as converging (positive) lenses

*Slide not shown in class lecture*
I.B DESIGN OF THE TEM

I.B.3 Lens Aberrations

Lots and lots of them:

- **Spherical aberration**
- Distortion
- Chromatic aberration
- Lens asymmetry
- Lens current fluctuations
- Curvature of field
- Coma and anisotropic coma
- Space charge distortion
I.B DESIGN OF THE TEM

I.B.3 Lens Aberrations

Lots and lots of them:

- Spherical aberration
- Distortion *(lecture notes, pp. 49-50)*
- Chromatic aberration
- Lens asymmetry
- Lens current fluctuations
- Curvature of field
- Coma and anisotropic coma
- Space charge distortion
I.B DESIGN OF THE TEM

I.B.3 Lens Aberrations

Lots and lots of them:

- Spherical aberration
- Distortion (lecture notes, pp.49-50)
- Chromatic aberration
- Lens asymmetry
- Lens current fluctuations
- Curvature of field
- Coma and anisotropic coma
- Space charge distortion
I.B.3 Lens Aberrations
I.B.3.d Chromatic Aberration

OK, what is chromatic aberration?

khroma: Greek for “color”
Recall: For an IDEAL lens, all rays from an object point will be focused by the lens at a point in the image plane.
REAL lens: **Electrons** of **different wavelength** (velocity) leaving a point in object space are not brought to the same point in image space.
I.B.3 Lens Aberrations
I.B.3.d Chromatic Aberration

**REAL lens**: Electrons of different wavelength (velocity) leaving a point in object space are not brought to the same point in image space.

\[ f = \frac{KV_r}{(N \cdot I)^2} \]
What is the nature of an image with CA?

Images with CA are the combination (superposition) of a series of images.

- A given lens has a different focal length for each λ electron.

- For each λ, an ‘in focus’ image forms at a specific and different image plane behind the lens and at a particular magnification.

- Final image formed at a particular image plane is a superposition of images, each at a different rotation and magnification, and only one of which is in focus.
I.B.3 Lens Aberrations

I.B.3.d Chromatic Aberration

What is the nature of an image with CA?

Images with CA are the combination (superposition) of a series of images

- A given lens has a different focal length for each $\lambda$ electron

- For each $\lambda$, an ‘in focus’ image forms at a specific and different image plane behind the lens and at a particular magnification

- Final image formed at a particular image plane is a superposition of images, each at a different rotation and magnification, and only one of which is in focus

- The effects of CA in images become progressively worse for image points at increasing distances from the optic axis
I.B.3 Lens Aberrations

I.B.3.d Chromatic Aberration

Chromatic Change of Magnification

Central part of the micrograph is the sharpest. Out-of-focus effect becomes increasingly noticeable at increasing distance from the optical axis of the TEM. Effect is more noticeable at low magnifications.

From Meek, 1st ed., Fig. 3.11, p.79
I.B.3 Lens Aberrations
I.B.3.d Chromatic Aberration

What about photons and glass lenses?

Exactly the opposite occurs with glass optics.

Photons of short $\lambda$ (blue) are refracted more in glass than those of longer $\lambda$ (red).

Net effect (image blurring) occurs with electrons and photons.
What causes electrons to have different velocities?

- Instabilities in high tension ($\Delta V/V < 10^{-5}$)

- Variation in velocity of $e^-$ emitted by the cathode ($\pm 3.5$ parts/$10^6$)

- Energy losses when beam electrons interact with specimen atoms
I.B.3 Lens Aberrations

I.B.3.d Chromatic Aberration

Does CA limit resolution?

Of course it does……BUT……

… for TEM imaging of most specimens (thin ones: \( \leq 100 \text{ nm} \)), chromatic aberration is NOT a major limit to resolution in electron images.

… however, for thick specimens, effects of CA can be appreciable.

Limit to resolving power strictly due to CA estimated as follows (notes p.52):

\[
d_{cv} = C_c \alpha_o \frac{\Delta V}{V} \\
d_{ci} = 2C_c \alpha_o \frac{\Delta I}{I}
\]
I.B DESIGN OF THE TEM

I.B.3 Lens Aberrations

Lots and lots of them:

- **Spherical aberration**
- Distortion (lecture notes, pp.49-50)
- **Chromatic aberration**
- **Lens asymmetry**
- Lens current fluctuations
- Curvature of field
- Coma and anisotropic coma
- Space charge distortion
I.B.3 Lens Aberrations

I.B.3.e Lens asymmetry - Astigmatism

- Impossible to produce lens pole pieces completely free from mechanical and magnetic imperfections

- Irregularities induce an asymmetry in the magnetic field (focal length **varies with direction**)

www.tedmontgomery.com/.../Astigmatism-graphc.jpg
I.B.3 Lens Aberrations

I.B.3.e Lens asymmetry - Astigmatism

**Image formation with an astigmatic lens**

Lens **stronger** in plane ⊥ to the screen compared to plane of screen

Point object O is imaged into two focal lines in ⊥ planes, $Z_a$ apart

From Agar, Fig. 1.8, p.12
I.B.3 Lens Aberrations
I.B.3.e Lens asymmetry - Astigmatism

Condenser Lens Astigmatism

Images of focused electron beam

From Agar, Fig. 4.6, p.129
I.B.3 Lens Aberrations

I.B.3.e Lens asymmetry - Astigmatism

**Objective Lens Astigmatism**

From Agar, Fig. 4.12, p.139
I.B.3 Lens Aberrations

I.B.3.e Lens asymmetry - Astigmatism

**Objective Lens Astigmatism**

From Agar, Fig. 4.12, p.139
I.B DESIGN OF THE TEM

The TEM Top to Bottom:
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§ I: The Microscope

I.B Design of the TEM

I.B.4 Objective Lens and Specimen Stage

(pp.54-62 of lecture notes)
I.B.4 Objective Lens and Specimen Stage

**Bottom Line:**

**Objective** lens is the **most critical** lens in the TEM

- Performs **first stage of imaging**

- Determines instrument **resolving power** and **image contrast**
I.B.4 Objective Lens and Specimen Stage

I.B.4.b Objective Lens Construction

From Agar, Fig. 2.11, p.51
I.B.4 Objective Lens and Specimen Stage

I.B.4.b Objective Lens Construction

**Main Requirements**

- **Specimen** situated *close to* and *before* the *front focal plane* of the objective lens

- Specimen sits *inside* the *lens field* (necessary to obtain short focal length)

- **Space is very cramped** (need adequate clearance for inserting several items):
  
  Specimen
  
  Aperture
  
  Anticontaminator
  
  Stigmators to correct for asymmetries in the lens field
I.B.4 Objective Lens and Specimen Stage

I.B.4.e Objective Aperture (OA)
I.B.4 Objective Lens and Specimen Stage
I.B.4.e Objective Aperture (OA)

**FUNCTION:** Intercepts electrons *scattered* by the specimen through large angles

**POSITION:** Right at the *back focal plane* of the objective lens

OA does not restrict field of view

From Wischnitzer 2nd ed., Fig. 51, p.60
I.B.4 Objective Lens and Specimen Stage

I.B.4.e Objective Aperture (OA)

**FUNCTION:** Intercepts electrons *scattered* by the specimen through *large angles*

**POSITION:** Right at the *back focal plane* of the objective lens

Here, the OA screens out widely scattered electrons from being imaged.
I.B.4 Objective Lens and Specimen Stage

I.B.4.e Objective Aperture (OA)

**FUNCTION:** Intercepts electrons *scattered* by the specimen through *large angles*

**POSITION:** Right at the *back focal plane* of the objective lens

Here, the OA screens out widely scattered electrons from being imaged.