I.D ALIGNMENT/ADJUSTMENT OF THE TEM

I.D.1 Introduction

KEY CONCEPTS:

- **Misalignment** of TEM interferes with **resolving power**
- Misalignment of a lens means **e^- beam not centered on lens axis** but instead at an angle
- Owing to e^- lens aberrations, an **acceptable quality** image only forms within a limited **paraxial region**
- Instabilities in voltage or lens current produce **image movements**, which are **exaggerated by microscope misalignment**

I.D ALIGNMENT/ADJUSTMENT OF THE TEM

I.D.1 Introduction

MORE KEY CONCEPTS:

- Misalignment causes **inconveniences in operation**

  Example: movement of field of view during magnification/focusing changes

- **Goals:** ***Want to be able to***
  - Change magnification without losing center of field of view
  - Vary illumination without it becoming uneven or off-center
  - Focus image without it moving across screen
  - Switch from one operation mode to another without loss of illumination (*e.g.* from normal imaging to electron diffraction mode and back)

I.D ALIGNMENT/ADJUSTMENT OF THE TEM

I.D.1 Introduction

Goal of Alignment Procedure

Arrange all optical elements of microscope to be **coaxial**

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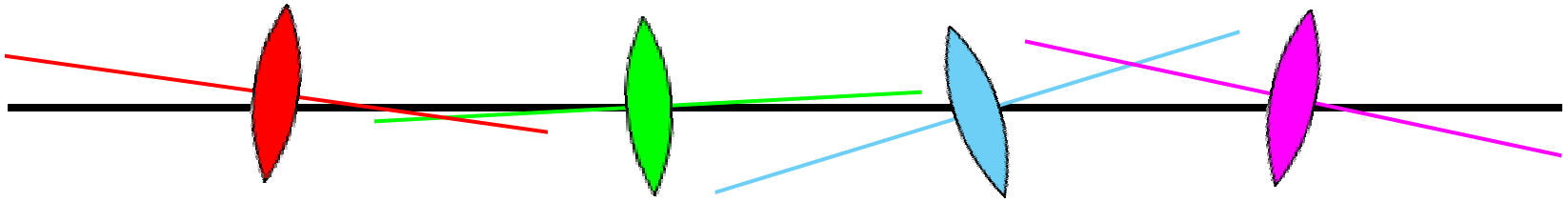

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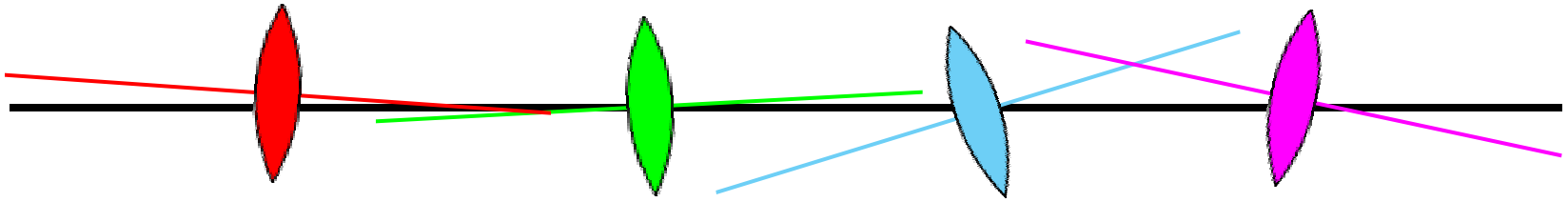

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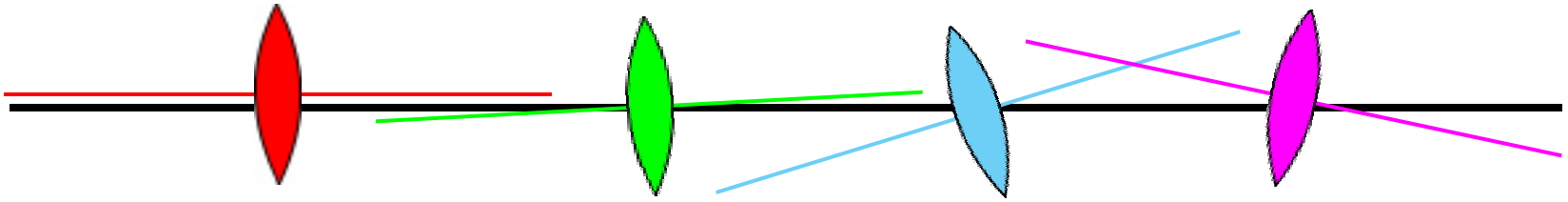

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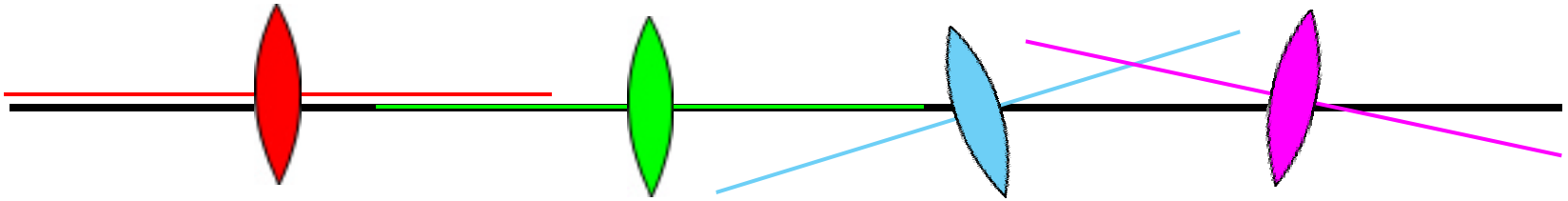

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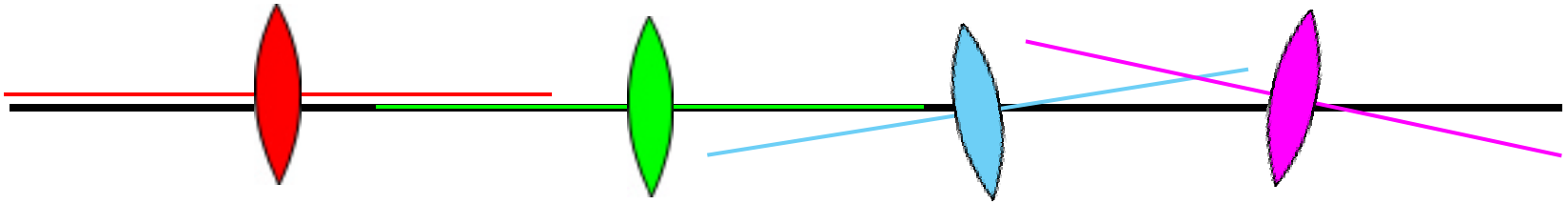

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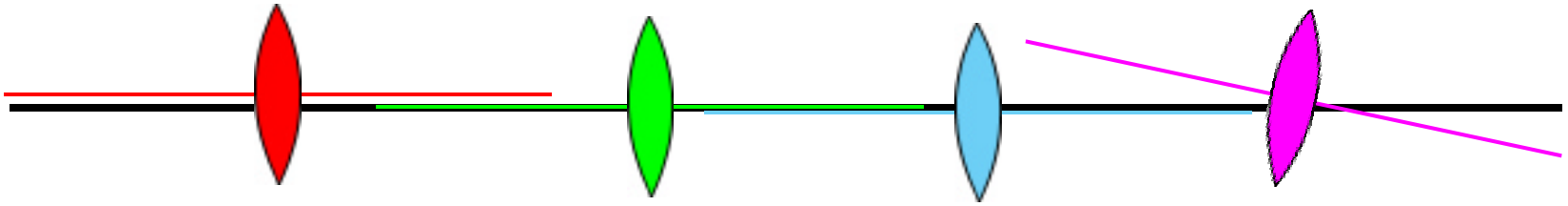

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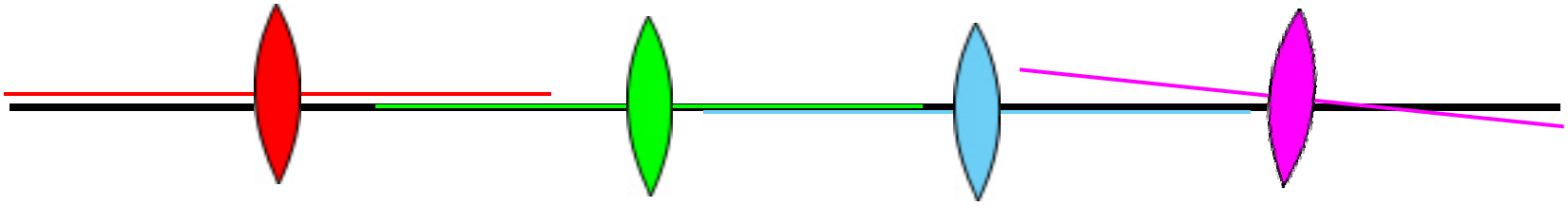

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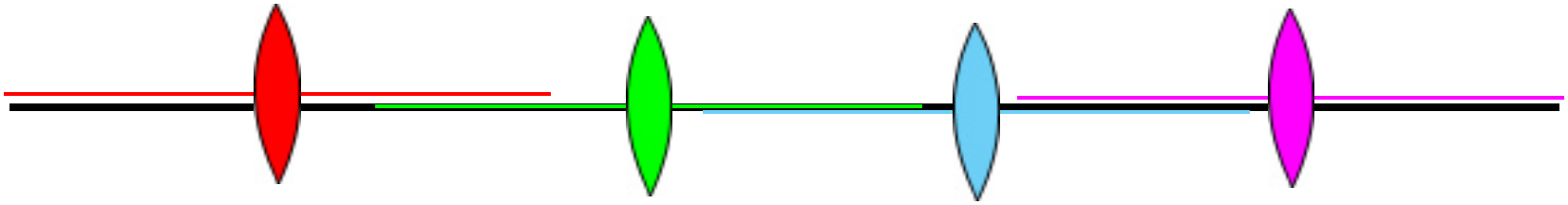

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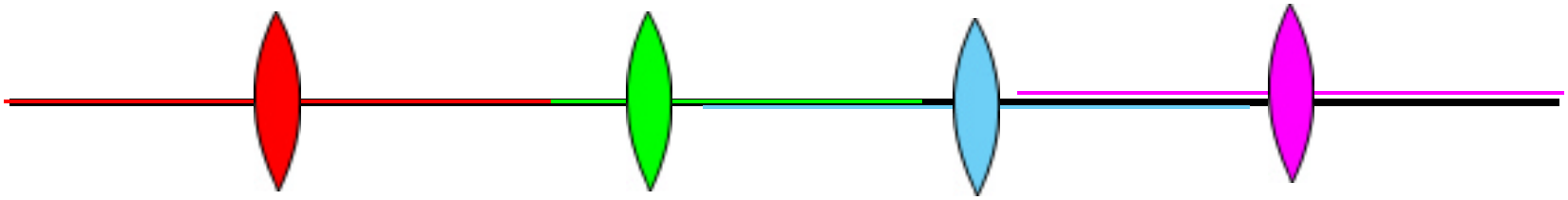

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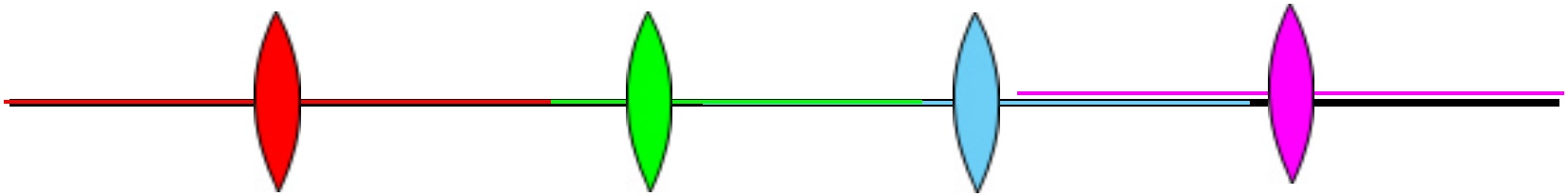

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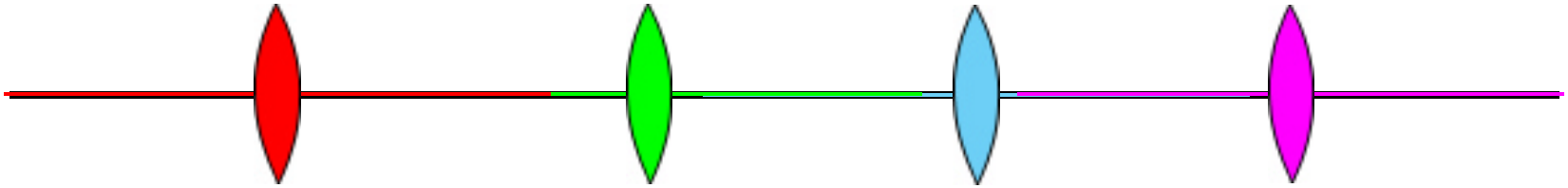

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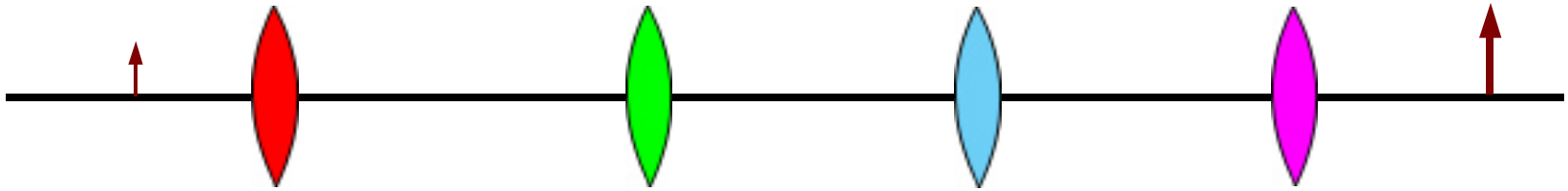

Imagine (*i.e.* I can't think of a good way to draw this) what the final image formed by the pink lens would look like if one or more lenses were misaligned!

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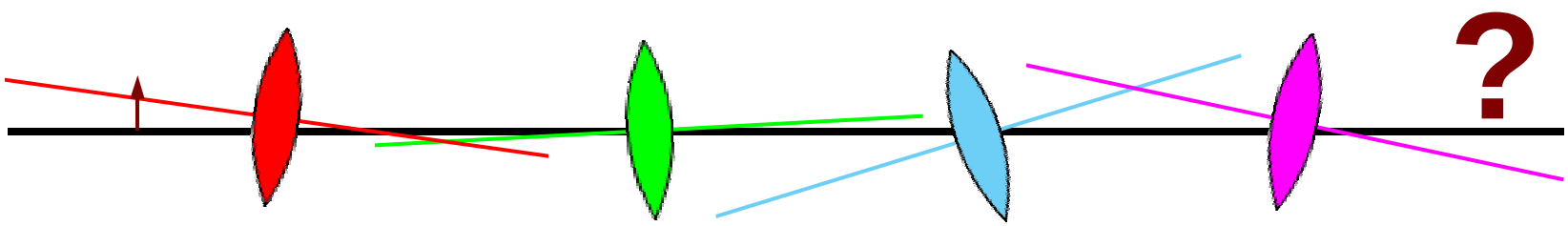


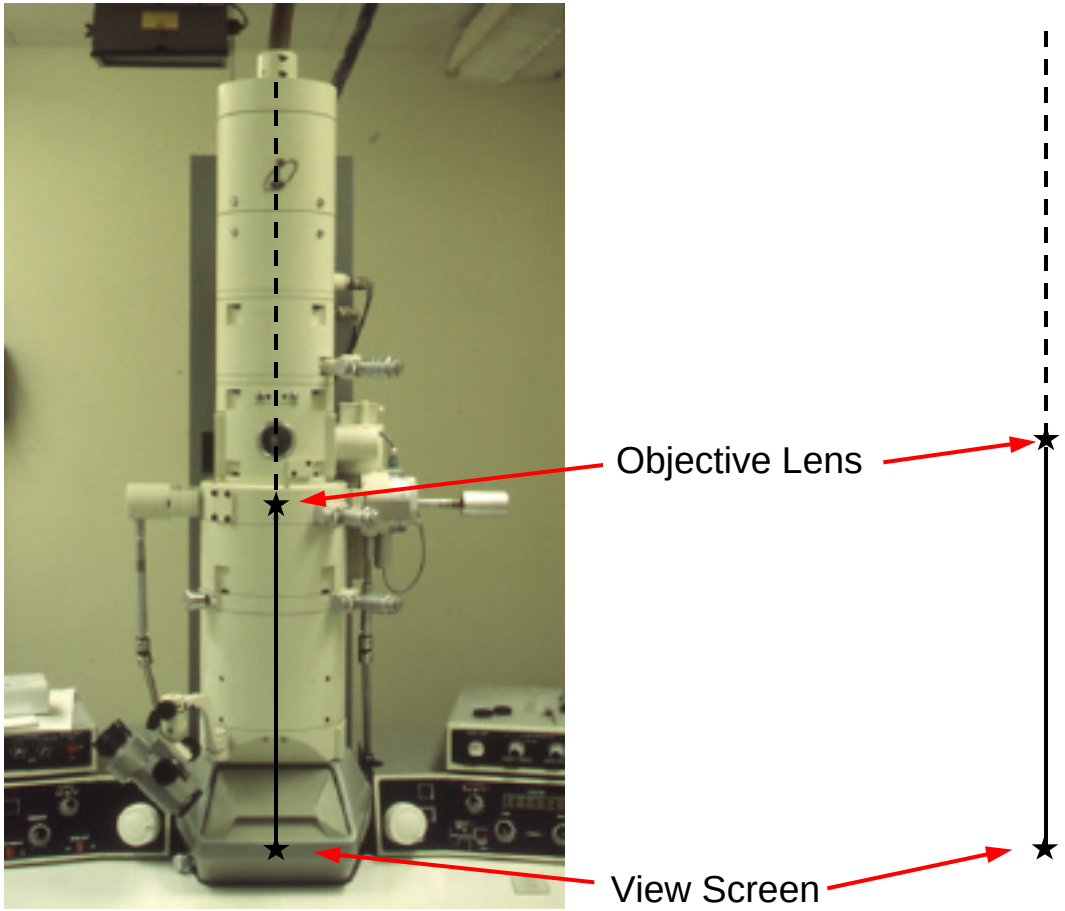
Imagine (*i.e.* I can't think of a good way to draw this) what the final image formed by the pink lens would look like if one or more lenses were misaligned!

I.D ALIGNMENT/ADJUSTMENT OF THE TEM

I.D.1 Introduction

Optic Axis

Defined by two points: **objective lens center** and **viewing screen center**



I.D ALIGNMENT/ADJUSTMENT OF THE TEM

I.D.1 Introduction

Optic Axis

Defined by two points: **objective lens center** and **viewing screen center**

Axis of symmetry of each lens must exactly coincide with optic axis

Alignment is performed with respect to electron gun, condenser and imaging lenses

RESULT: optical center of image coincides with center of viewing screen

I.D ALIGNMENT/ADJUSTMENT OF THE TEM

I.D.2 Alignment of TEM Components

KEY CONCEPT

The devil is in the details!

- Concentrate on understanding the principles

- The detailed procedures of TEM column alignment differ for each microscope

I.D ALIGNMENT/ADJUSTMENT OF THE TEM

I.D.2 Alignment of TEM Components

I.D.2.a Electron Gun

First step in TEM column alignment:

Adjust position of **gun and condenser lenses** in **relation to objective lens**

1. Gun position relative to condenser lens
2. Gun-condenser lens system relative to the objective lens

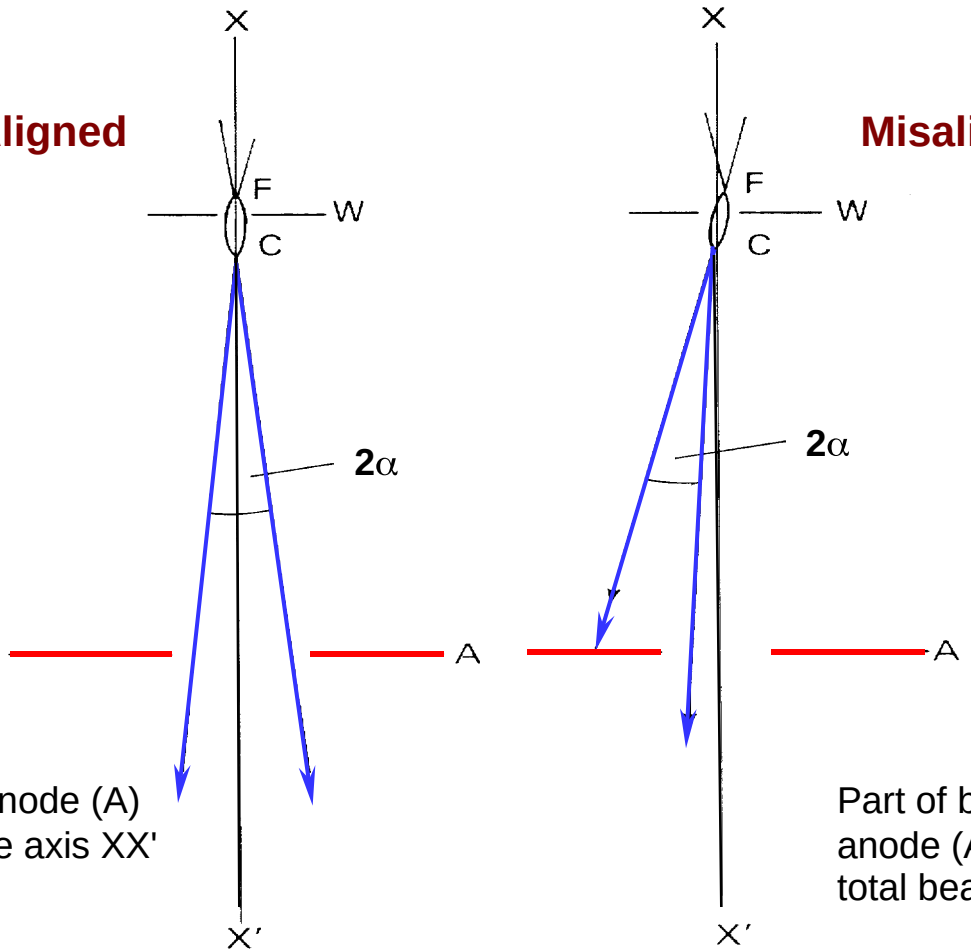
Gun alignment:

- - Adjust tilt and translation of filament with respect to aperture (~ 1mm diam.) in Wehnelt cap
- - Alignment centers image of emitting filament on viewing screen

I.D.2 Alignment of TEM Components

I.D.2.a Electron Gun

Effect of misalignment of the filament (F) with respect to Wehnelt cylinder (W)



Beam passes through anode (A) **symmetrically** down the axis XX' of condenser lens.

Part of beam is **lost** on hitting the anode (A), hence reducing the total beam angle 2α.

From Agar, Fig. 4.1, p.124

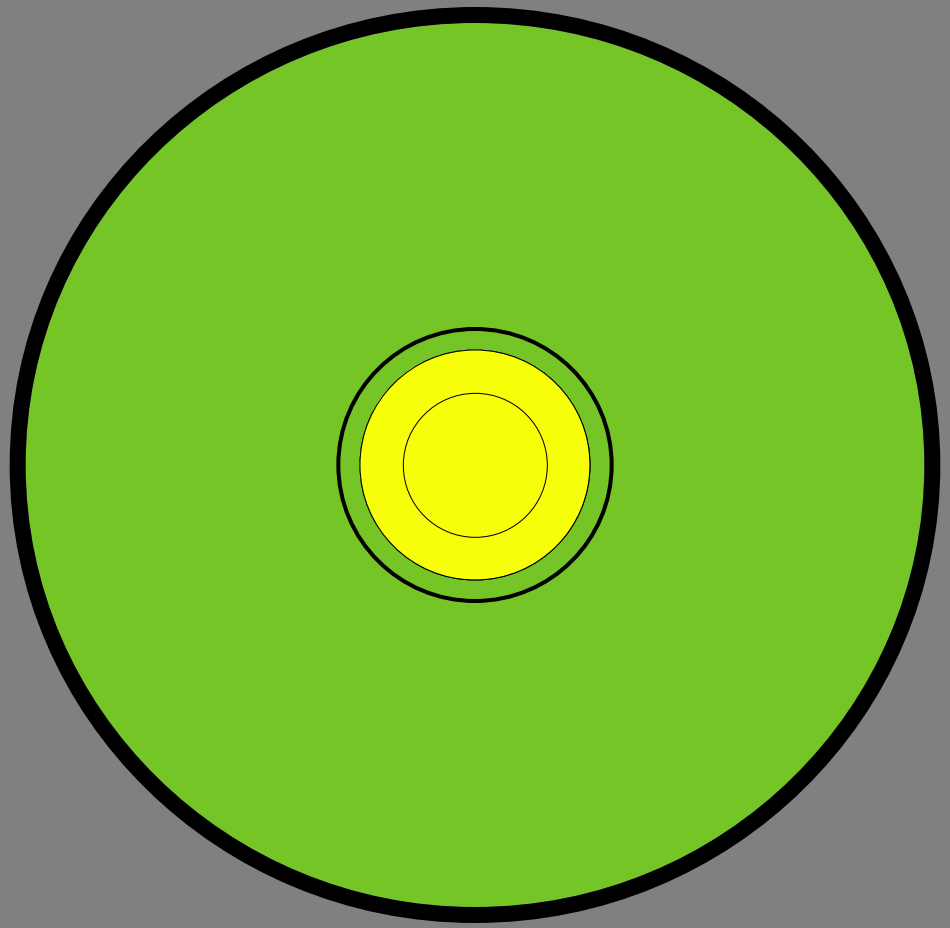
I.D.2 Alignment of TEM Components

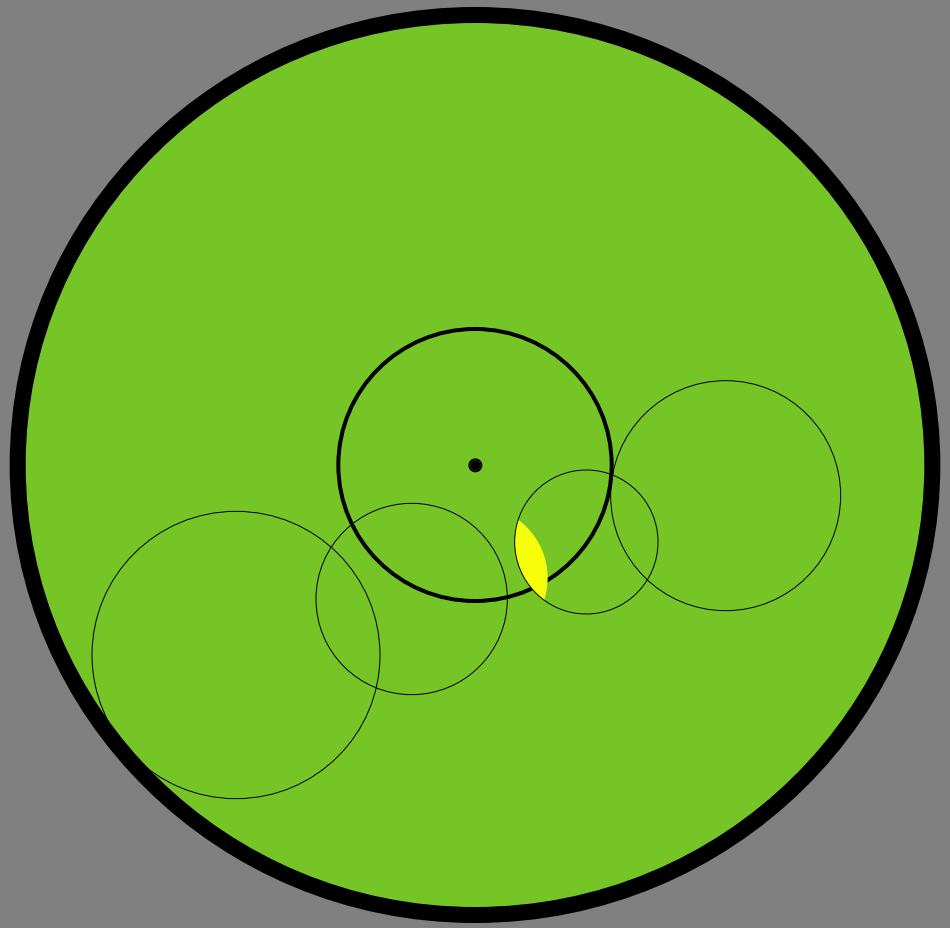
I.D.2.b Condenser System

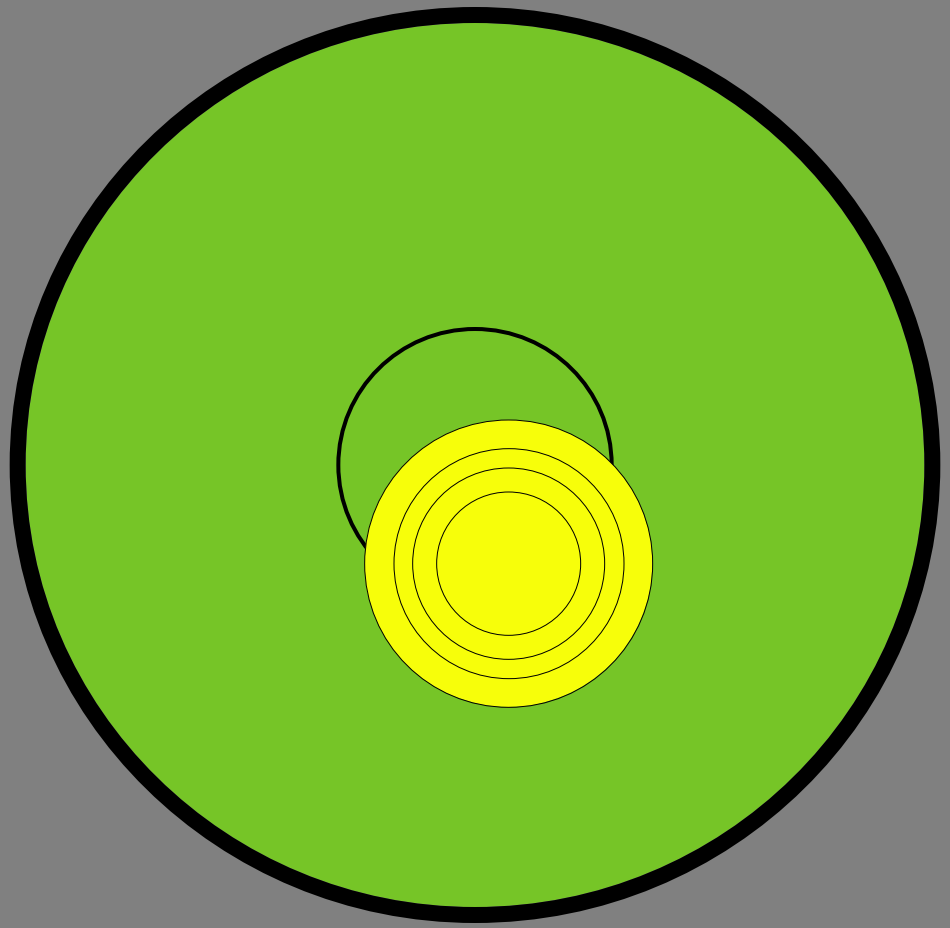
- Alignment of condenser lenses assures that illumination is centered at **all levels** of condenser current

- Bad misalignment leads to **illumination sweep**

- Illumination is not uniform unless the condenser lens **apertures** are properly centered







I.D.2 Alignment of TEM Components

I.D.2.b Condenser System

Principles of condenser alignment:

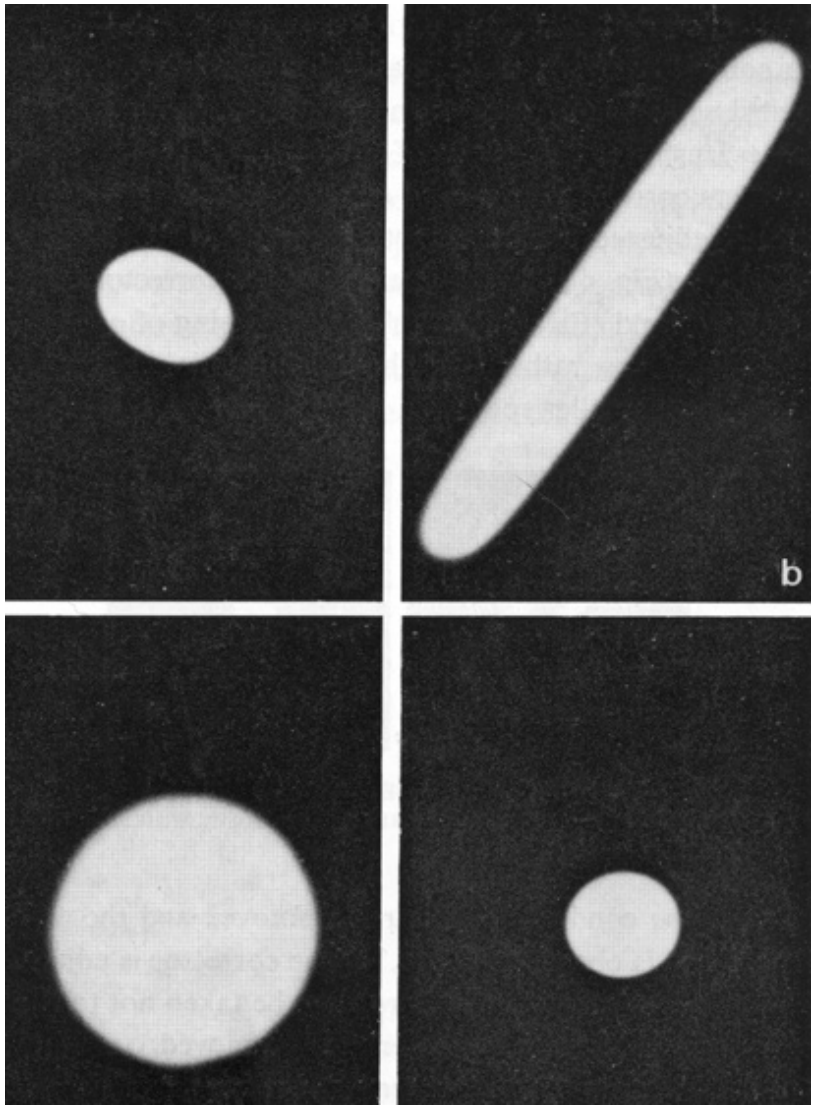
- Make **small, incremental** changes

- Work **back and forth** between condenser and gun translation and gun tilt controls **until crossover** focus on screen **remains centered and symmetrical** as condenser is alternately underfocused and overfocused.

I.D.2 Alignment of TEM Components

I.D.2.b Condenser System

Astigmatism in the 2nd condenser lens leads to elongated, asymmetrical spot shape on either side of focus



From Agar, Fig. 4.6, p.129

I.D.2 Alignment of TEM Components

I.D.2.c Imaging System

Alignment procedure:

- Make axes of all imaging lenses **coincide** with instrument mechanical (optical) axis

When all imaging lenses are in line:

- An object point on the objective lens axis will be imaged at the viewing screen center **whatever the magnification setting**

I.D.2 Alignment of TEM Components

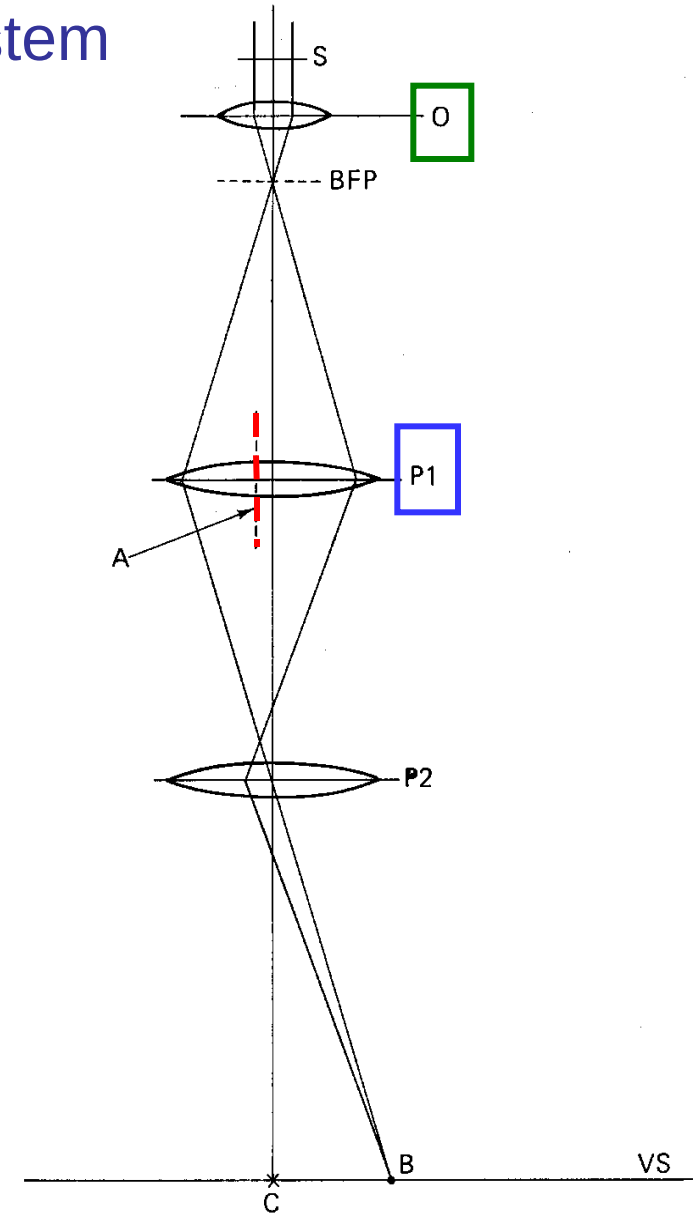
I.D.2.c Imaging System

Alignment of the intermediate (or first projector lens)

- Image of the source is formed on the axis of the objective lens O in the back focal plane (BFP)

- If the axis A of P1 is not on the axis of O and P2 (second projector lens), the image of the crossover is formed at B on the viewing screen (VS), away from the screen center C

- When A is aligned with the instrument axis, B moves to C.



From Agar, Fig. 4.9, p.133

I.D.2 Alignment of TEM Components

I.D.2.c Imaging System

Voltage Center

Principle of imaging lens alignment:

Changes in accelerating voltage create expansion or contraction of image as well as **image rotation**

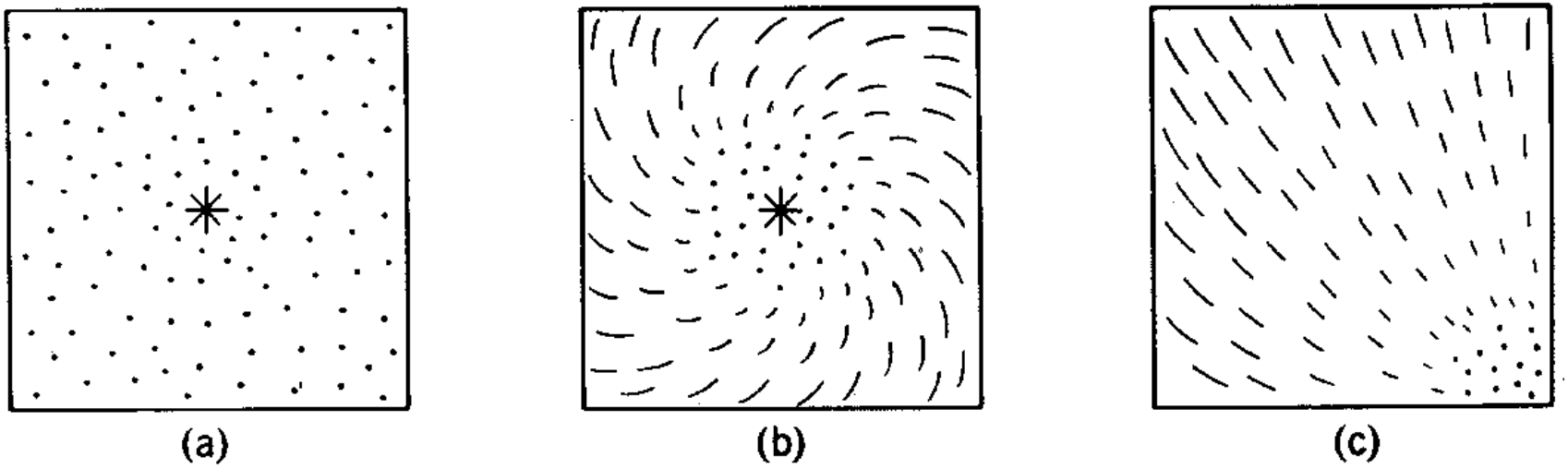
With high voltage fluctuations, the image will be **sharpest only** at an axis or **voltage center**

Image quality is **least affected** if voltage center is made to appear at the viewing screen center (*i.e.* on the optic axis)

I.D.2 Alignment of TEM Components

I.D.2.c Imaging System

Voltage Center



- Effects of misalignment and high voltage ripple: (a) ideal image; (b) image formed when regulation of high voltage is defective; (c) misaligned image.

From Slayter, Fig. 18-16, p.401

I.D.2 Alignment of TEM Components

I.D.2.c Imaging System

Current Center

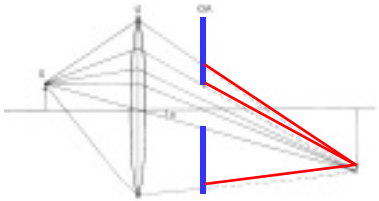
- Just as with voltage fluctuations, **lens current fluctuations** give rise to **superimposed images** of different magnifications and hence blurring
- Image will only be sharp at an axis, the **current center**
- Ideally voltage and current centers should coincide
  - In practice they do not because axial asymmetries hard to eliminate during lens manufacture
  - Microscope has to be aligned with respect to **either** high-voltage or lens current fluctuations
- Voltage fluctuations > than current fluctuations

  Hence, desirable to align **voltage center**

I.D.2 Alignment of TEM Components

I.D.2.c Imaging System

Objective Aperture Alignment



Objective aperture is centered with either of two methods:

1) Viewing the aperture plane (back focal plane of objective) in diffraction mode (must have “specimen” inserted)

2) Center on viewing screen at low magnification (~ <2000)

#1 is the preferred method - **fast and accurate**

I.D ALIGNMENT/ADJUSTMENT OF THE TEM

I.D.3 Disturbances to Microscope Performance

a. Contamination

b. Image drift and mechanical instabilities

c. Electrical and magnetic instabilities

d. Image astigmatism

e. Focal drift

I.D.3 Disturbances to Microscope Performance

I.D.3.a Contamination

Contamination of TEM column, apertures, and specimen lead to:

- Astigmatism
- Drift
- Decreased contrast

Specimen **contrast reduced** by the deposition of a uniform layer of contamination

Small details in specimen structures **obscured** by the layer of contamination

I.D.3 Disturbances to Microscope Performance

I.D.3.a Contamination

Two, simple solutions:

- Keep your grimey hands off parts exposed to vacuum!
- Use an **anticontaminator**

From www.gatan.com/holders/index.html

Device that uses a **cooled surface**, placed close to the specimen, that preferentially condenses potential contaminants (i.e residual gases) on its surface and thereby protects the specimen

Most anticontaminators are cooled with **liquid nitrogen**

I.D.3 Disturbances to Microscope Performance

I.D.3.b Image Drift and Mechanical Instabilities

Important consideration:

Exposure times of ~ **1-4 seconds** required for photography of electron image

Consequence:

Specimen **movements** of a few tenths of a nm / sec can (and do!) **limit resolution**

Movements caused by instabilities in:

- - Specimen holder
- - Stage assembly
- - Specimen

I.D.3 Disturbances to Microscope Performance

I.D.3.b Image Drift and Mechanical Instabilities

Thermal Drift of Specimen

Occurs when:

- Support film expands or shrinks
- Specimen grid or grid holder expands asymmetrically

Culprits:

- Support film too thin or too thick
- Presence of dirt particles
- Poor contact between support film and grid

One way to help minimize thermal drift:

- Use **smaller** beam SPOT sizes to reduce the specimen area exposed to the beam (reduces specimen heating)

I.D.3 Disturbances to Microscope Performance

I.D.3.b Image Drift and Mechanical Instabilities

Thermal Drift of Specimen

- Minute drift may go undetected during viewing on screen

  Photographic image reveals the truth!

  Drift shows up as unidirectional blurring of image details

- Drift measured by making a **series of multiple exposures** over a time span of a few minutes

I.D.3 Disturbances to Microscope Performance

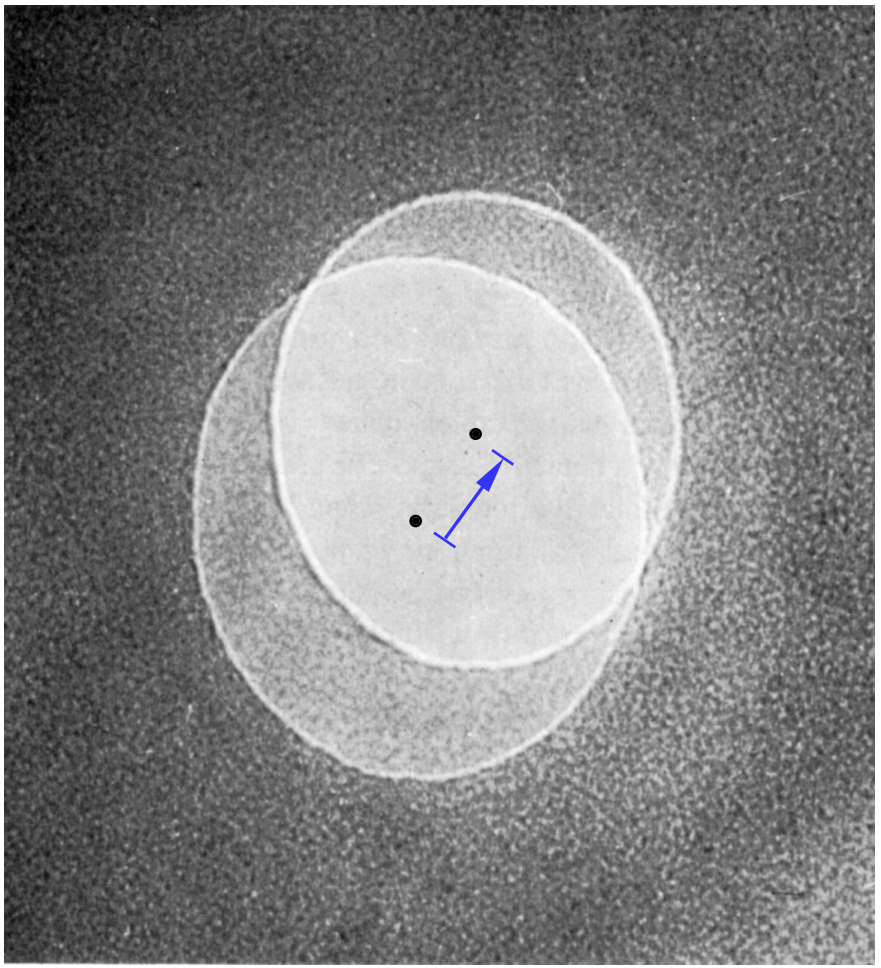
I.D.3.b Image Drift and Mechanical Instabilities

Thermal Drift of Specimen

Measuring Drift Rate

- Record **double exposure** of a hole in a carbon film

- Shows amount of specimen drift between exposures



From Agar, Fig. 5.7, p.154

I.D.3 Disturbances to Microscope Performance

I.D.3.b Image Drift and Mechanical Instabilities

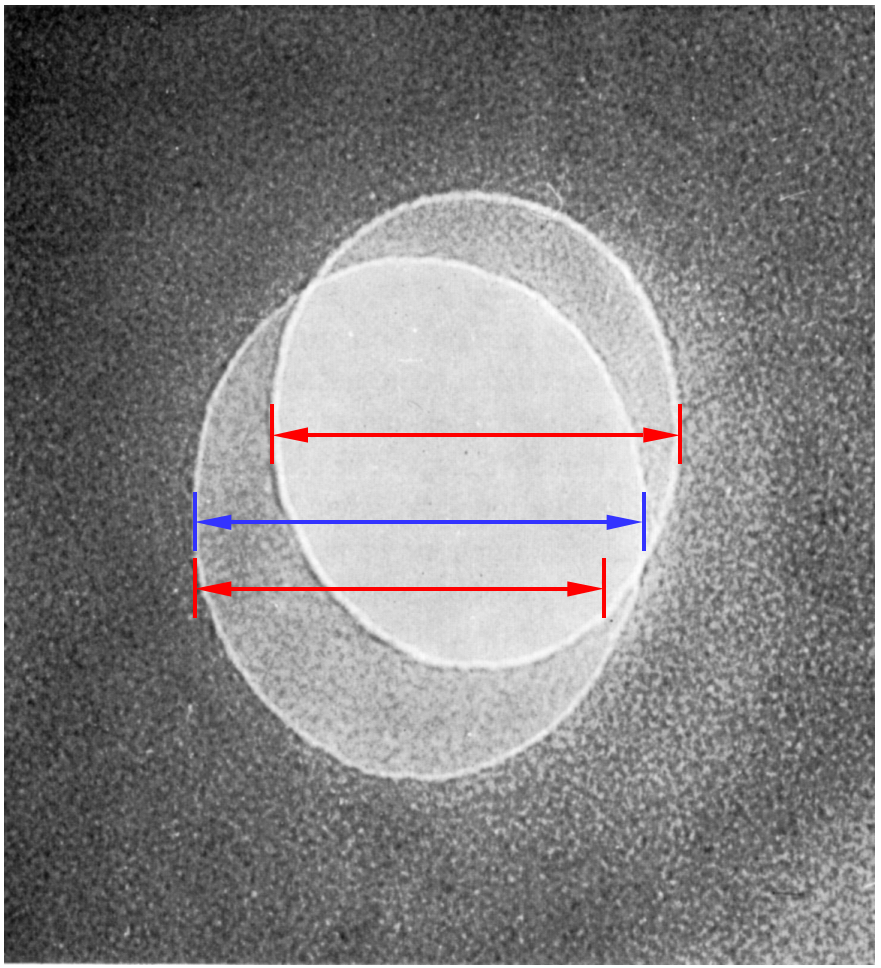
Thermal Drift of Specimen

Measuring Drift Rate

- Record **double exposure** of a hole in a carbon film

- Shows amount of specimen drift between exposures

- Example also allows measurement of TEM **contamination rate**
  (deposit of contamination layer shows up as a reduction in hole diameter)



From Agar, Fig. 5.7, p.154

I.D.3 Disturbances to Microscope Performance

I.D.3.b Image Drift and Mechanical Instabilities

Thermal Drift of Specimen

- Minute drift may go undetected during viewing on screen

  Photographic image reveals the truth!

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- Drift measured by making a **series of multiple exposures** over a time span of a few minutes

- Drift **distinguished from astigmatism** by comparing pictures taken at different focusing conditions

I.D.3 Disturbances to Microscope Performance

I.D.3.b Image Drift and Mechanical Instabilities

Mechanical Vibration

A few observations:

- **Ground vibrations** (outside traffic, slamming doors, earthquakes, etc.) lead to directional blur in images in the direction of the vibration

- Appropriate location and mounting of TEM is essential to eliminate microscope column vibrations

- Vibrations from mechanical pump must be isolated

I.D.3 Disturbances to Microscope Performance

I.D.3.c Electrical and Magnetic Instabilities

Electrical Interference

- TEM columns are designed to shield the electron beam from external fields
- **BUT: strong stray fields can deteriorate** image quality
- Microscope **must** be located away from power lines, magnets (*e.g.* NMR equipment), large electrical equipment, etc.
- If source of trouble is an **electrical field**, the blur will be **reduced at higher voltages**
- If blur results from **mechanical vibrations**, the **magnitude will remain unchanged at different voltages**

I.D.3 Disturbances to Microscope Performance

I.D.3.d Image Astigmatism

In absence of other aberrations, **resolving power**, *d*, is **limited by objective lens asymmetry** approximately to the extent given by:

$$d = \sqrt{\lambda \ \ \Delta f}$$

Δf = maximum difference in focal length of asymmetric lens

λ = electron wavelength

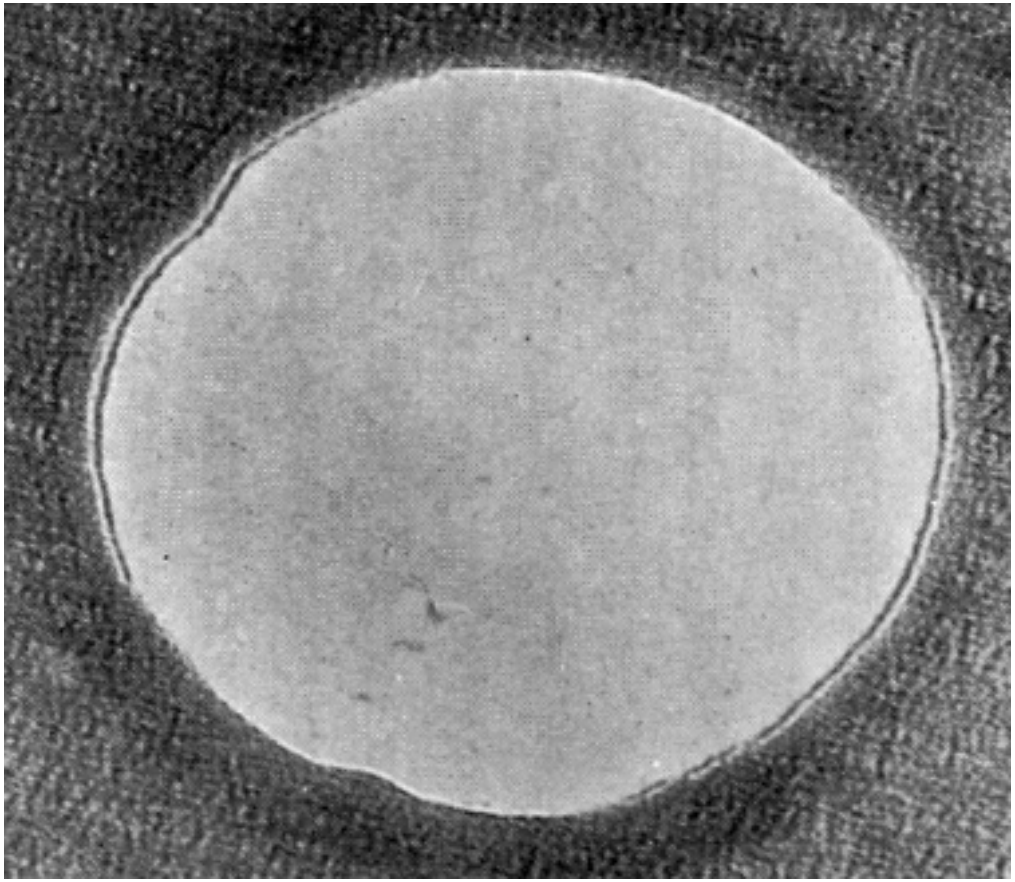
I.D.3 Disturbances to Microscope Performance

I.D.3.d Image Astigmatism

Measuring Astigmatism

Measure Fresnel fringe width in overfocused pictures

J. Turek may say more about this when he discusses resolution tests (Notes: I.E.7.c, page 84)



From Agar, Fig. 4.12, p.139

I.D.3 Disturbances to Microscope Performance

I.D.3.d Image Astigmatism

Correcting Astigmatism

Holey-carbon film method:

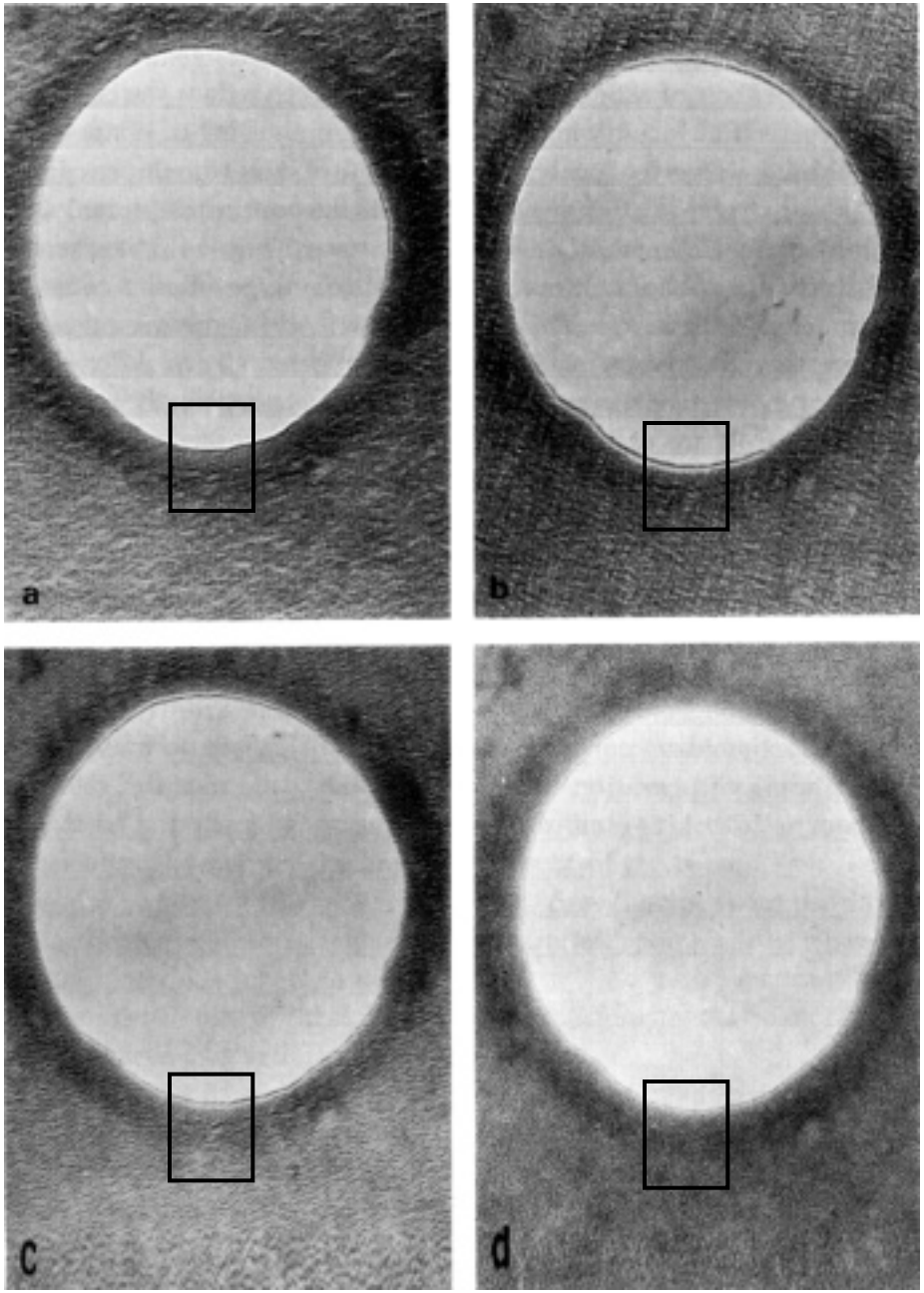
- Locate a **small hole** at 50,000-100,000X

- Adjust objective lens strength to give **slightly over-focus** image showing Fresnel fringes around the hole

- **Adjust objective lens stigmators** to make the over-focus fringe **symmetrical** with respect to the hole

I.D.3.d Image Astigmatism

Correcting Astigmatism



a. Fresnel fringe with astigmatism

b. Astigmatism corrector switched on, full strength, arbitrary direction

c. Corrector oriented to oppose the objective astigmatism

d. Corrector strength reduced to obtain a uniform fringe

From Agar, Fig. 4.12, p.139

I.D.3.d Image Astigmatism

Correcting Astigmatism

a. Fresnel fringe with astigmatism

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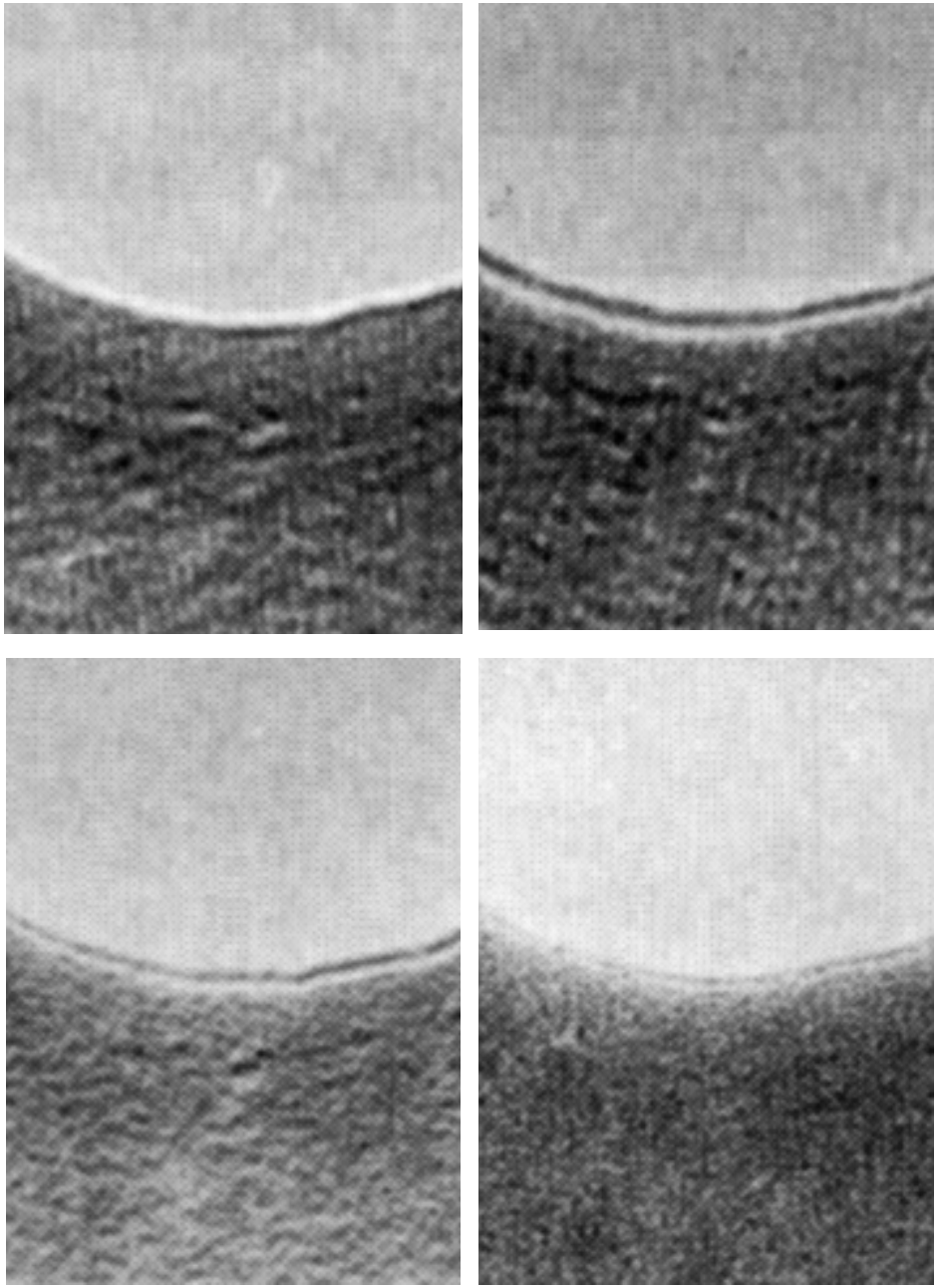
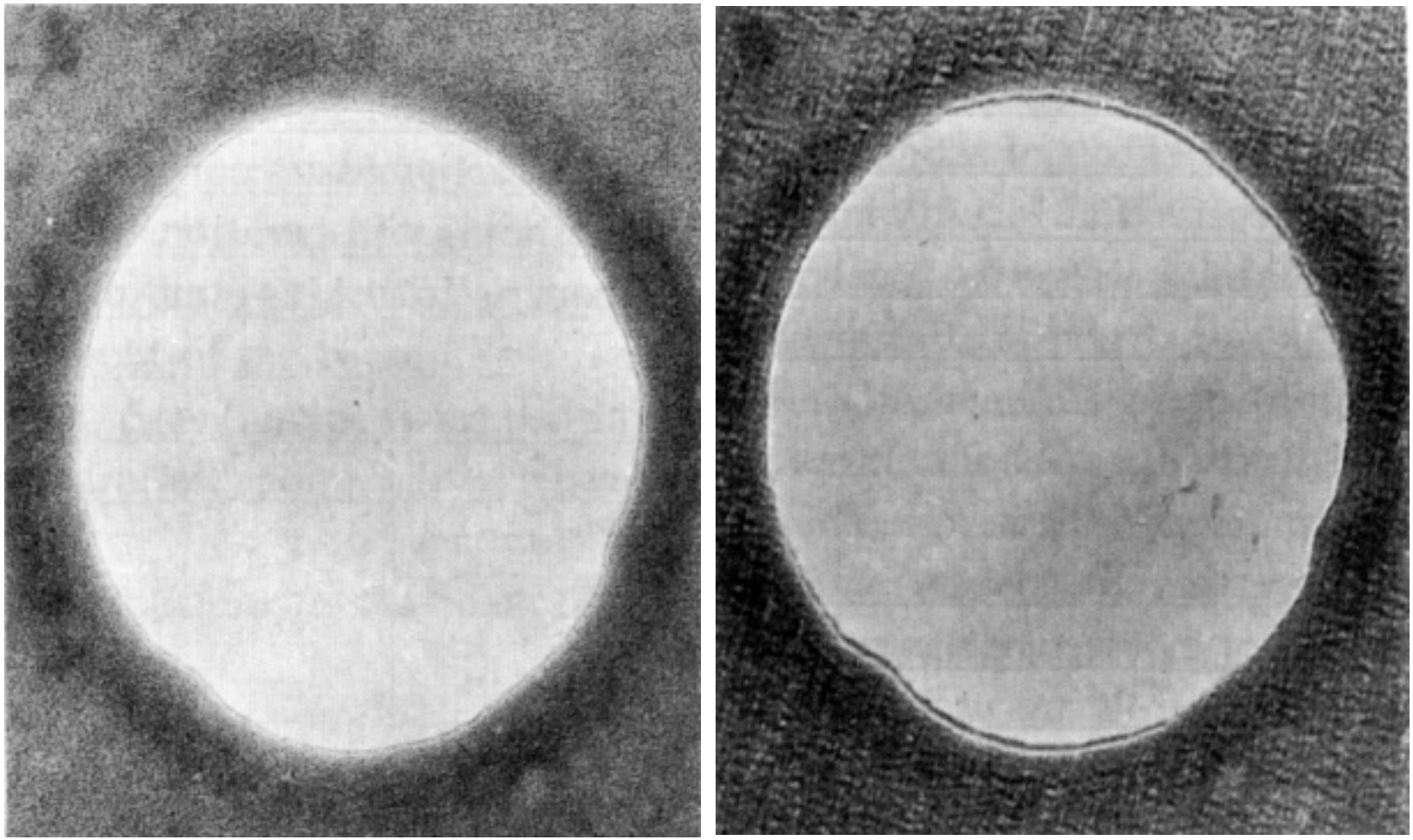


From Agar, Fig. 4.12, p.139

I.D.3 Disturbances to Microscope Performance

I.D.3.d Image Astigmatism

Correcting Astigmatism



From Agar, Fig. 4.12, p.139

I.D.3 Disturbances to Microscope Performance

I.D.3.d Image Astigmatism

Correcting Astigmatism

Minimize phase contrast method (*the best method*!):

- Obtain a **high magnification** (100,000X or higher) view of a carbon support film and adjust objective lens strength to give an image as **close to 'true' focus** as possible (will be difficult depending on level of astigmatism present)

- Use the stigmators to "focus away" (*i.e.* reduce) the phase contrast in the support film background

Main objective: Try to make support film background **DISAPPEAR**

Practical consideration:

It takes practice, practice, practice to learn and use this procedure

I.D.3 Disturbances to Microscope Performance

I.D.3.d Image Astigmatism

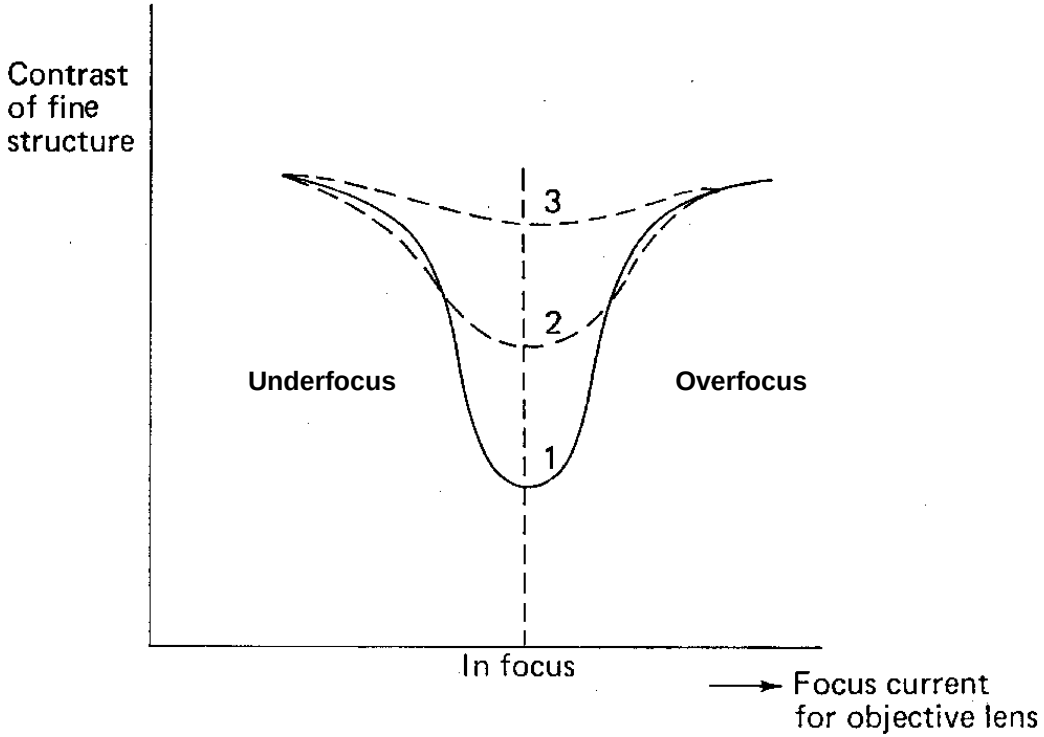
Correcting Astigmatism

Effect of Objective Lens Astigmatism on Image Contrast at 'Near' Focus

(1) No residual astigmatism:
Large drop at true focus

(2) Slight astigmatism:
Smaller drop

(3) Considerable astigmatism:
Imperceptible change



From Agar, Fig. 4.13, p.140

I.D.3 Disturbances to Microscope Performance

I.D.3.e Focal Drift

When small *focus* changes are observed in the image:

- Likely to be due to **dirt in the gun** than a fault in the electrical supplies.

- Any dirt leads to **micro-discharges** in the gun and hence a **change in accelerating voltage** which causes a **change of focus**

End of Sec.I.D