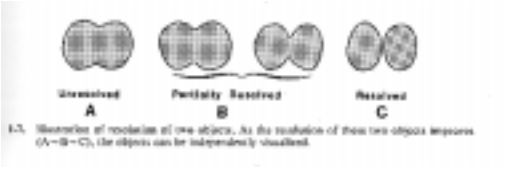
Scanning Electron Microscopy

Considerations in Microscopy

- Magnification
- Resolution
  - Smallest separation of two points that are visible as distinct entities
  - Headlights
- High magnification without high resolution is “empty”

Resolution



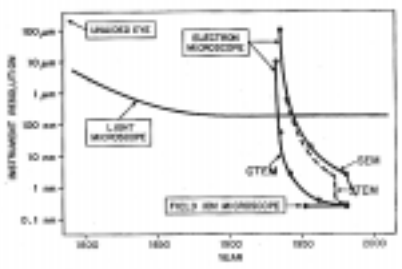
Light Microscopy

- Resolving limit
  - Eye 0.1 mm
  - Light microscope 0.2 μm
  - SEM 3 nm
  - TEM 0.2 nm

Abbe’s Equation

- Resolution in the light microscope is limited by the wave nature of light
- $$d = \frac{0.612\lambda}{n\sin\alpha}$$
- Where:
  - d is the resolution
    - Smaller is better
  - λ is the wavelength
  - n is the index of refraction
  - α is the aperture angle

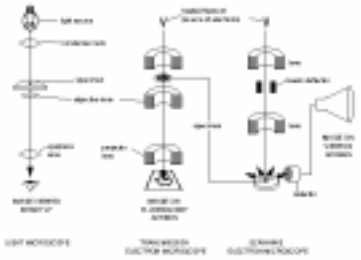
Evolution of Resolution



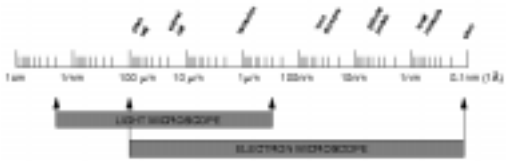
Light vs. e^-

- As λ increases, d increases
- Best resolution is lowest λ
- λ(Blue) ≅ 400 nm
- λ = h/mv
- λ(e^- 60 kV) = 0.005 nm

Light Microscope vs. EM

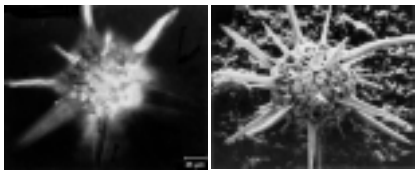


Light Microscope vs. SEM



SEM

- Magnification < 100,000 X
- Large Depth of Field



- Radiolarian

SEM

- Advantages
  - Magnification
  - Resolving Power
  - Depth of Field
- Disadvantages
  - Vacuum
    - ex situ
  - Conductive
  - Expensive
  - Maintenance

SEM History

1878 Abbe	Light limit
1923 de Broglie	e^-'s are waves
1926 Busch	Can focus e^-'s with H
1932 Ruska	TEM
1938 Von Ardenne	built first SEM
1938 Siemens	First commercial TEM
1965	First commercial SEM

SEM Applications

- Topography
  - Surface features
- Morphology
  - Shape, size, arrangement, etc.
- Composition
  - Elemental information
- Crystallographic
  - Arrangement of atoms in single crystals

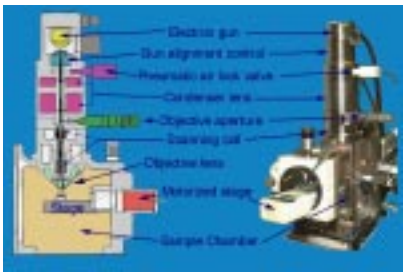
SEM Components

- Vacuum System
  - Mechanical Pump (Fore, or Rotary)
    - 500-1000 lpm
    - Achieve vacuum of 0.01 torr
  - Oil Diffusion Pump
    - 500-1000 lps
    - Achieve $10^{-(5-7)}$ torr
    - Can't be used above 0.01 torr

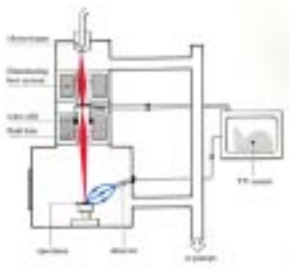
SEM Components

- Microscope Column
  - Electron Gun
  - Electromagnetic Lenses
  - Aperatures

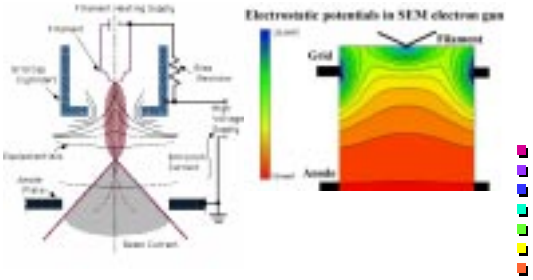
Beam Path Through Column



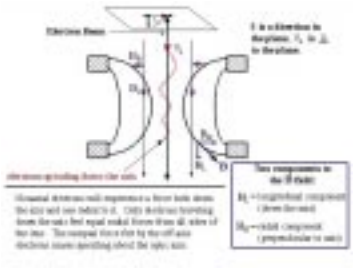
SEM Image Formation



Electron Gun



Cylindrical Magnetic Lenses



Electron vs. Optical Lenses

- e⁻'s don't actually touch lens
  - No definite interface
- e⁻'s rotate in magnetic field
- e⁻'s repel each other
- $f \propto H \propto I$
  - Focus and Magnification controlled electrically
  - No physical movements

Electron vs. Optical Lenses

- e^- lenses can only be positive elements (converging)
- Can't correct e^- lens aberrations like you can with compound optical lenses
- e- lenses always operate at small aperatures

SEM Components

- Scan Coils
- Specimen Stage

Sample Stage