Chapter 1. Basic Electron Optics (Lecture 2)

- Basic concepts of microscope (Cont’)
- Fundamental properties of electrons
- Electron Scattering
- Instrumentation
Basic conceptions of microscope (Cont’)

- Ray diagram
- Magnification
- Resolution
- Depth of field and depth of focus
- Aberration of optical system
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.

**Rayleigh Criterion:**

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

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

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

Resolution of the Human Eye \( \sim 0.1 \text{ mm} \)
Aberration of lens

- Chromatic aberration $C_c$
- Spherical aberration $C_s$
- Astigmatism

Disc of least confusion

Shorter wavelength to a focus near to lens

Longer wavelength to a focus further to lens

Chromatic aberration $C_c$
Aberration of lens

- Chromatic aberration $C_c$
- Spherical aberration $C_s$
- Astigmatism

Disc of least confusion

Focus for marginal rays is nearer to lens than the focus for paraxial rays

Axial focus

Spherical aberration $C_s$
Aberration of lens

- Chromatic aberration $C_c$
- Spherical aberration $C_s$
- Astigmatism
Astigmatism

No astigmatism
Aberration correction in TEM

The principle of the monochromator with a picture of a Wien-filter type monochromator
The aberration correctors and monochromators in the electron microscopes means tighter, brighter beams, yielding a stronger signal, higher imaging contrast, and higher resolution to 0.08 nm.

An aberration-free image of atoms of gold produced by the FEI Titan 300 kV transmission electron microscope (2006 release). The gold atoms are spaced ~ 0.2 nm apart.
Comparison of a not Cs-corrected (left) and a Cs-corrected (right) HR-TEM image on the same area of a polycrystalline gold sample in <110> direction. The delocalisation due to spherical aberration is visible at the grain boundary in the uncorrected image (left). The exact positions of the atoms on the grain boundary can be clearly seen in the Cs-corrected image (right), while Móire patterns are degrading the resolution in the uncorrected image (left). Sample courtesy: C. Kisielowski, from the National Center of Microscopy in Berkeley, CA
Electron Properties

1. Particle and wave dual characteristics
   • Fundamental constant and definitions
   • de Broglie’s wave-particle duality
   • Wave length
   • Wave length with relativistic effect

Theoretical estimates of the electron density for the first few hydrogen atom electron orbitals shown as cross-sections with color-coded probability density (source: Griffiths, David J. (2004). *Introduction to Quantum Mechanics*)
HW# 3: Due day: 09/10/08, Wed.

1. Using Spreadsheet to calculate the electron mass ($\times m_0$) and wave length (with/without relativistic effect) as a function of acceleration voltage (KV) at 100, 120, 200, 300, 400, 500, 1000.

2. Plot the wavelength vs. acceleration voltage with/without relativistic effect respectively in one plot to showing how relativistic effect affects the electron wavelength with increase of voltage

HW#4: Due day: 09/10/08, Wed

Think about your term project and tell me what sample you will use, and briefly give your sample information
Inside an Atom  
Electron Shells

Basic Arrangement of Electrons in Iron (Fe)

Tracy V. Wilson: How atom works

CHEM 793, 2008 Fall
The electron is a wave system.
The wave nature of electron
The Ties That Bind

A group of scientists at Arizona State University has used X-rays and electron diffraction techniques to capture direct images of the electronic bonds that keep together the atoms of oxygen and copper in a compound called cuprite.

Source: Arizona State University
Beam-Specimen Interactions: The Scattering of Electrons

- without interaction we observe nothing
**Electron Microscopy**

**Electron Beam**

- Scanning Electron Microscope (SEM) Dealing mainly with Surface
- Backscattered Secondary Electron to Image Specimen Topography
- Transmission Electron Microscope (TEM) Dealing mainly with Internal Structure
- Transmitted and Diffracted Electron to Image Specimen Internal Structure
Two Monte Carlo simulation of 50 µm thick foils C and Cu. Note that the increase in scattering and decrease in path with atomic number
What happens when an energetic electron (100-400kv) strikes the specimen? Mostly, consider electron particle nature.

Direction changes, but electron energy does not change much ($\leq 10^\circ$).

The electron energy changes, but the direction does not change much ($\sim 0.1^\circ$).
Scattering Events

**Single Scattering:** each electron scatters only once on average while traversing the sample

- good for TEM analytical work

**Plural Scattering:** each electron scatters more than once but less than 20 times

**Multiple Scattering:** each electron scatters more than 20 times as it traverses the sample

- sample is too thick for any reasonable analytical work, difficult to predict what will happen to electron
Next lecture

• Electron-specimen interaction (cont’)
• TEM Instrumentation