Transmission Electron Microscopy

Part I: History and Introduction

Christoph T. Koch

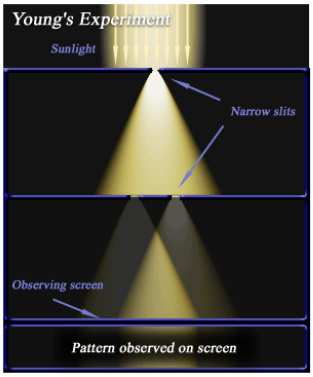
Max Planck Institut für Metallforschung
Heisenbergstr. 3, 70569 Stuttgart
Raum 5N8, Tel: 0711/689-3647

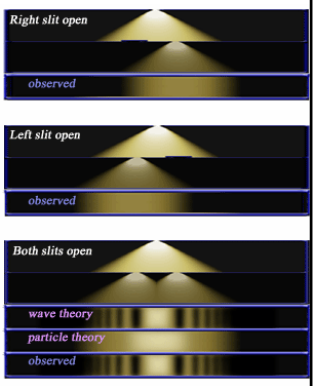
Literature

- Thorough theoretical foundation:
  J.C.H. Spence, “High-Resolution Electron Microscopy”
  Oxford University Press, Oxford (2003)
- Inelastic electron scattering:
  R.F. Egerton, “Electron Energy-Loss Spectroscopy in the Electron Microscope”, Plenum Press, New York (1996)
- Overview of different methods with focus on applications:
  D.B. Williams and C.B. Carter “Transmission Electron Microscopy”
  Vol. 1-4, Plenum Press, New York (1996)
- Optics Background:
  M. Born and E. Wolf, “Principles of Optics”,
  Pergamon Press, Oxford (2005)

Light = Waves

Thomas Young
(1773 –1829)



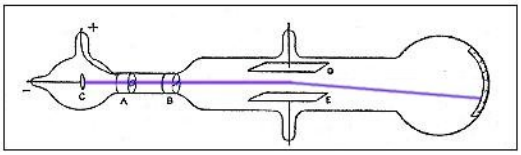


Young's double slit experiment (1805) to solve the dispute of whether light is made of particles or waves

=> Discovery of interference of waves

ELECTRON = charged PARTICLE

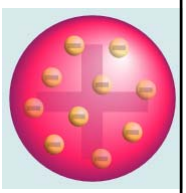
Sir Joseph John Thomson
(1856 – 1940)
Nobelpreis 1906



J.J. Thomson's 2nd Cathode ray experiment

1897: discovered "corpuscles", small particles with a charge/mass ratio more than 1000 times greater than that of protons, swarming in a see of positive charge ("plum pudding model").

=> Discovery of the ELECTRON



Plum pudding
model (1904)

ELECTRON = WAVE

Sir George Paget Thomson
(1892 – 1975)
Nobel Prize: 1937
(shared with C.J. Davison)

Observed electrons forming diffraction patterns when passing through a thin film of metal.

=> Discovery of WAVE-like nature of the electron

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ELECTRON = PARTICLE & WAVE

Louis-Victor Pierre Raymond de Broglie
(1892 - 1987)
Nobel prize: 1929

De Broglie's doctoral thesis (1924):

Application of the idea of particle – wave dualism (only known for photons up to then) for any kind of matter.

=> Matter Waves

$$\lambda = \frac{h}{p} = \frac{h}{mv}$$

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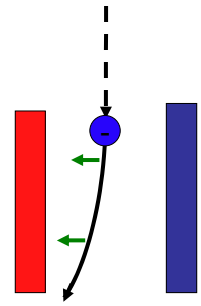
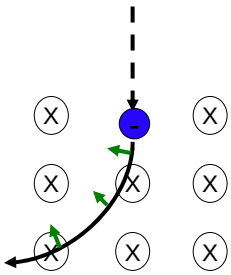
Electrons in electric and magnetic fields



Electrostatic force



Lorentz force

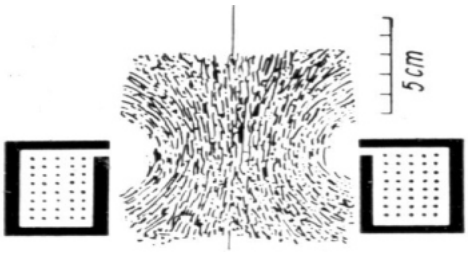
F=qE

F=qv⊗B

Use these as the only optical elements (q=-e)

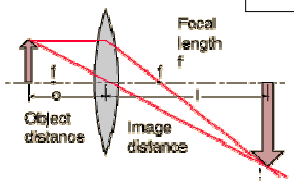
Electron Optics

Hans Busch
(1884 - 1973)
1949 Ehrenmitglied der "Deutsche Gesellschaft für Elektronenmikroskopie" (DGE) ernannt und mit dem Titel "Vater der Elektronenoptik" geehrt



Electrons are focused by a short magnetic coil

Electron optics was born in 1927, when Hans Busch showed that the elementary lens equation is applicable to short magnetic coils.



$$\frac{1}{d_{object}} + \frac{1}{d_{image}} = \frac{1}{f} \qquad M = \frac{d_{image}}{d_{object}}$$

Electron Microscope

Ernst Ruska
(1906-1988)
Nobel prize: 1986

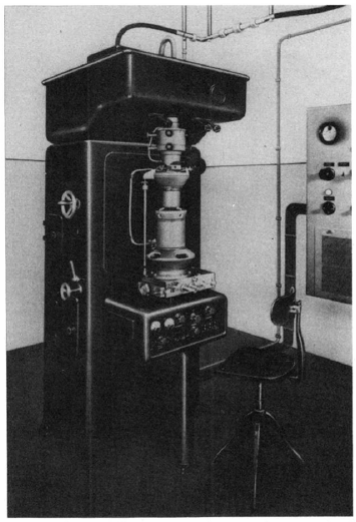


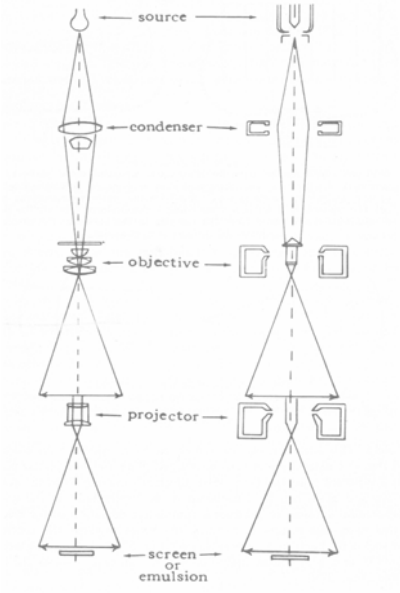
FIG. 11. First serially produced electron microscope, by Siemens. General view (von Borries and Ruska, 1939).

History of the transmission electron microscope (TEM)

- 1897: Joseph John Thompson: Discovers the electron
- 1924: Louis de Broglie: Wavelength of electron $\lambda=h/mv$
- 1926: H. Busch: Lenses for electrons
- 1931: Ruska & Knoll: 1st TEM
- 1938: M. von Ardenne: 1st STEM
- 1945: 1nm resolution
- 1986: E. Ruska: Nobel Price
- 1997: O. Krivanek: 1st Aberration corrector for STEM
- 1998: M. Haider: 1st Aberration corrector for TEM
- … (more work to be done) …

The electron microscope

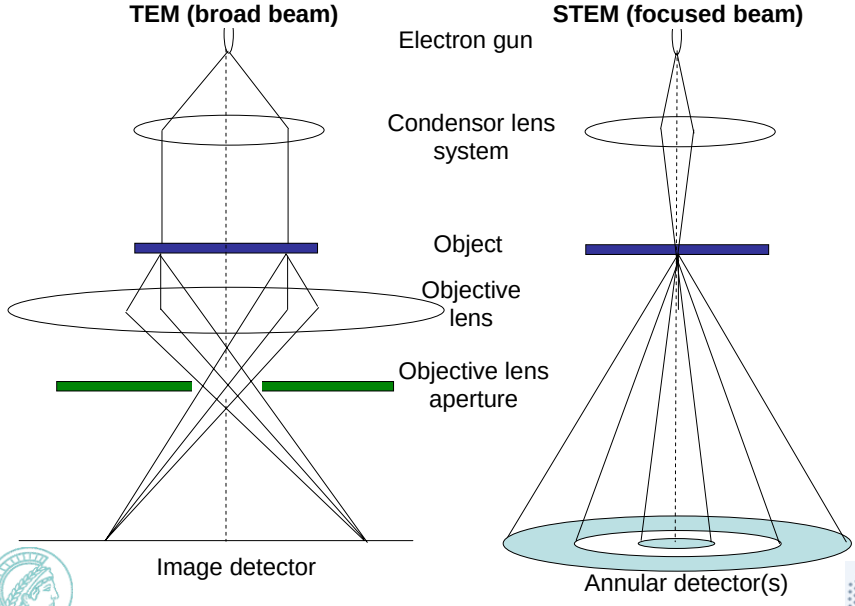
Light Microscope



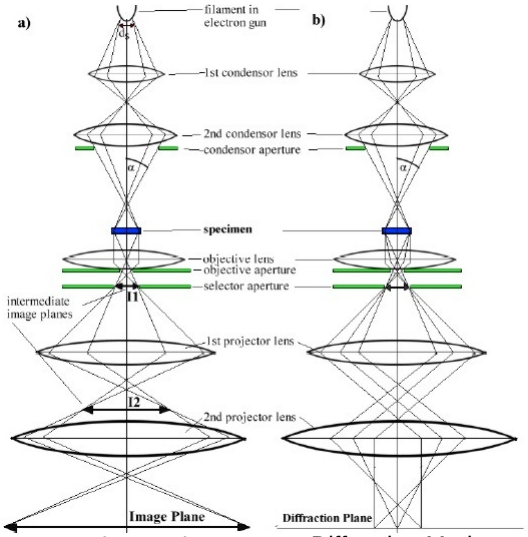
Electron Microscope

Transmission Electron Microscopy

TEM (broad beam) **STEM (focused beam)**

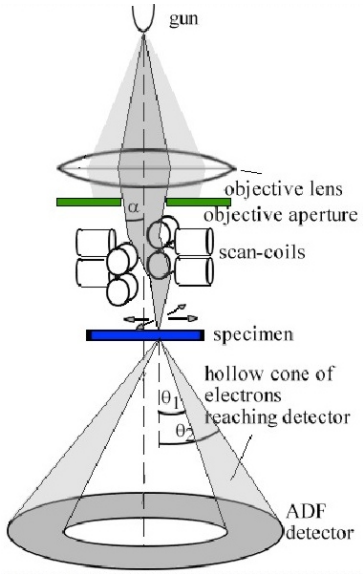


(conventional) TEM



Imaging Mode Diffraction Mode

Scanning TEM (STEM)



Abbreviations

- HEED: high energy electron diffraction
- LEEM: low energy electron microscope (many variations with special names)
- EELS: electron energy loss spectroscopy
- EDXS: energy dispersive X-ray spectroscopy
- SEM: scanning electron microscope (electrons do NOT normally transmit the sample)

Themen im ersten Semester

- Physik der Elektronenstreuung und –beugung, Streufaktoren, Bethe-Mott Formel
- Reziproker Raum, Fourier Transformation, Kinematische Beugungstheorie, Strukturfaktoren, Indizierung von Beugungsmustern
- Phasenproblem und Methoden zu dessen Lösung
- Kohärente Abbildung im TEM, Effekt von Linsenfehlern, kohärente Elektronenquellen
- Aufbau eines Durchstrahlungselektronenmikroskops, Elektronenlinsen, Detektoren
- Holographie (off-axis und inline)
- Inelastische Elektronenstreuung (EELS, ELNES, EXELFS), Methoden zu deren Berechnung
- TEM Probenpräparation für Materialwissenschaftliche und Biologische Anwendungen

Themen im zweiten Semester

- Dynamische Streutheorie und deren Berechnung (Blochwellen, Multislice)
- Konvergente Elektronenbeugung (CBED), HOLZ-Linien, QCBED
- Thermisch diffuse Streuung, Kikuchi- und Kossellinien
- Kontrast von Kristallstrukturdefekten (Versetzungen, Stapelfehlern, etc) in „weak beam“ Bildern und LACBED
- Tomographie, Beugungstomographie
- Mathematische Methoden zur Lösung des Inversionsproblems der dynamischen Elektronenbeugung

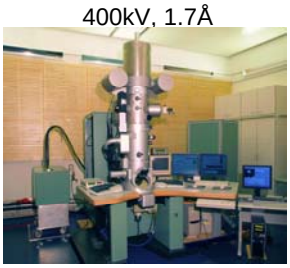
A Selection of Microscopes at the MPI für Metallforschung

Zeiss 912: 200kV, in-column filter

JEOL 4000 EX/FX 400kV, 1.7Å

JEOL ARM, 1250kV, 1.1Å

VG HB501-STEM 100kV, EELS/EDXS



Zeiss Libra 200FE+MC 200kV, in column filter

Zeiss SESAM 200kV, <0.1eV, <1Å