Diffraction and the Microscope Image

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The Carl Zeiss Workshop 1864

Optische Werkstatt von 1864.
Some properties of wave radiation

- Beams of light or electrons may be regarded as electromagnetic waves.

- Waves can interfere: adding together (in certain special circumstances):
  
  **Constructive interference** – peaks correspond
  
  **Destructive interference** – peaks and troughs

- Waves can be diffracted.
Waves radiating from a single point

Interference between waves radiating from two points x and x
Interference between waves radiating from two more-closely-spaced points $x$ and $x$

Interference between waves radiating from two points $x$ and $x$
Object

Objective lens

Back focal plane

Rays arranged according to direction

Image plane

Rays rearranged according to origin

-2 -1 0 +1 +2

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Diffraction in the microscope

Diffraction grating

Diffraction pattern in back focal plane of objective

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What will be the diffraction pattern of this grating?

As seen in the back focal plane of the microscope in white light.
Ernst Abbe’s Memorial, Jena

February 1994
Minimum resolved distance is now commonly expressed as

\[ d = 0.61 \frac{\lambda}{NA} \]
Abbe’s theory of microscopical imaging

1. The object diffracts light
   - finer detail more obliquely than coarser

2. Some – but not all – of these diffracted beams enter the objective

3. Diffracted beams are brought separately to focus in the back focal plane of the objective

4. Beams proceed up the microscope to the primary image plane, where they interfere to form the image.
Abbe’s Diffraction Apparatus

‘Drawer’ at level of back focal plane

Screw thread for objective lens

Masks for insertion into back focal plane
Demonstration microscope

Video screen

Diffraction pattern

Final image

Beam-splitter

Reflector

Back focal plane of objective
Imaging aperture reduced
Zero order removed
Dark field image

Mickey Mouse
Image at reduced aperture
Diffraction pattern of Mickey Mouse
Imaging aperture reduced
Zero order removed

From Harburn, Taylor & Welberry: Atlas of Optical Transforms
Do it yourself?

• **Light source:**
  – Remove condenser
  – Close illuminated field diaphragm
    Provides almost a point source, almost at infinity

• To see diffraction pattern in back focal plane:
  – Pinhole eyepiece, or
  – Telescope, or
  – Bertrand lens

• **Objective:**
  – Several of different numerical apertures to suit specimen fine detail
  – With iris diaphragm

• **Specimen:**
  – Diatom
  – Stage micrometer
  – CD (commercial, not writable, viewed from unprinted top side with 40/0.65)
Ernst Abbe to J. W. Stephenson
15 December 1876

Abbe’s explanation of the advantage of a full illuminating aperture