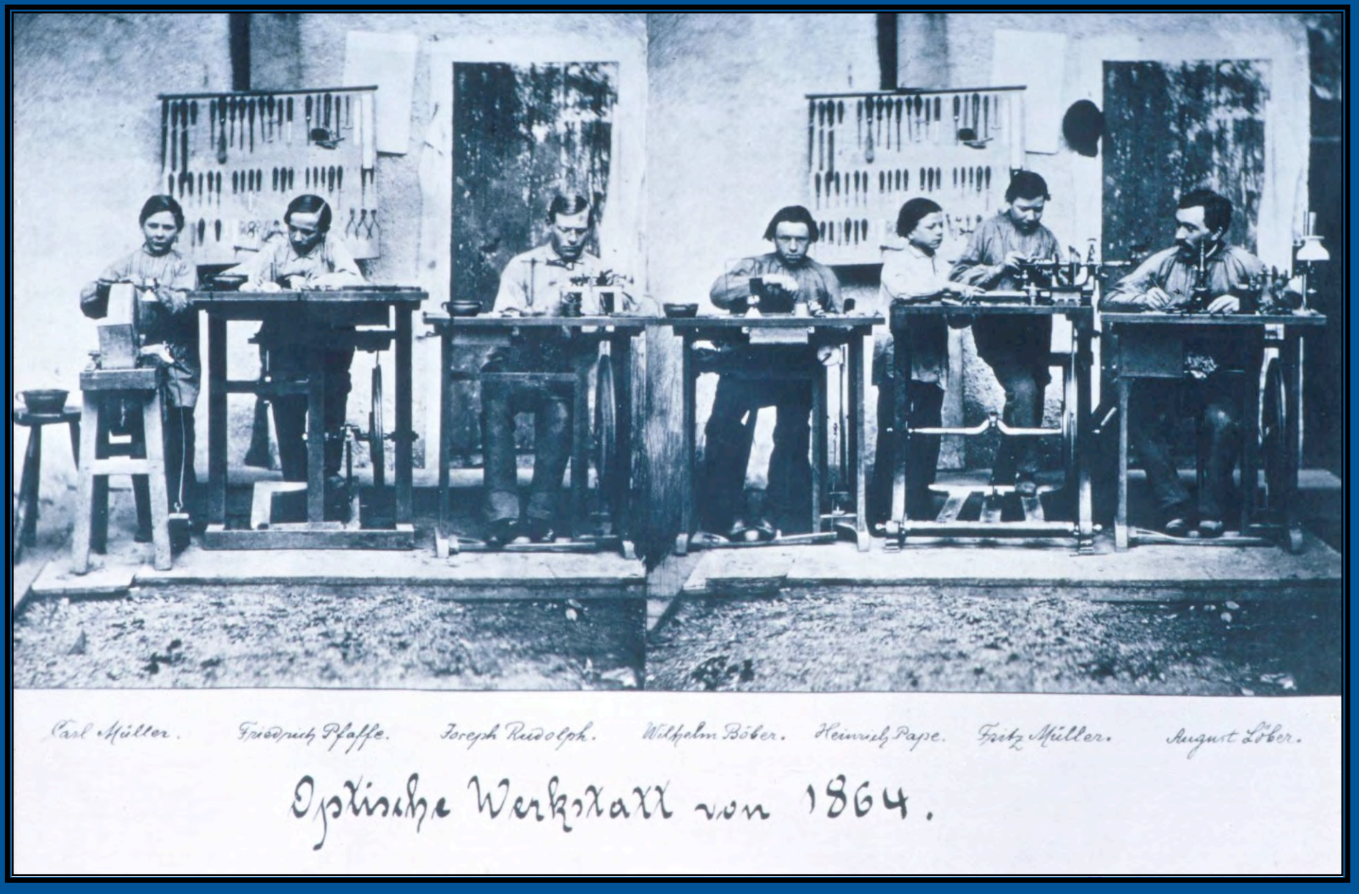
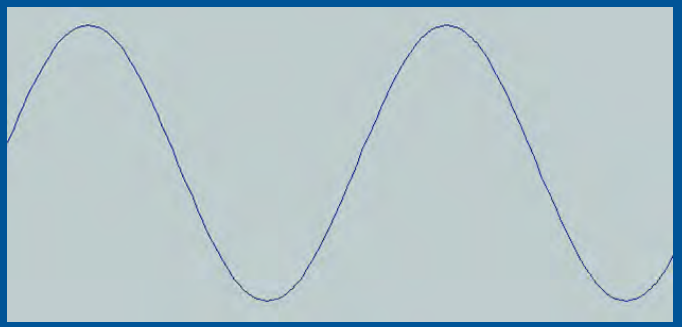
Diffraction and the Microscope Image

Peter Evennett, Leeds
peter@microscopical.co.uk

The Carl Zeiss Workshop 1864



Some properties of wave radiation



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

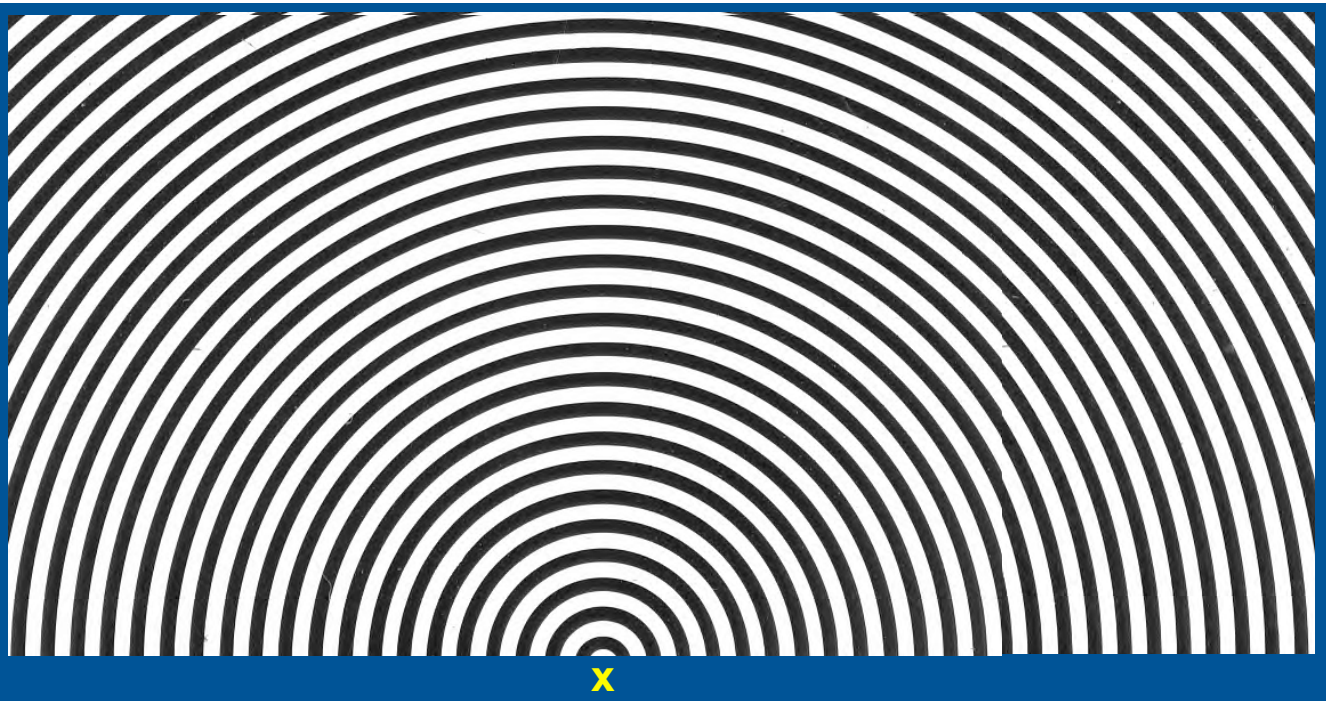
- Waves can interfere: adding together (in certain special circumstances):

  Constructive interference – peaks correspond

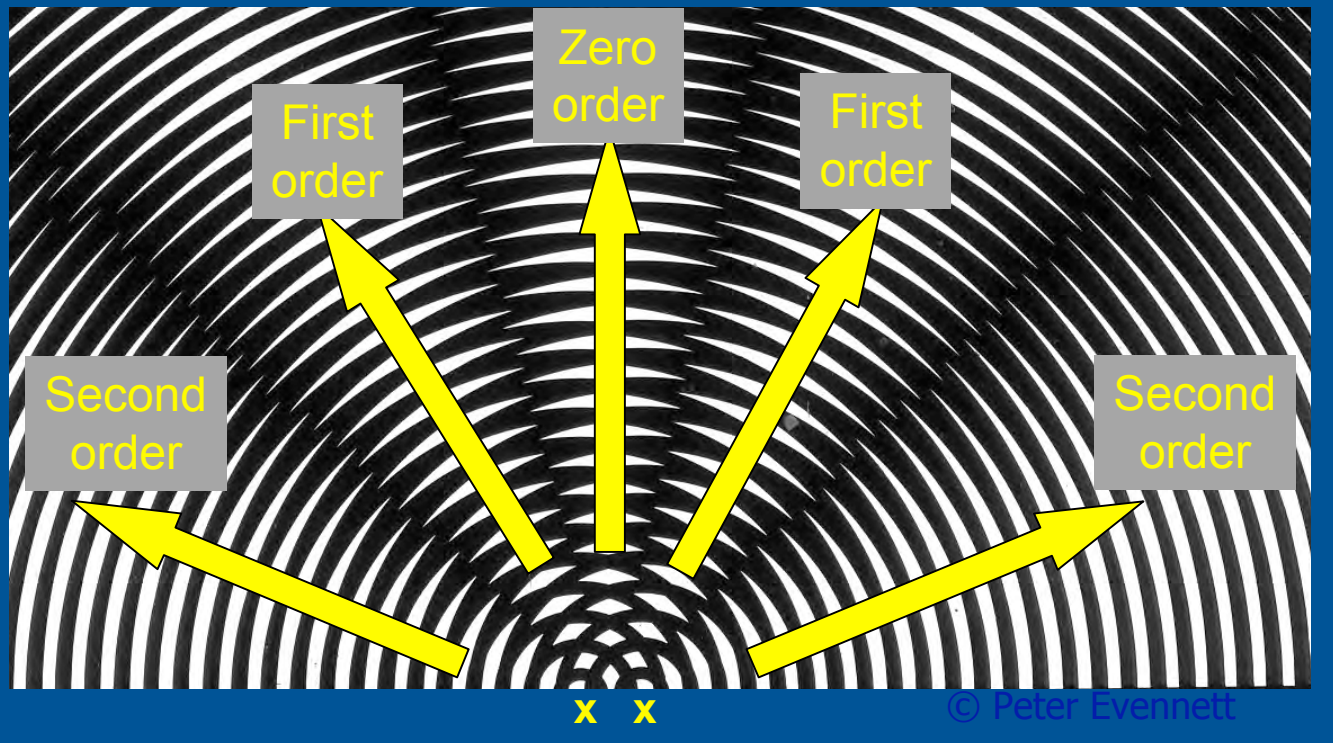
  Destructive interference – peaks and troughs

- Waves can be diffracted

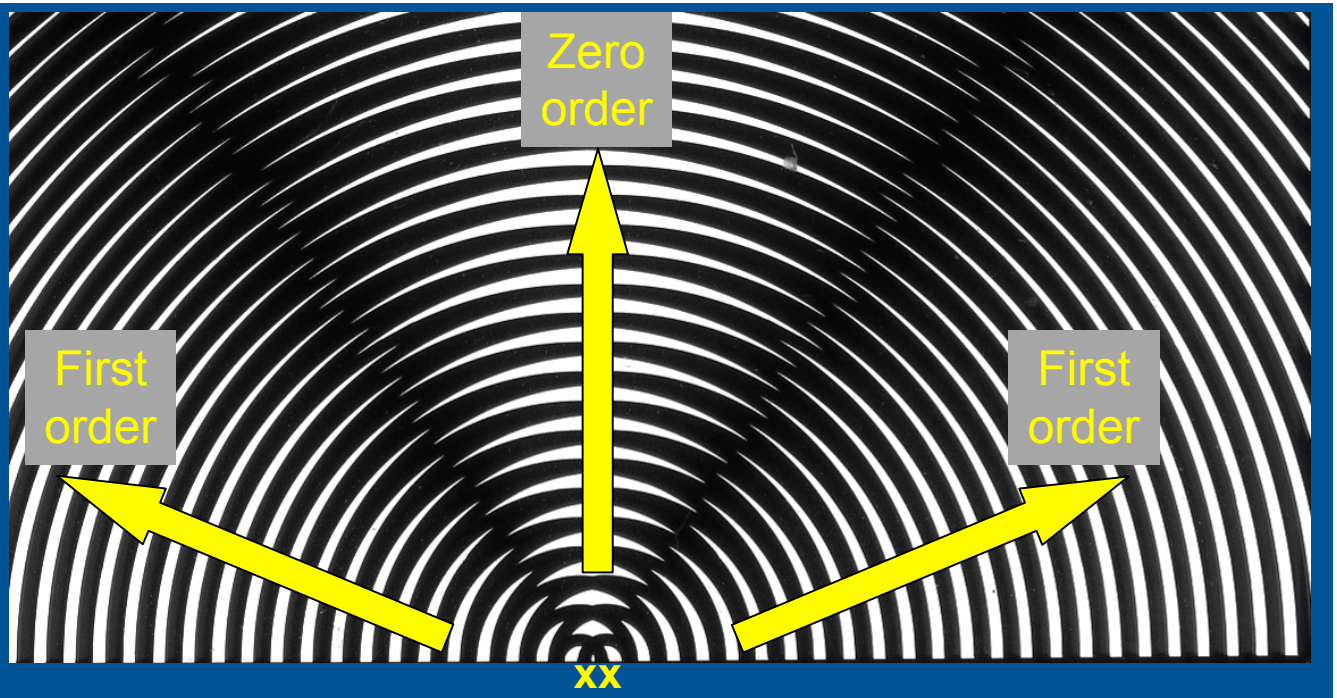
Waves radiating from a single point x



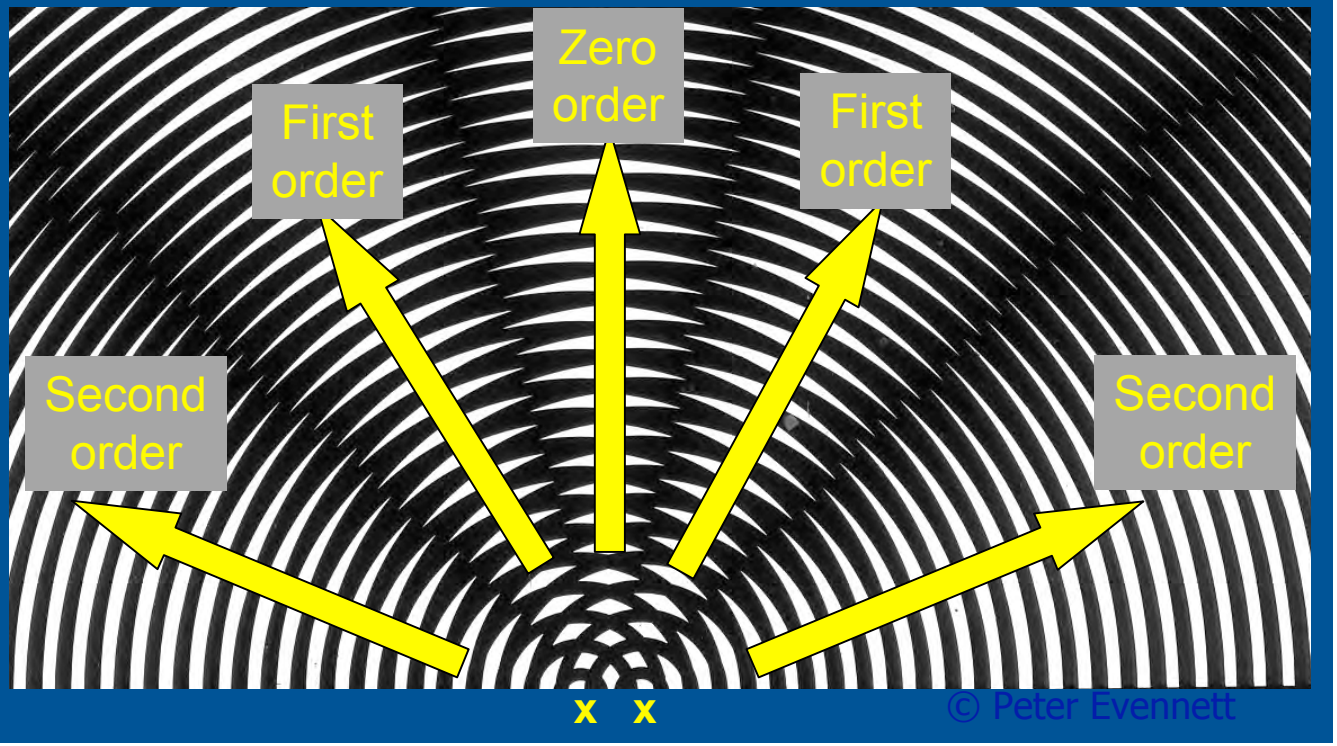
Interference between waves radiating from two points x and x

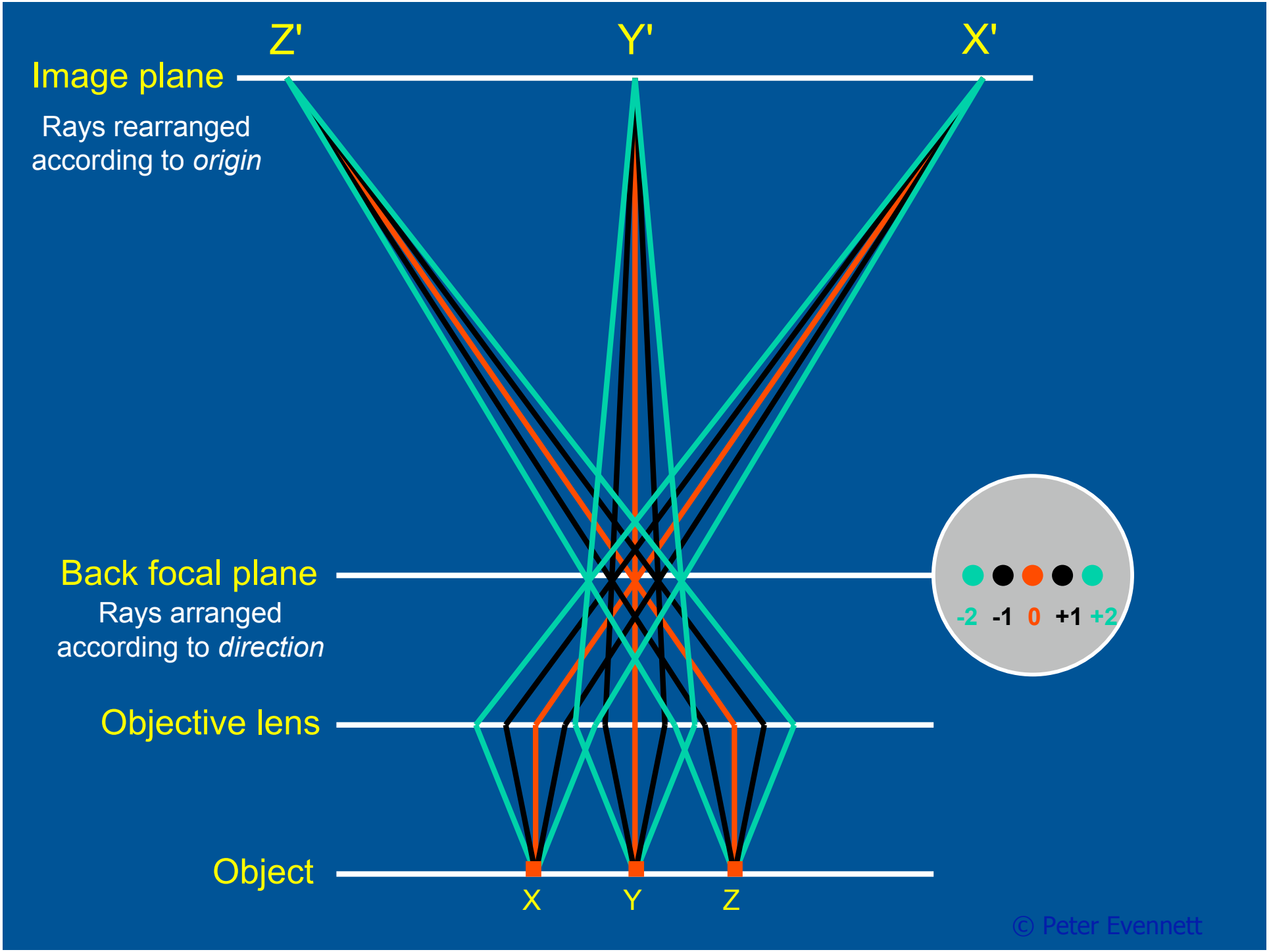


Interference between waves radiating from two more-closely-spaced points x and x



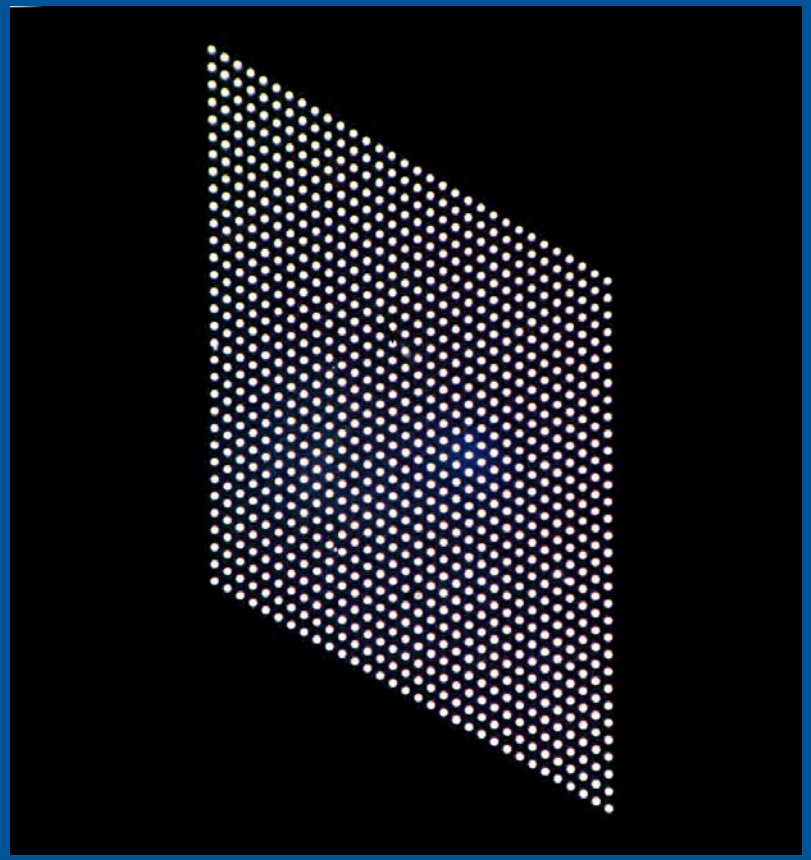
Interference between waves radiating from two points x and x



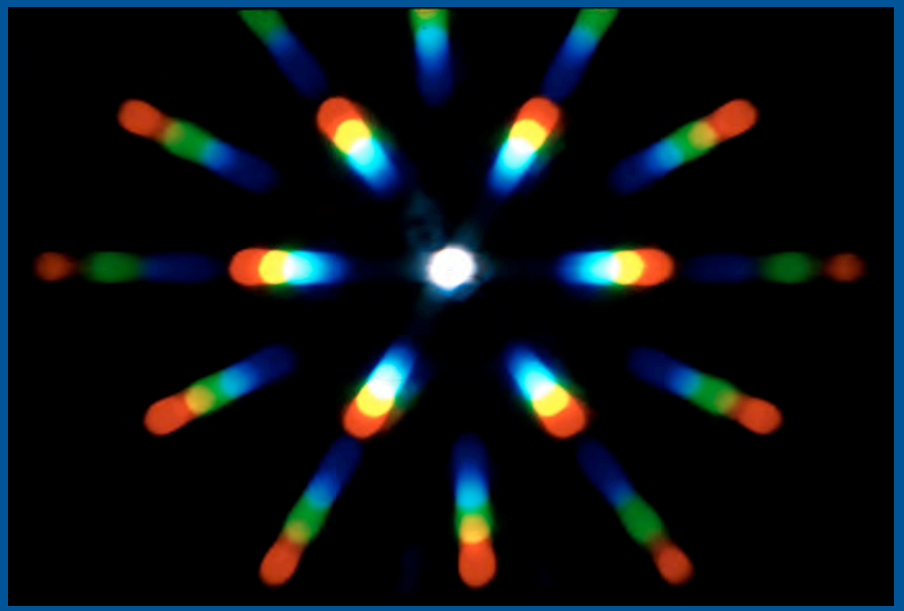

Z'
Y'
X'
Image plane
Rays rearranged
according to *origin*
Back focal plane
Rays arranged
according to *direction*
Objective lens
Object
X
Y
Z
-2
-1
0
+1
+2
© Peter Evennett

Diffraction in the microscope

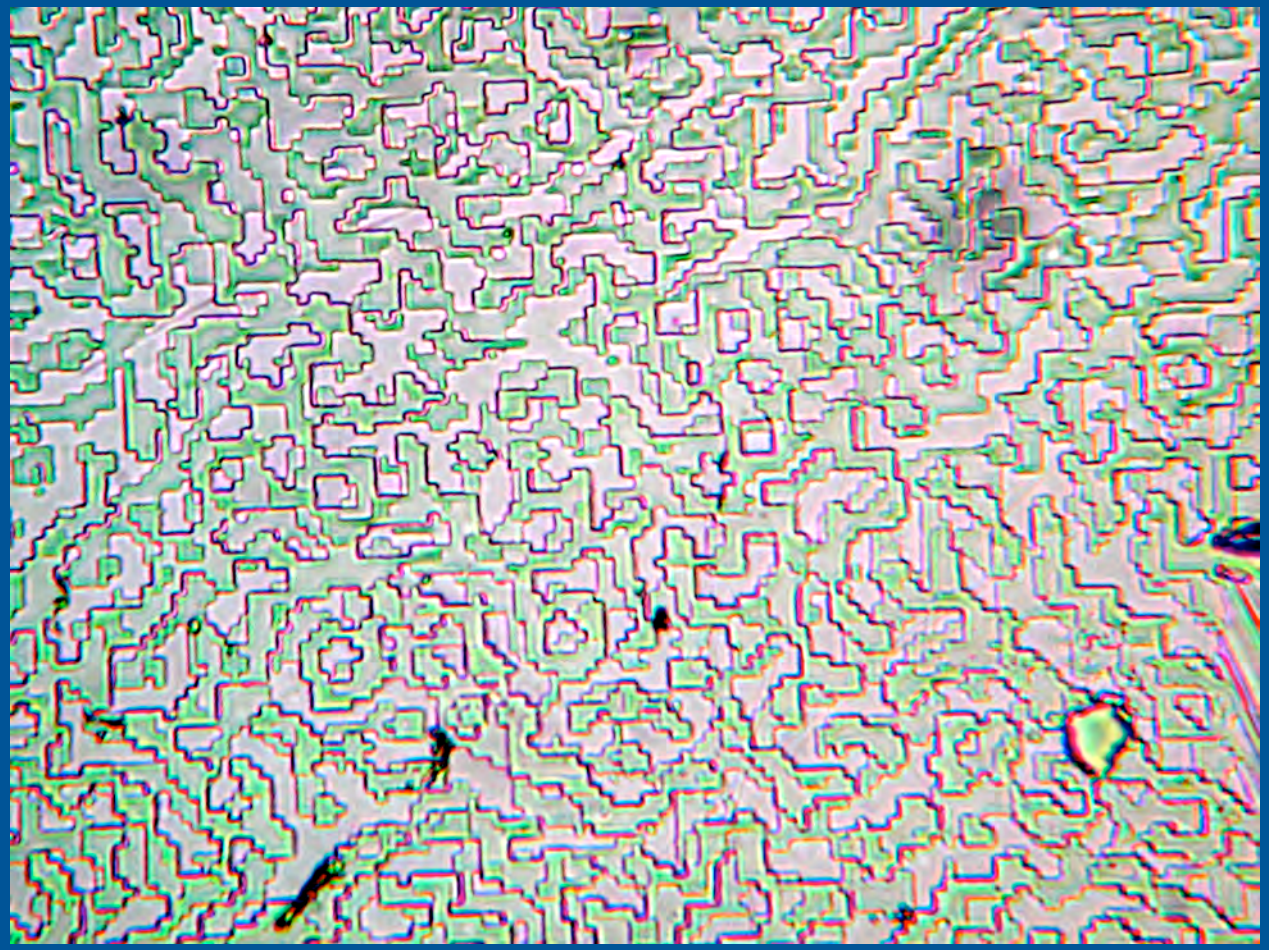
Diffraction grating



Diffraction pattern in back focal plane of objective



What will be the diffraction pattern of this grating?

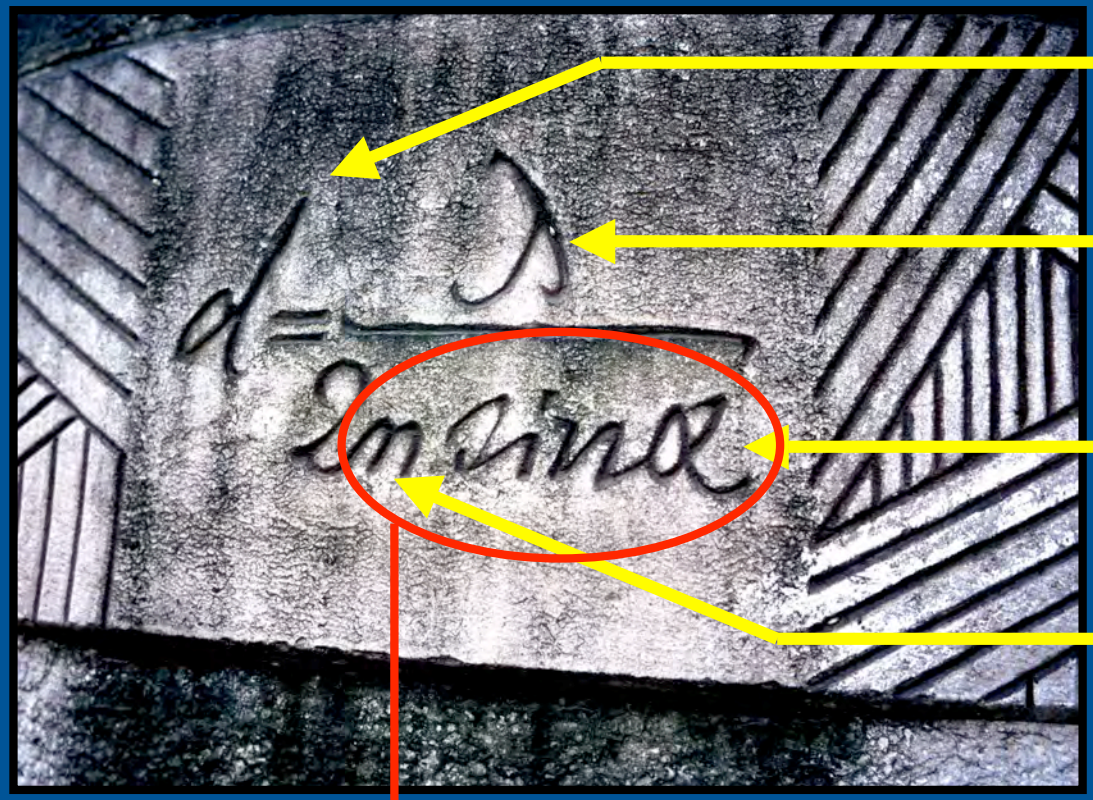


As seen in the back focal plane of the microscope in white light

Ernst Abbe's Memorial, Jena

February1994

Ernst Abbe's Memorial, Jena



d — Minimum resolved distance

λ — Wavelength of imaging radiation

α — Half-aperture angle

n — Refractive index of medium

Numerical Aperture

Minimum resolved distance is now commonly expressed as

$$d = 0.61\ \lambda / NA$$

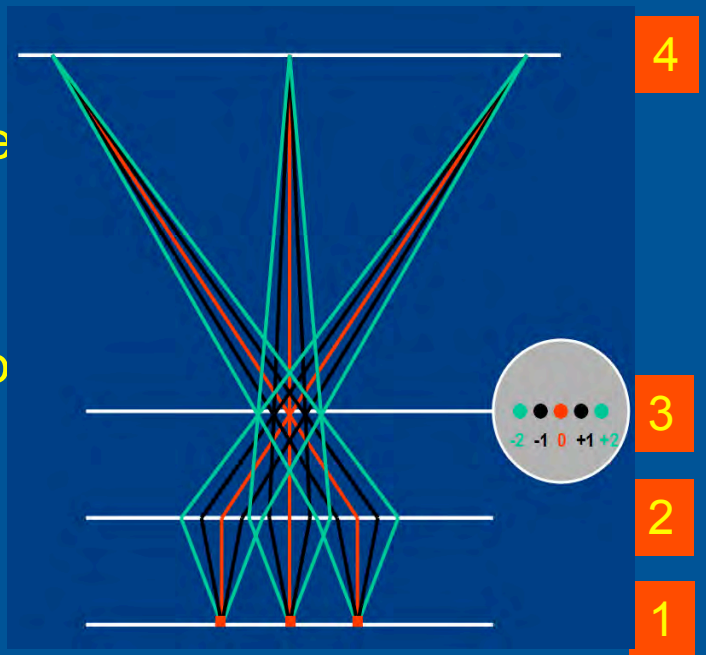
Abbe's theory of microscopical imaging

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.

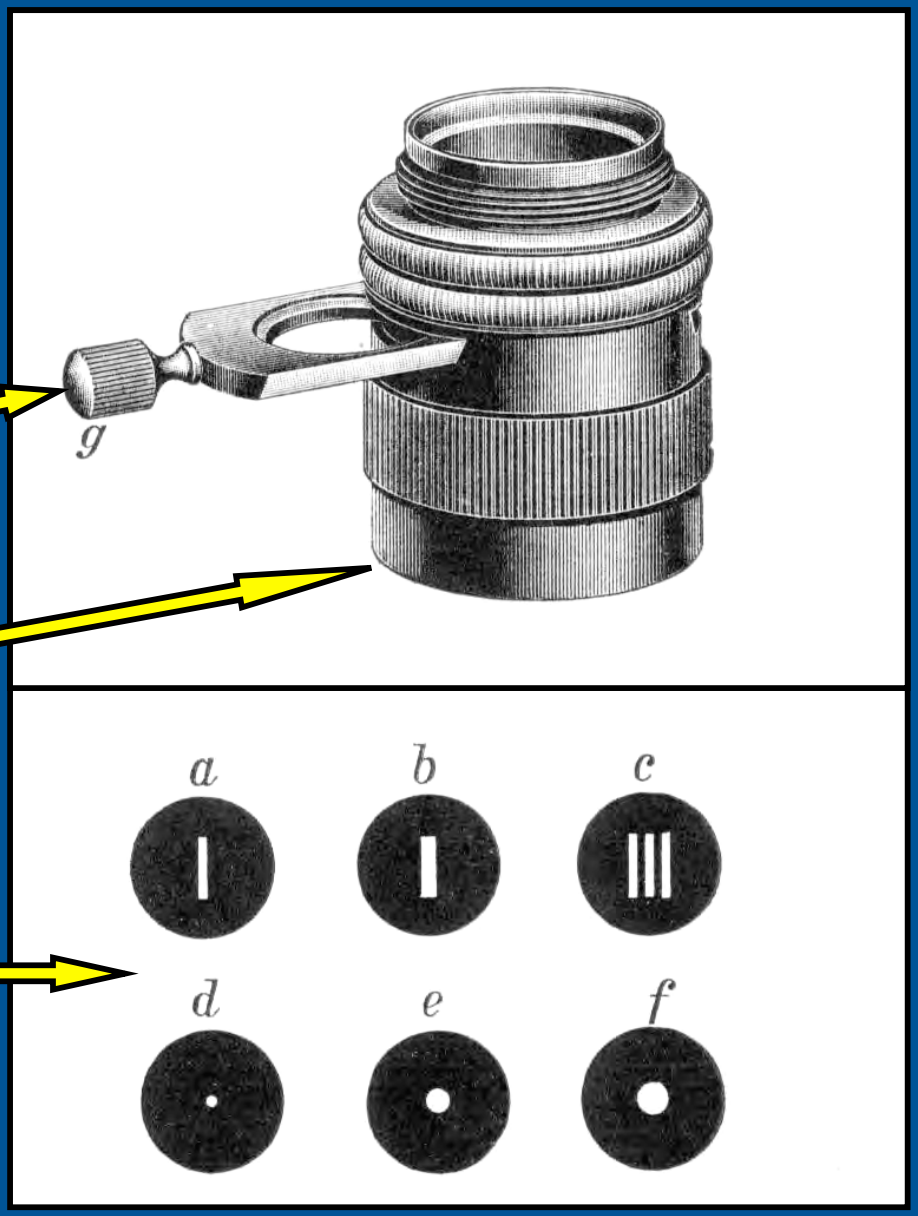


Abbe's Diffraction Apparatus

'Drawer' at level of back focal plane

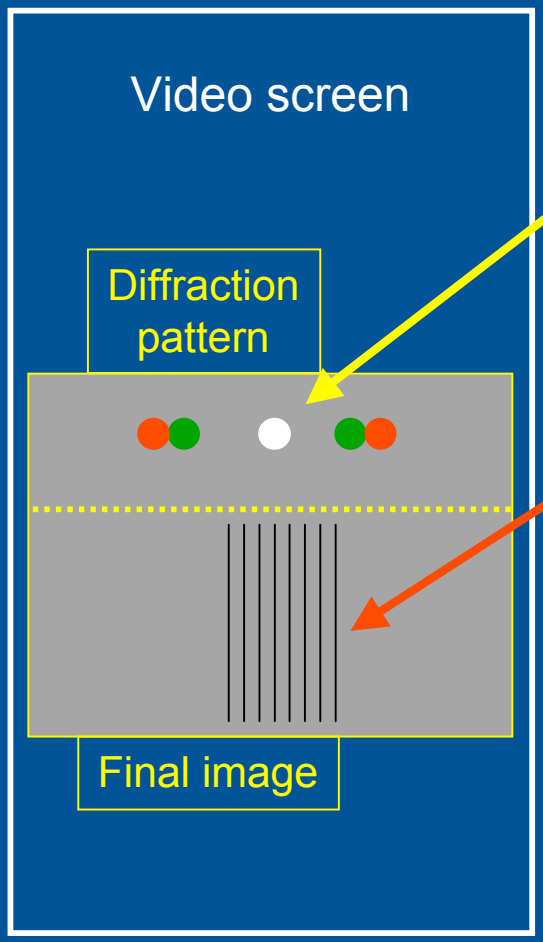
Screw thread for objective lens

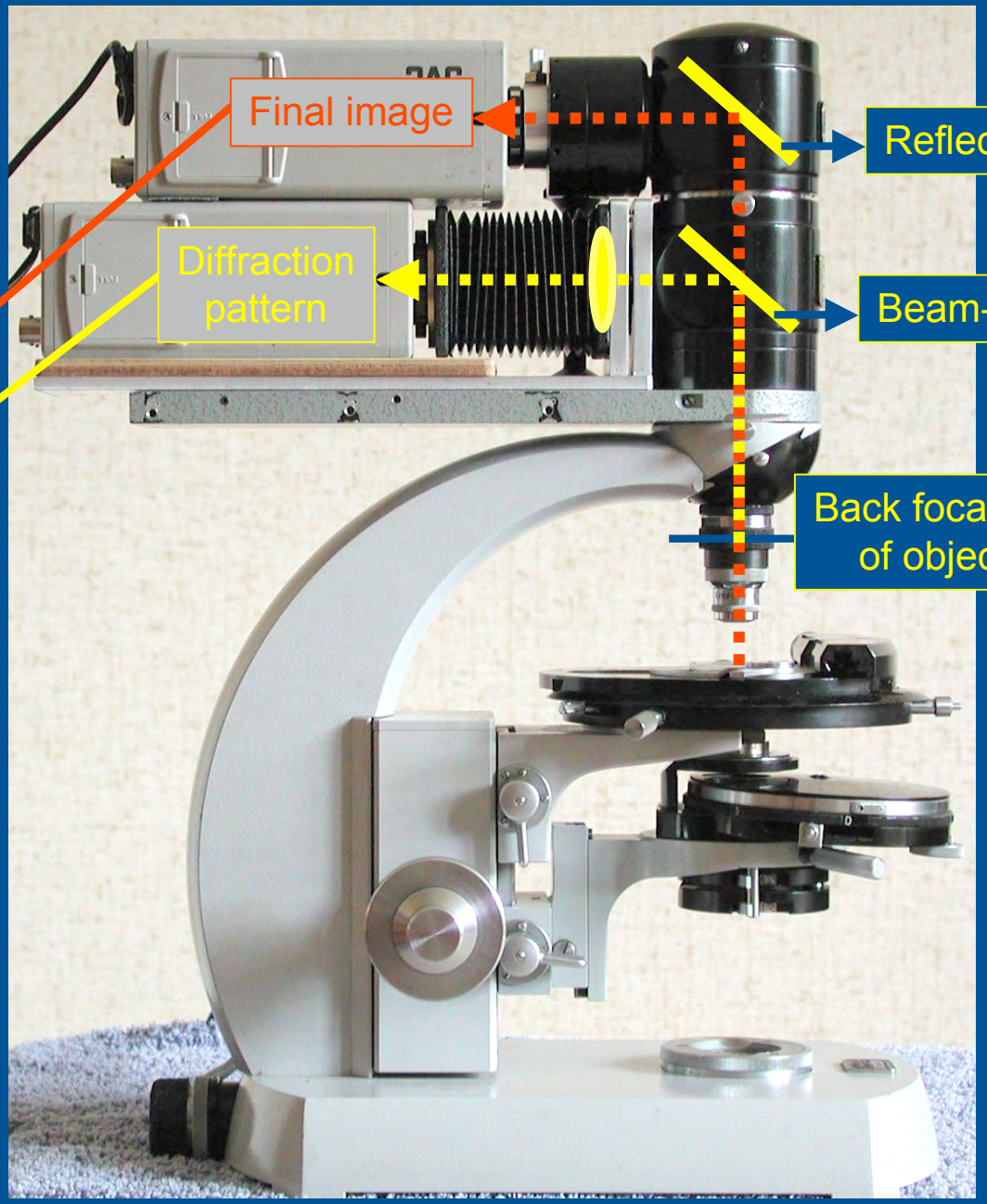
Masks for insertion into back focal plane

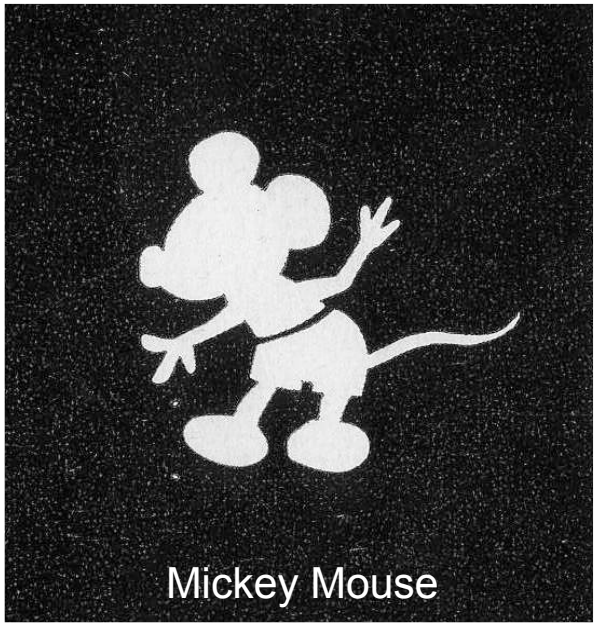


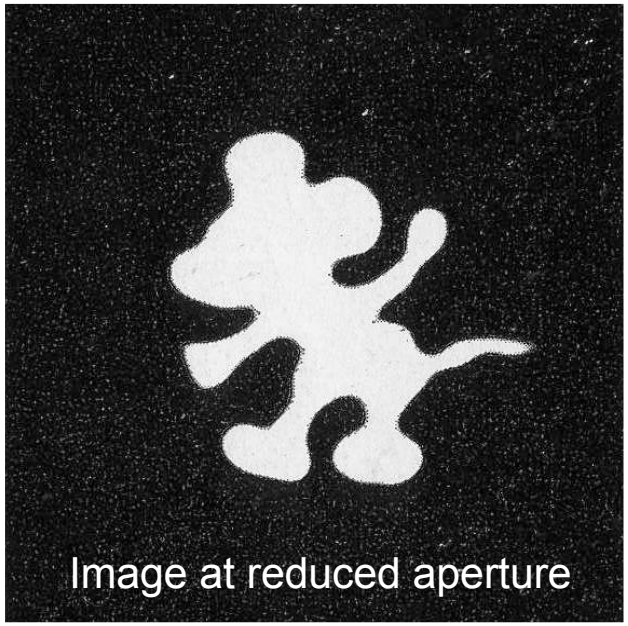

DIFFRACTIONSPLATTE
NACH ABBE
C.ZEISS JENA
Abbe's
Diffractions-
Platte
Carl Zeiss
Jena

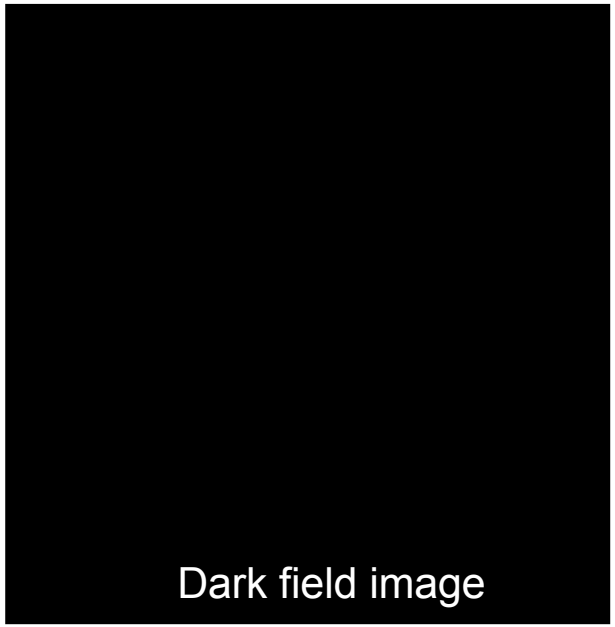
Demonstration microscope

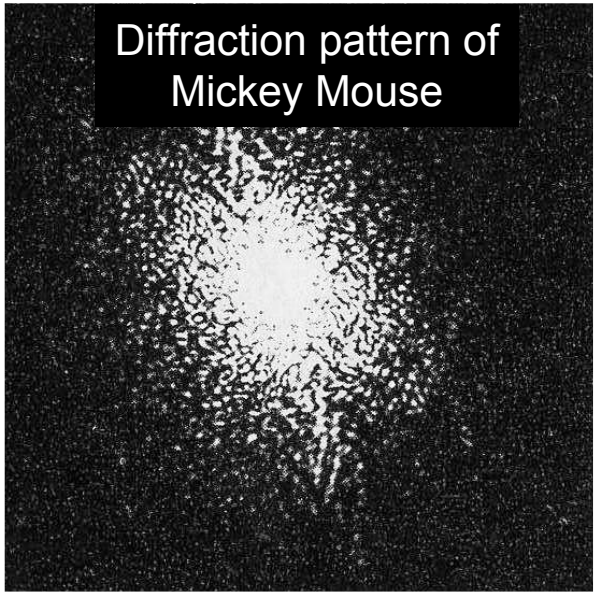


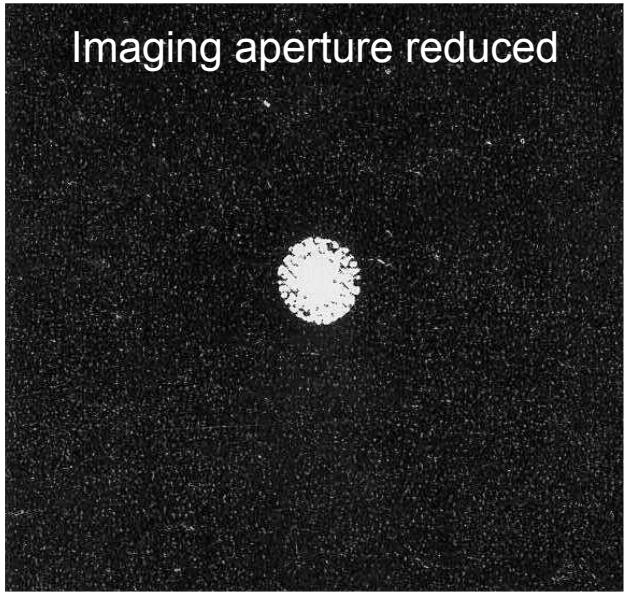


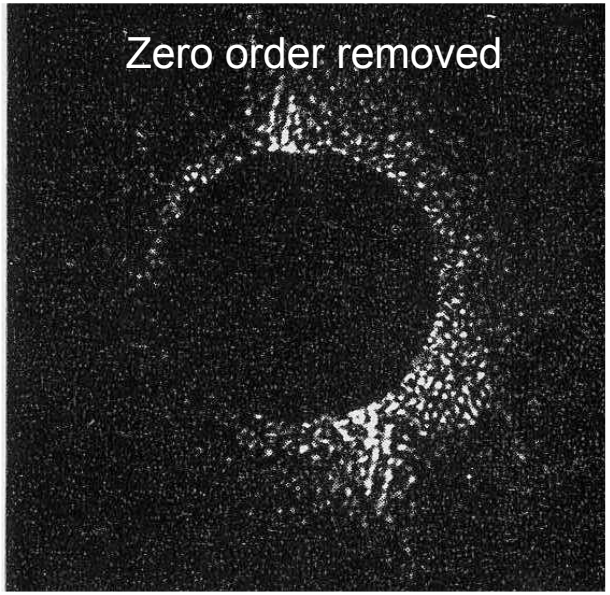












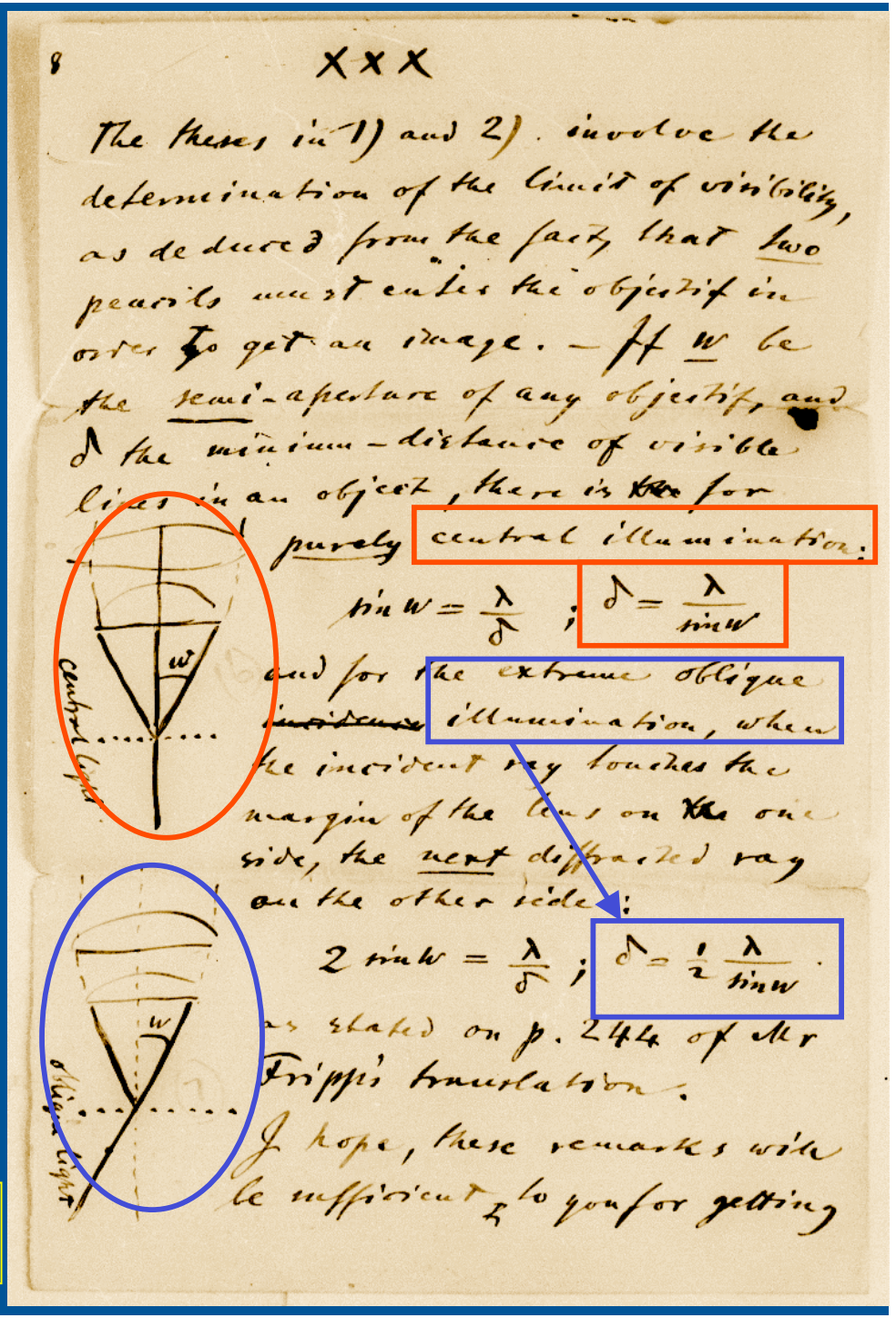
From Harburn, Taylor & Welberry: *Atlas of Optical Transforms*

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)

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



8 XXX

The theses in 1) and 2). involve the determination of the limit of visibility, as deduced from the fact, that two pearls must enter the objectiv in order to get an image. — If w be the semi-aperture of any objectiv, and δ the minimum-distance of visible lines in an object, there is for purely central illumination:

$$\sin w = \frac{\lambda}{\delta} \; ; \quad \delta = \frac{\lambda}{\sin w}$$

and for the extreme oblique illumination, when the incident ray touches the margin of the lens on the one side, the next diffracted ray on the other side:

$$2 \sin w = \frac{\lambda}{\delta} \; ; \quad \delta = \frac{1}{2} \frac{\lambda}{\sin w} .$$

as stated on p. 244 of Mr Fripp's translation.

I hope, these remarks will be sufficient to you for getting

Ernst Abbe to J. W. Stephenson
15 December 1876