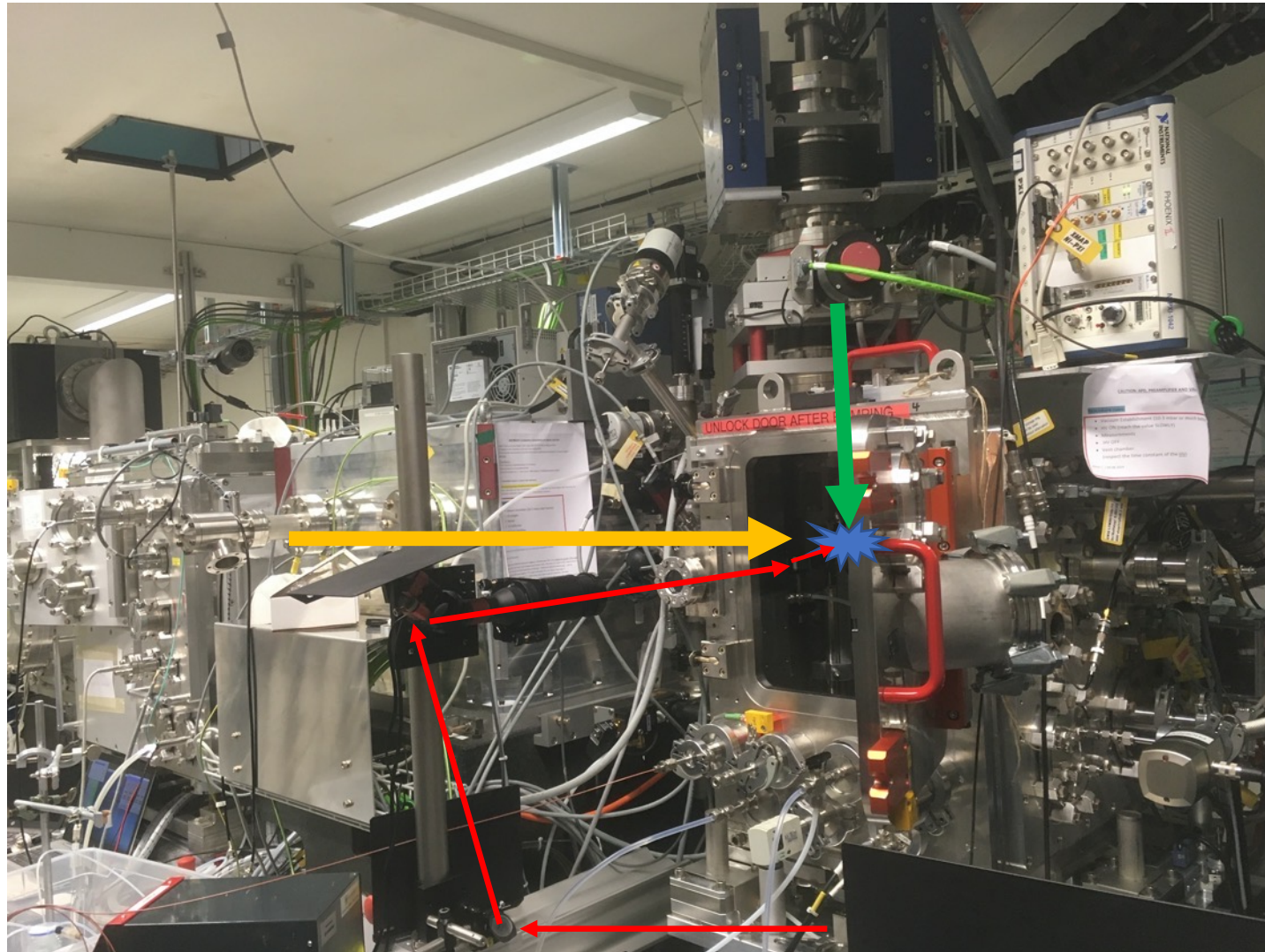


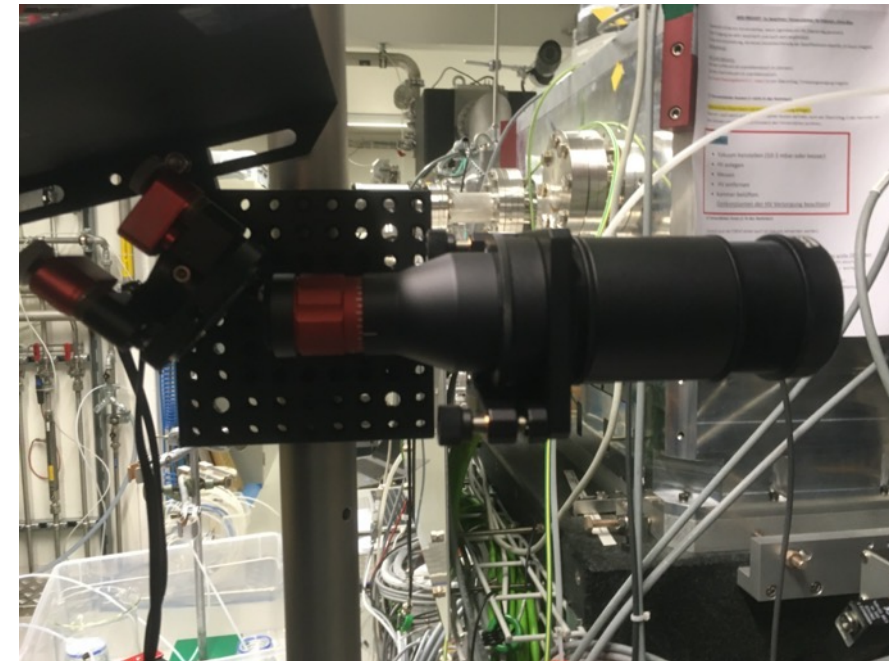
Optical methods in chemistry
or
Photon tools for chemical sciences

Session 6:

Prologue: Look inside Phoenix beamline for environmental spectroscopy, laser pump – x-ray probe spectroscopy of molecules in solution



Looks familiar? Why is this here?



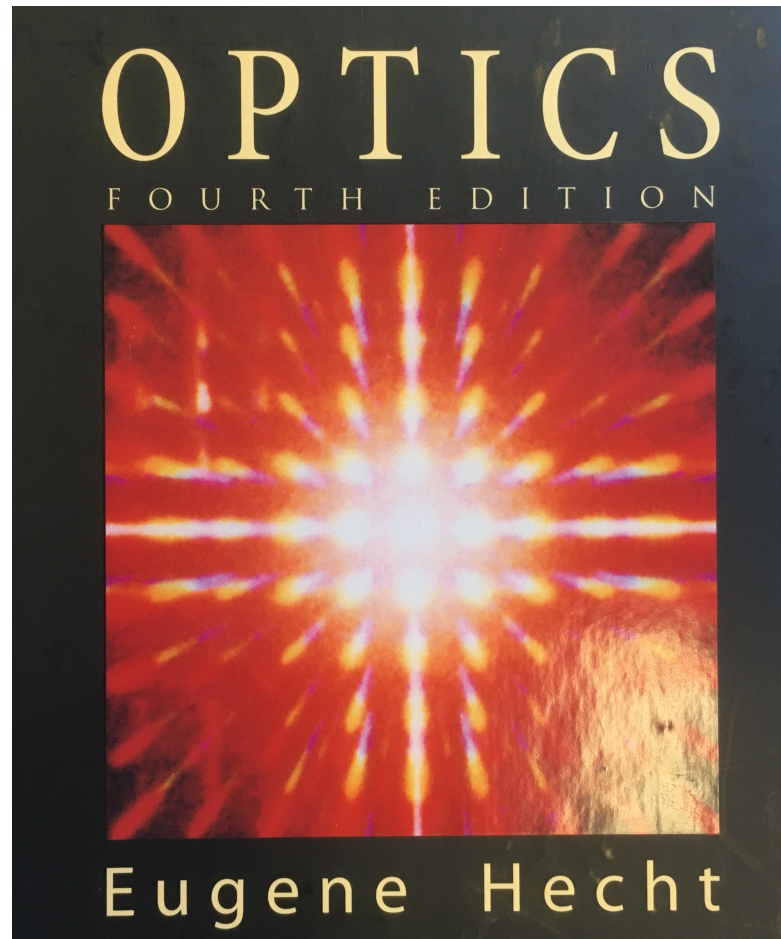
Course layout – contents overview and general structure

- Introduction and ray optics
- Wave optics
- Beams
- From cavities to lasers
- More lasers and optical tweezers
- From diffraction and Fourier optics
- Microscopy
- Spectroscopy
- Electromagnetic optics
- Absorption, dispersion, and non-linear optics
- Ultrafast lasers
- Introduction to x-rays
- X-ray diffraction and spectroscopy
- Summary

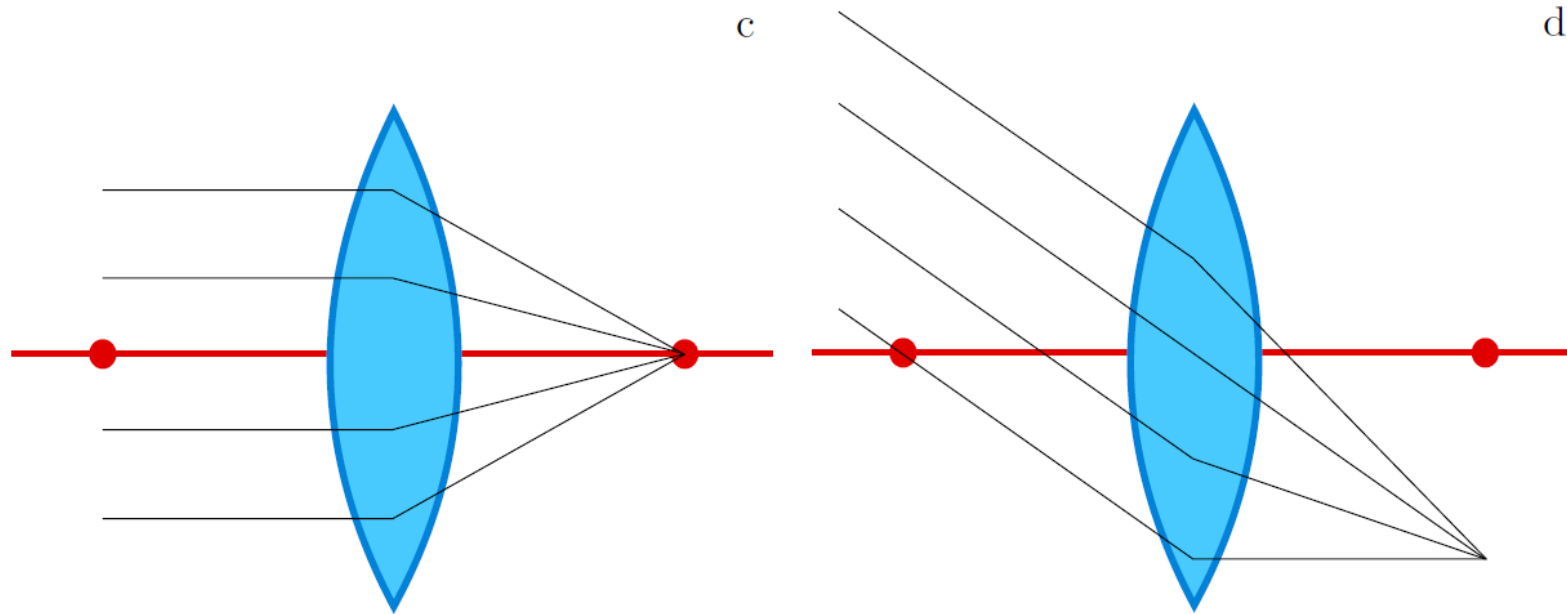
This week learning goal:
Change the way you think about diffraction and imaging. Get a different view on optics.

Literature

- Today's lecture relies mostly on "Hecht – Optics"

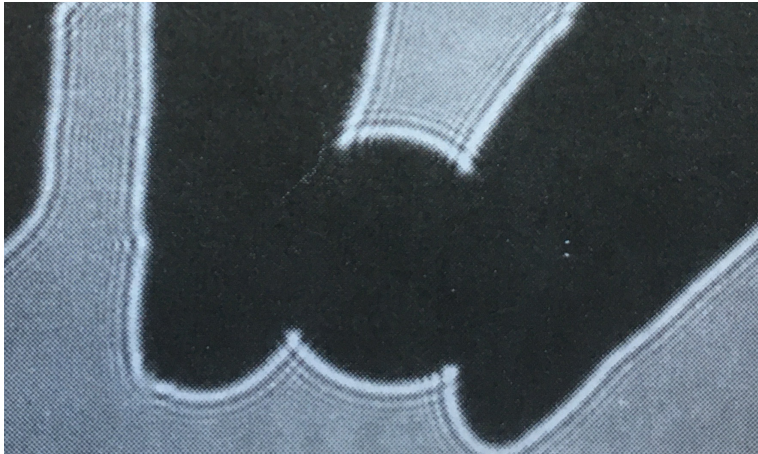


Recall: Focusing properties of a lens (ray optics)



Diffraction, a short review

- Should be familiar concept
- A wave encountering an object changes its wavefront. Note that this can also be a density change (later more)
- Fundamental properties of all waves with relevant effects from electron microscopy to shaping coastal landscapes
- In optics most commonly known for limiting resolution in optical setups (microscopes)
- But there is much more!

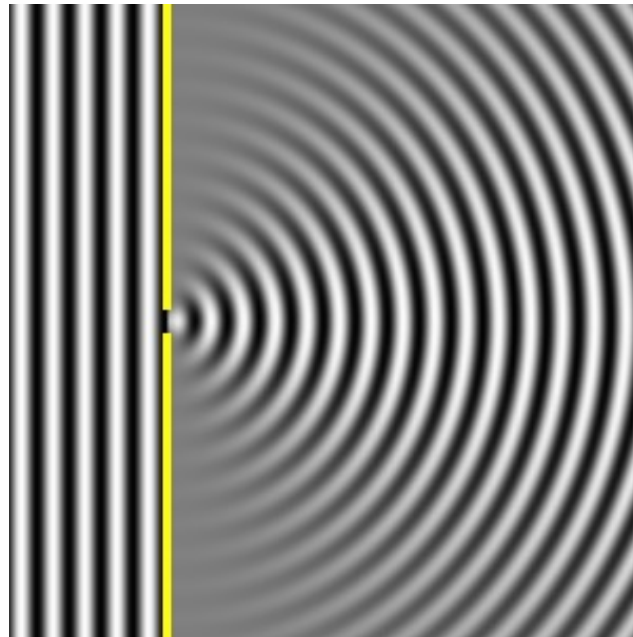


<https://physicsforme.com/2012/01/04/teaching-waves-with-google-earth/>



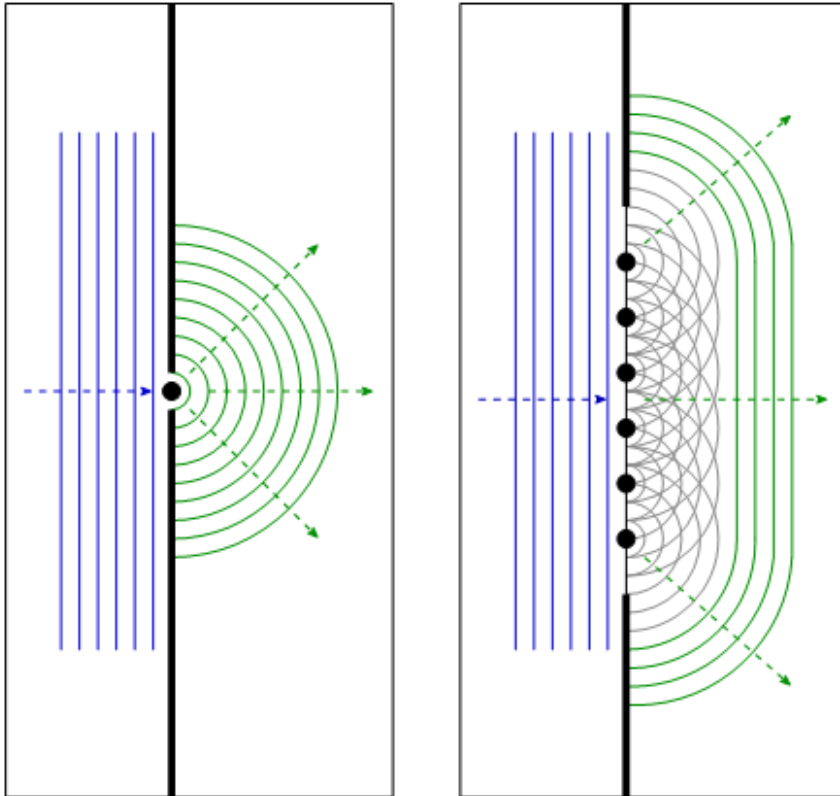
The Huygens-Fresnel Principle

- Hugen: every point a wave (a luminous disturbance) reaches becomes a source of a spherical wave; the sum of these secondary waves determines the form of the wave at any subsequent time.
- Huygens-Fresnel: every unobstructed point of a wavefront serves as a source of spherical secondary wavelets. The amplitude of the wave beyond is the superposition of all these wavelets. (includes amplitude and relative phase)

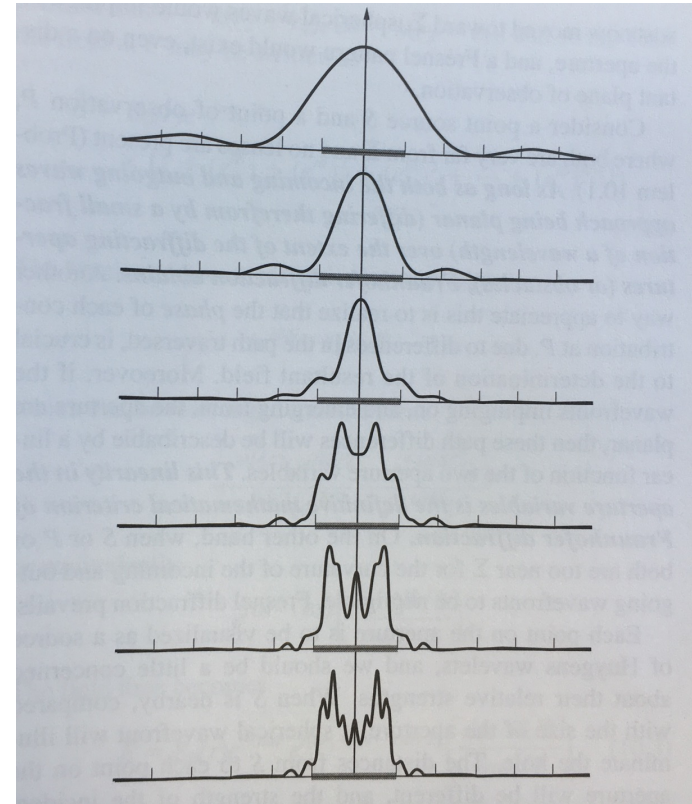


Wavefronts behind slit

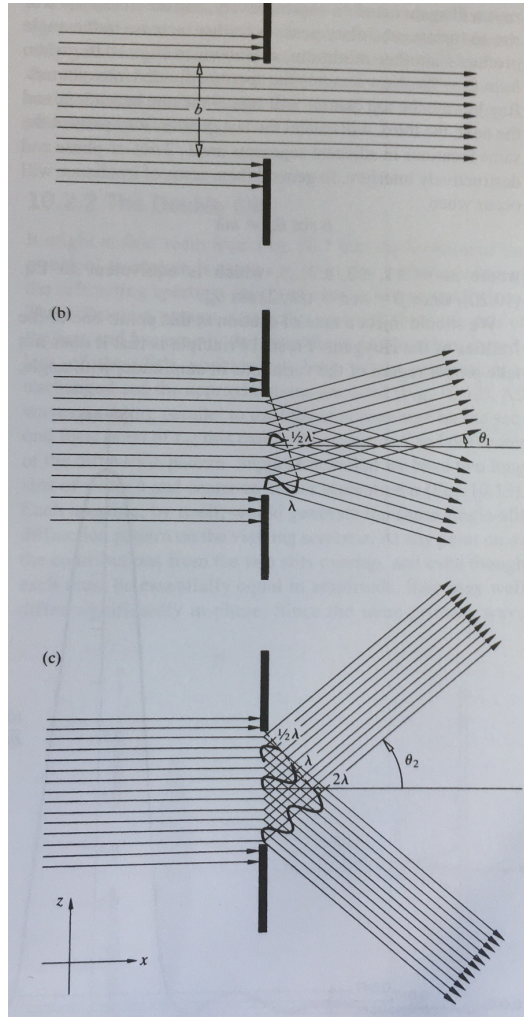
Small vs. real slit



Fresnel and Fraunhofer regime



Different views on Fraunhofer Diffraction ($R \gg D$) for single slit



Different views on Fraunhofer Diffraction ($R \gg D$) for single slit

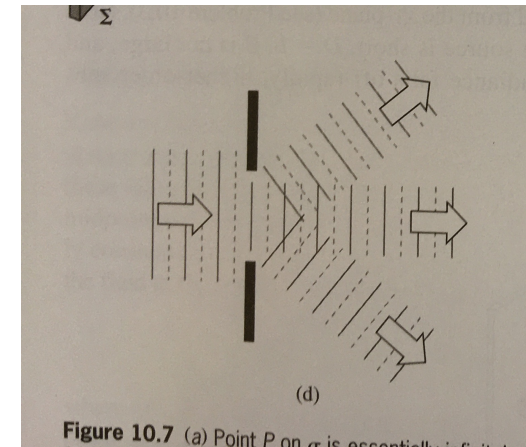
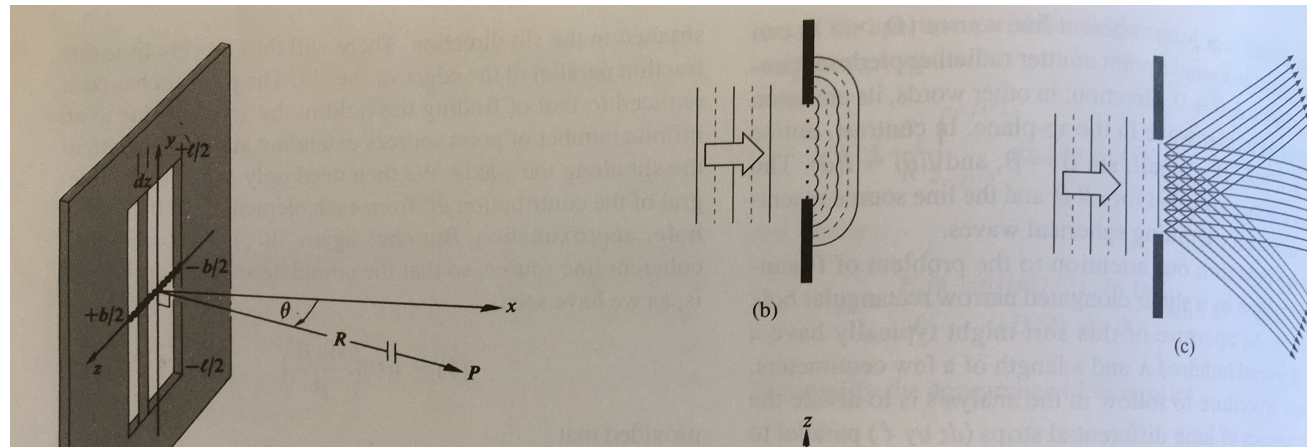
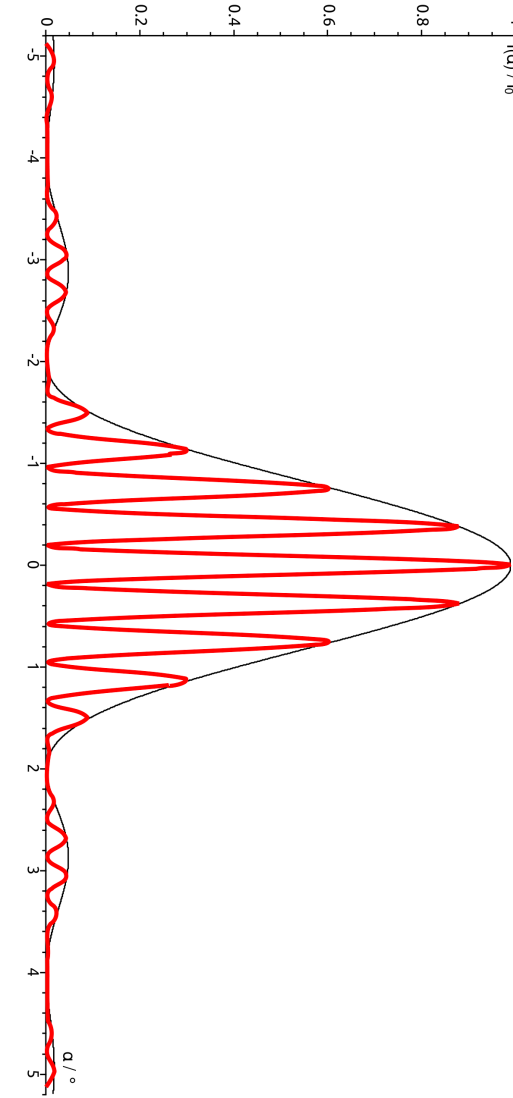
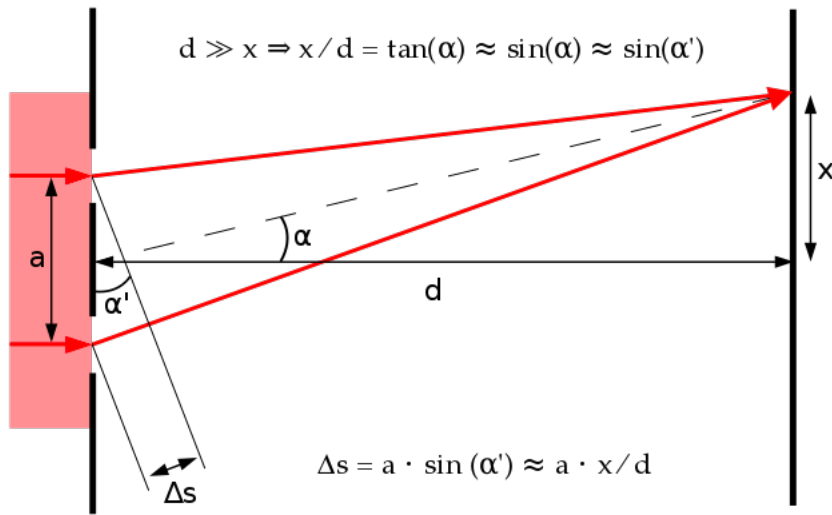


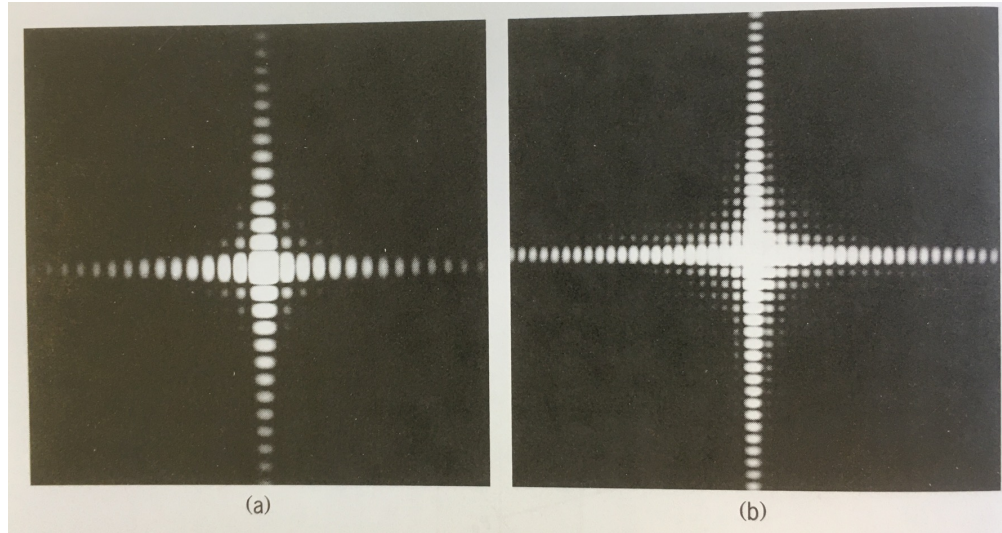
Figure 10.7 (a) Point P on σ is essentially at infinity.

Now the double slit

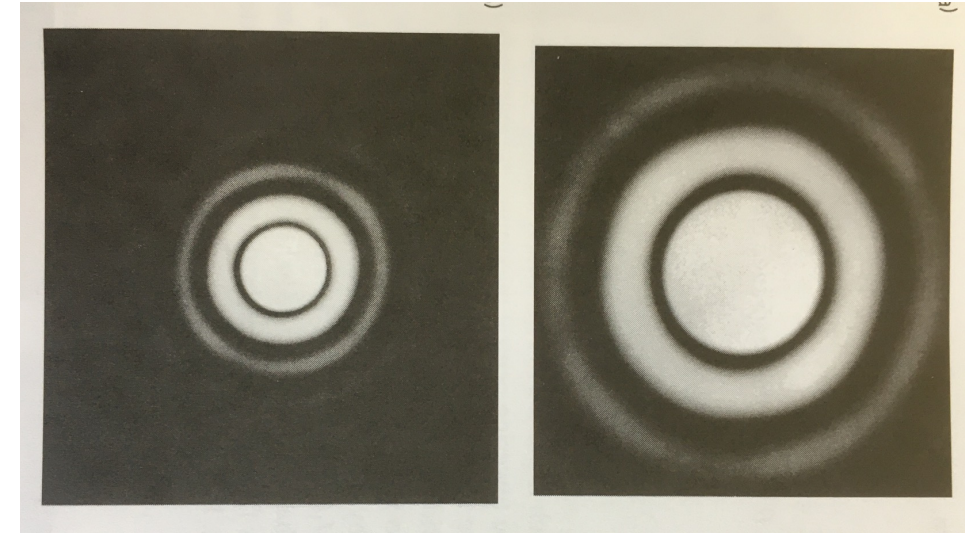


Diffraction pattern of 2D objects – 2 examples

Square aperture



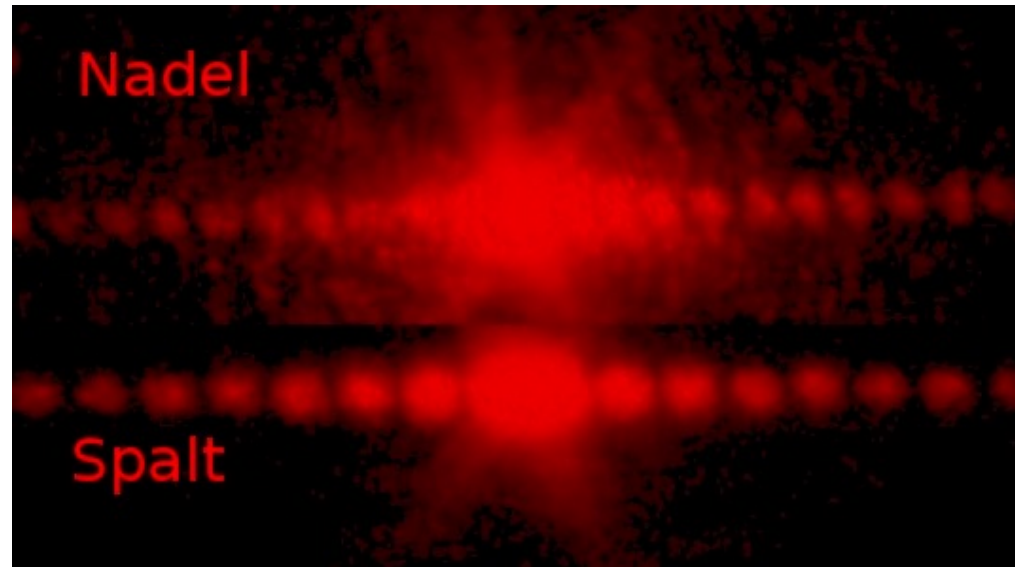
Round aperture



Note: Babinet's principle

The diffraction pattern of an opaque body is identical to the one of a hole of the same size and shape except in the forward direction.

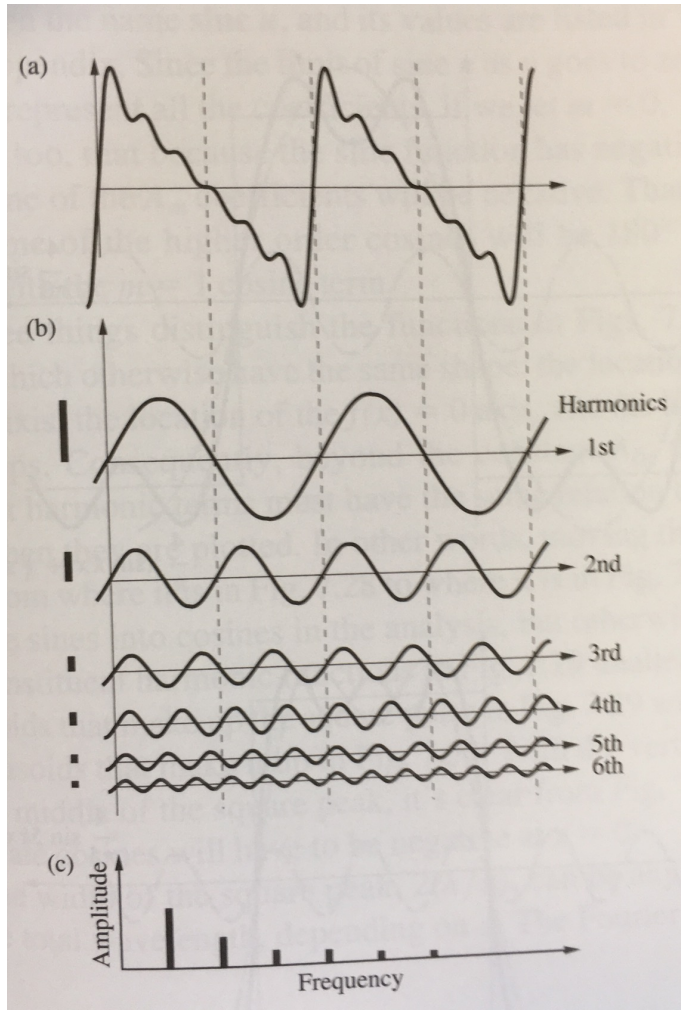
Example:



Intermezzo: Fourier Transformation

Principle idea

Principle idea



Mathematical description

- The principle idea of the Fourier analysis / transformation is that any function can be represented by an (infinite) series of harmonic functions.
- The Fourier transform decomposes a function into its constituent frequencies.

Thus we can write

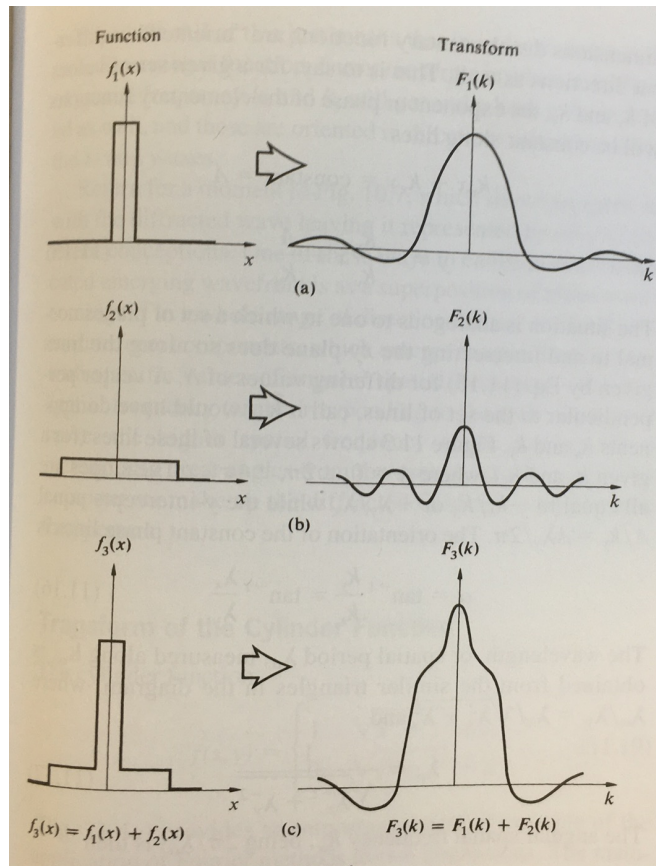
$$f(x) = \frac{1}{2\pi} \int_{-\infty}^{+\infty} F(k) e^{-ikx} dk$$

provided that

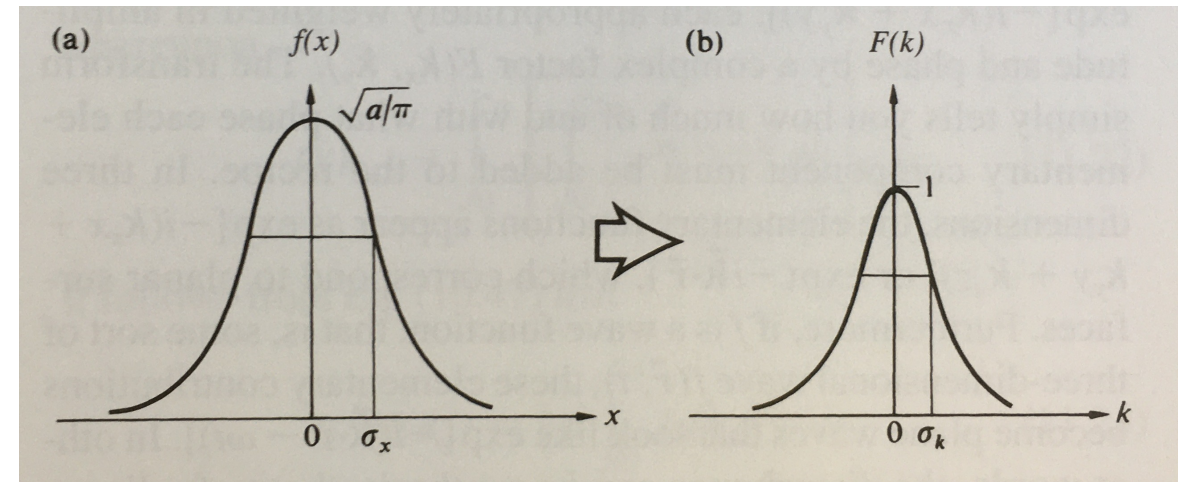
$$F(k) = \int_{-\infty}^{+\infty} f(x) e^{ikx} dx$$

Examples

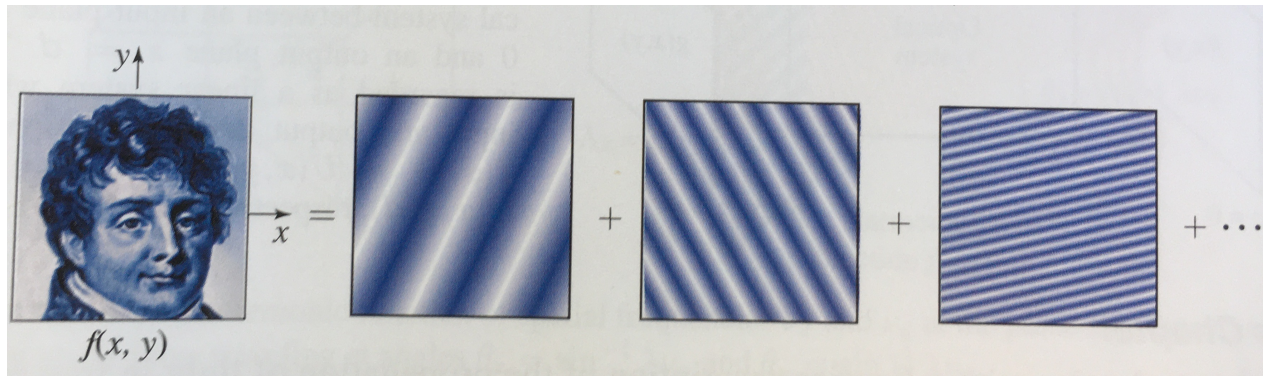
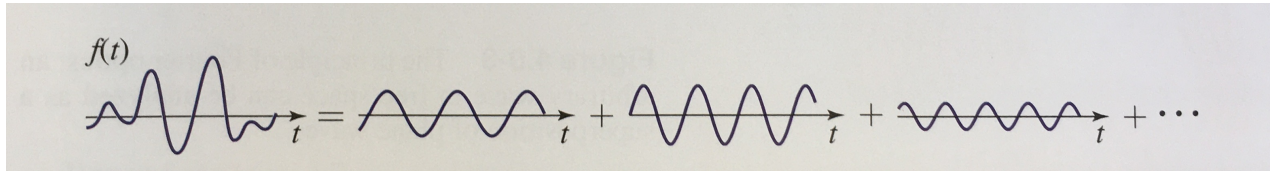
Squares and composite



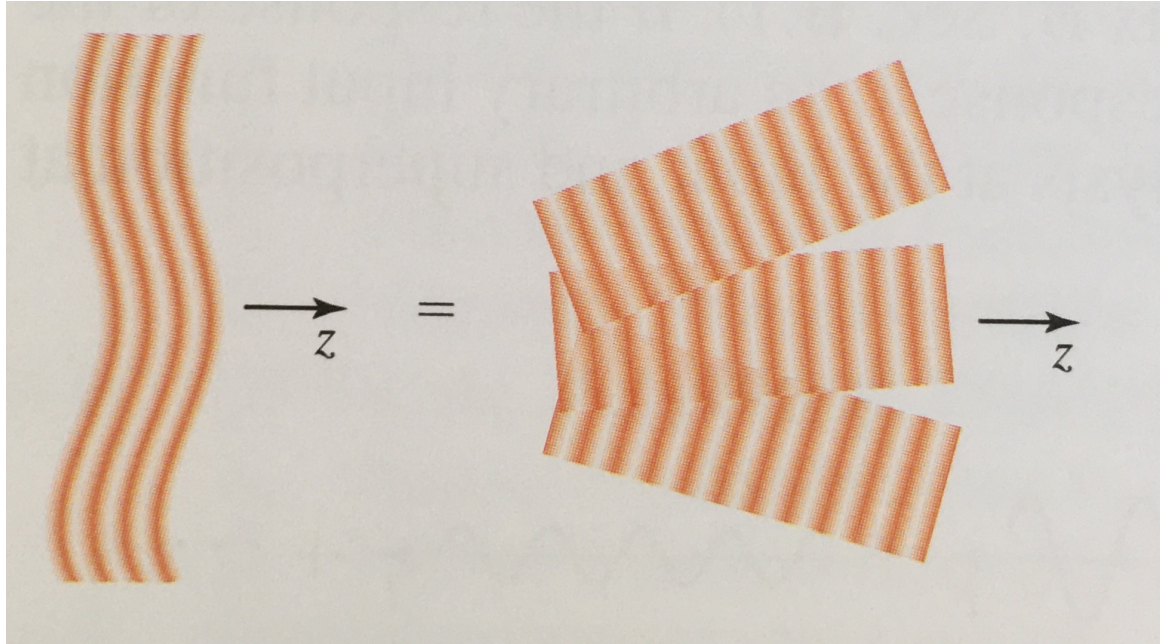
Gauss function



Expansion 2D



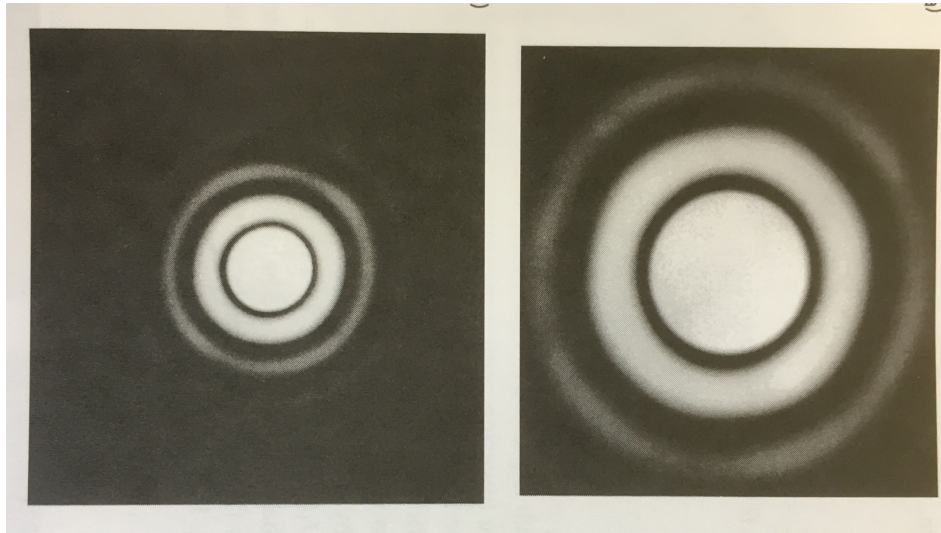
Principle of Fourier Optics: Any wavefront can be analyzed as superposition of plane waves



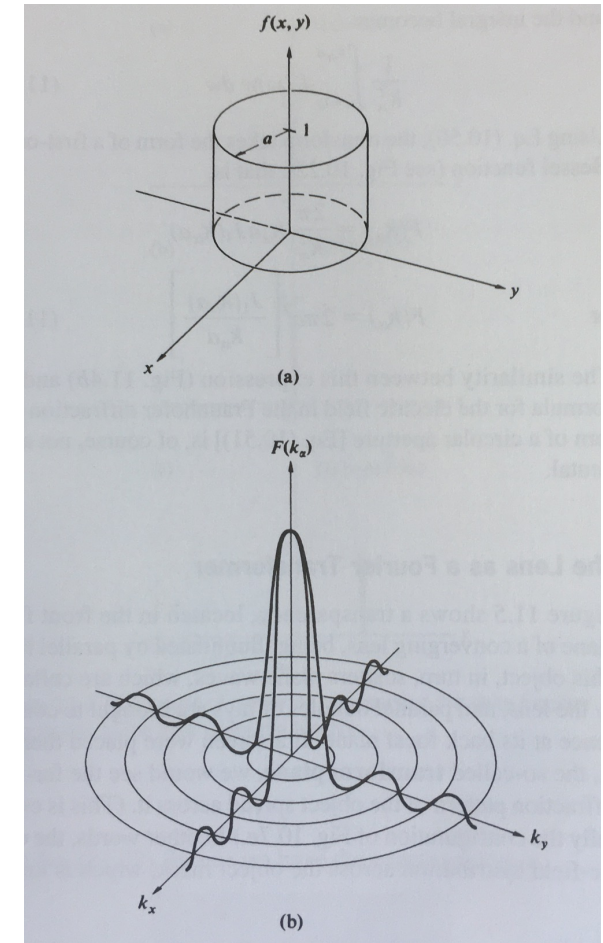
Implications

Fourier transform of round aperture and airy pattern

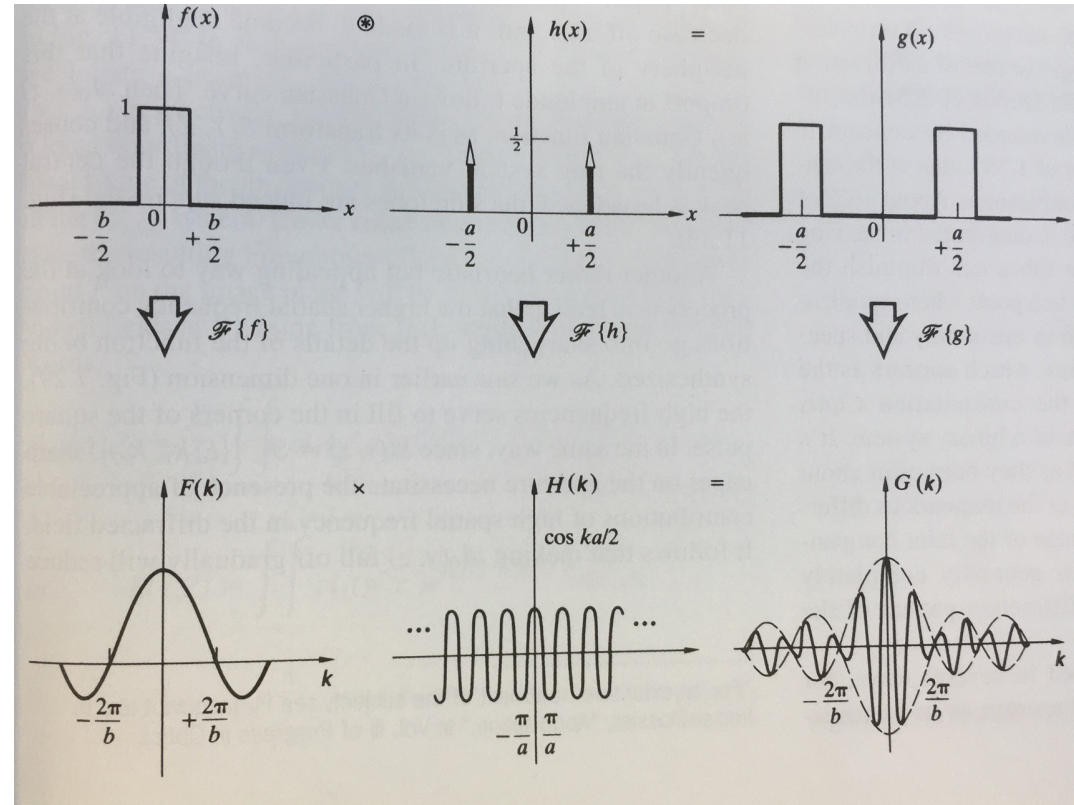
Experiment: Diffraction pattern of circular aperture, Airy pattern



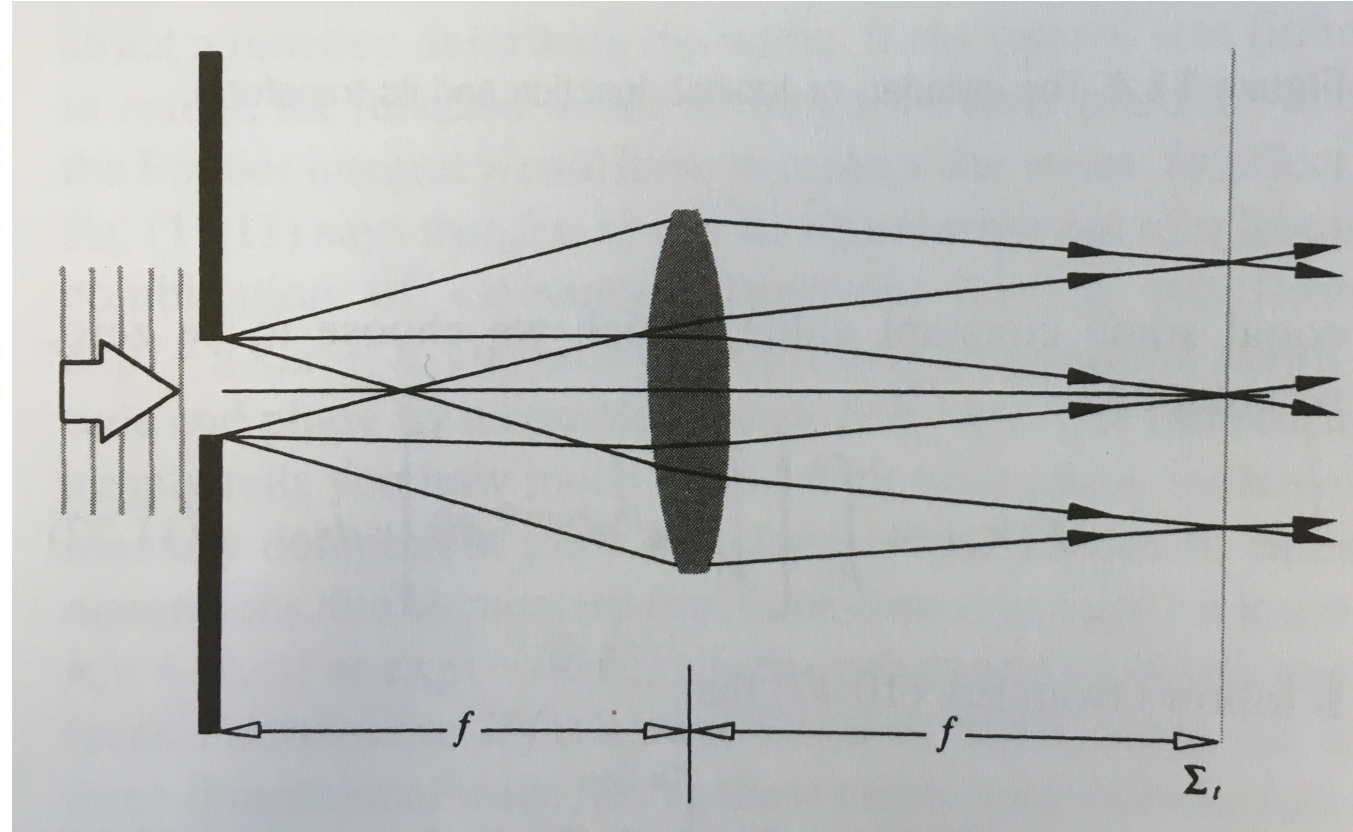
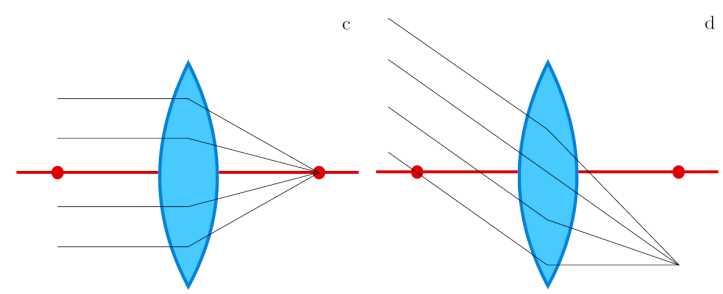
Theory: Fourier transform of cylinder or “top-hat” function



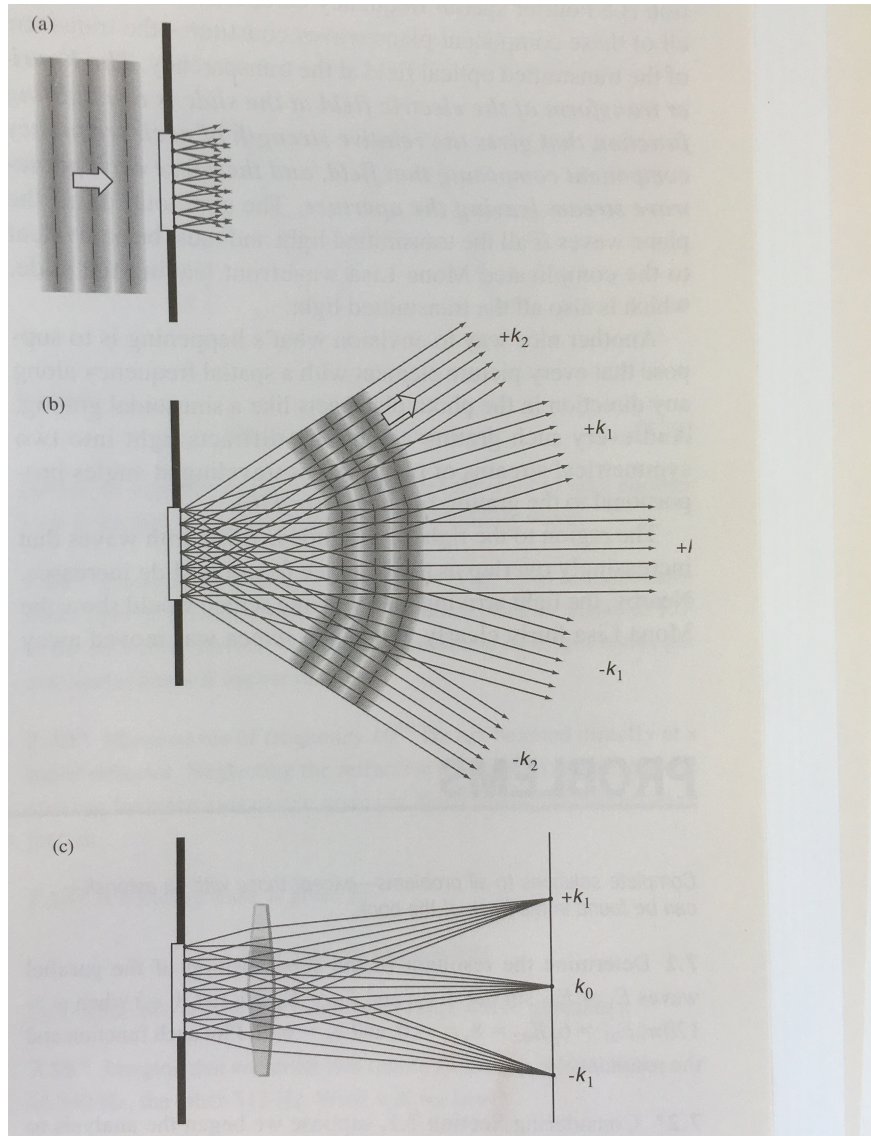
Diffraction as Fourier transform:



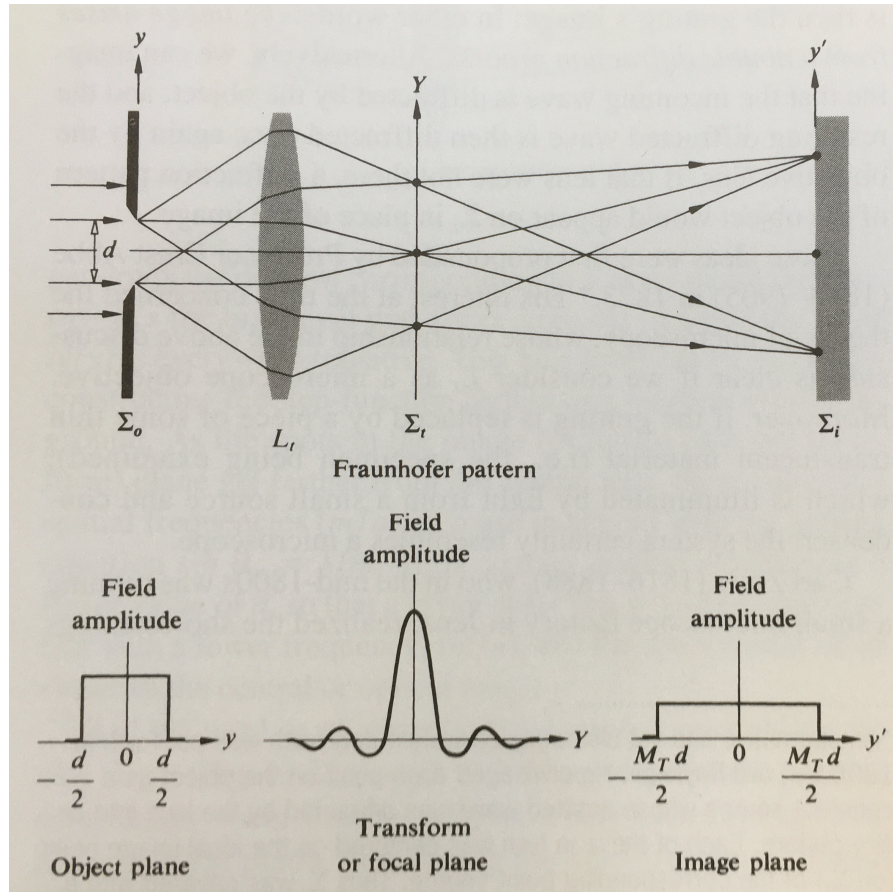
Lens as Fourier transformer



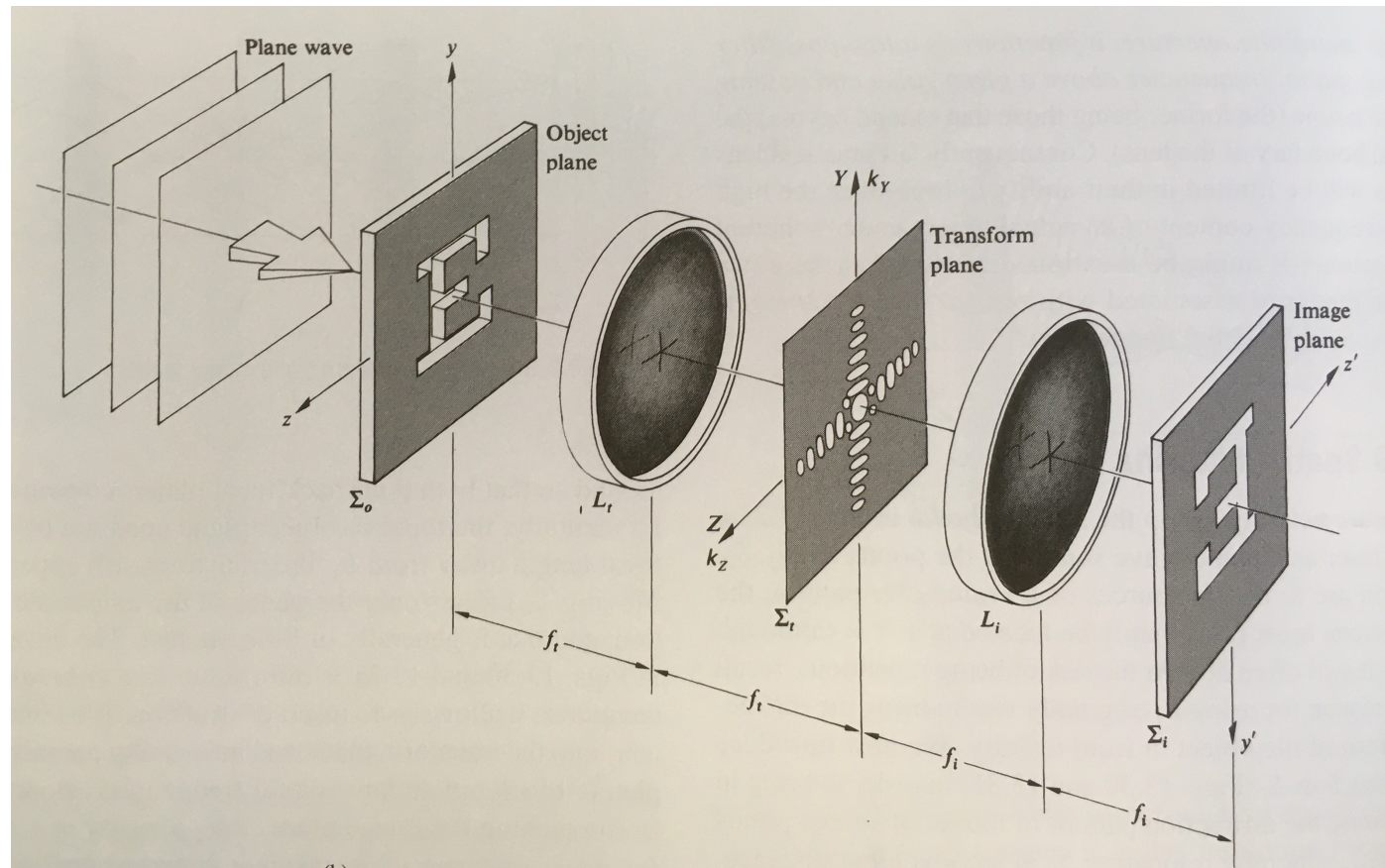
Gedankenexperiment for imaging:



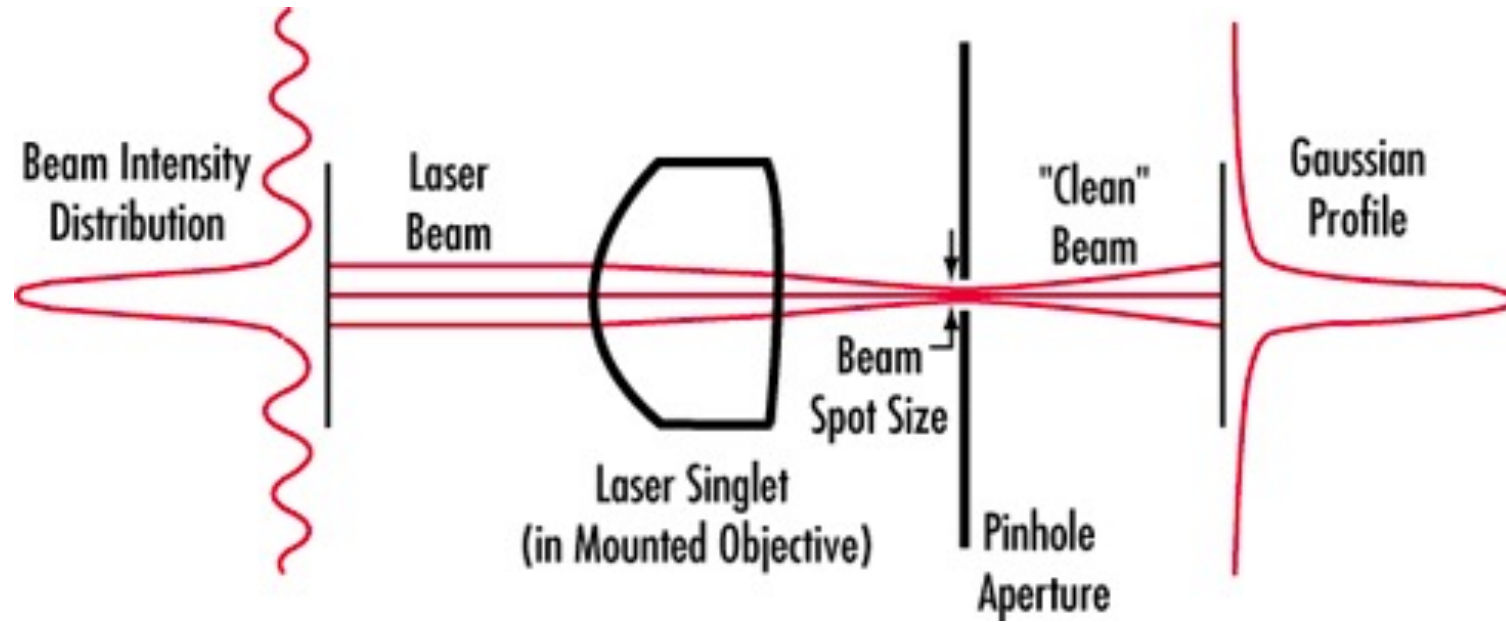
Abbe image formation



4f imaging setup



Note on optical tricks: How to make a Gaussian beam or “Spatial Filtering”



<https://www.edmundoptics.com/resources/application-notes/lasers/understanding-spatial-filters/>

Summary

- From familiar diffraction
- To Fourier transform in diffraction
- Learned that lens can do FT transform
- Concept maybe overwhelming BUT it has tremendous applications
 - Microscopy
 - TEM
 - X-ray techniques
- Image filtering

The end.