Optical methods in chemistry
or
Photon tools for chemical sciences

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
- Summary

Ray optics and basic optical components

Postulate of ray optics

- Light travels in form of rays
  - Rays are emitted by a light source and can be observed when they reach an optical detector
- An optical medium is characterized by a quantity n>=1 called refractive index with
  - $n = c_0/c$ and c = speed of light
  - Time for traveling a distance d takes:
  - nd is called the optical path length
- In an inhomogeneous medium the refractive indes n(r) depends on r(x,y,z)
  - Optical path length expressed as integral:
  - Time to travel from A to B is proportional to othe optical path length

Fermat's principle

Optical rays traveling between two points A and B follow a path such that the time of travel (that is optical path length) between the two points is at an extremum (usually minimum)

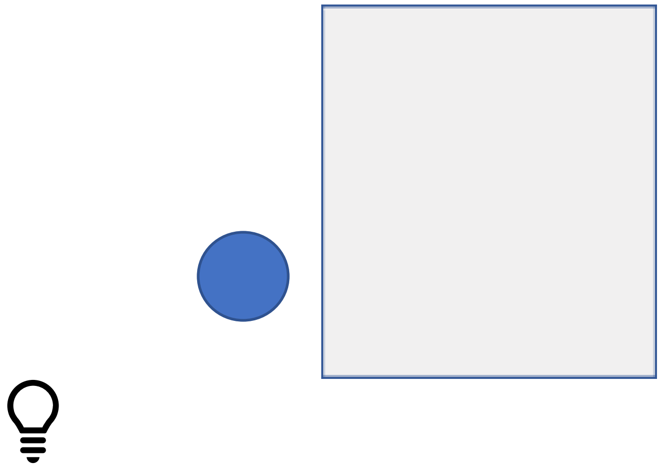
In other words: Light travels along the path of least time

In homogenous media this results in Hero’s principle

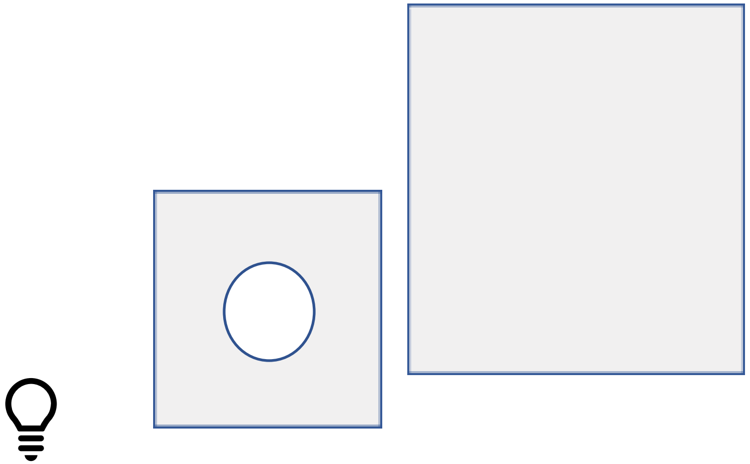
Hero’s principle: The path of minimal time is also the path of minimal distance.

Or in other words: Light travels in straight lines. Lets try it, draw an image of

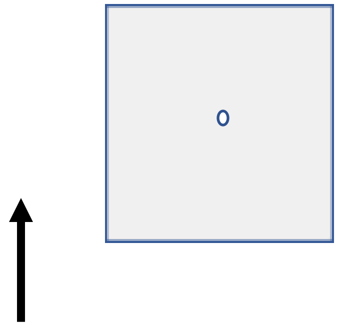
Shadow



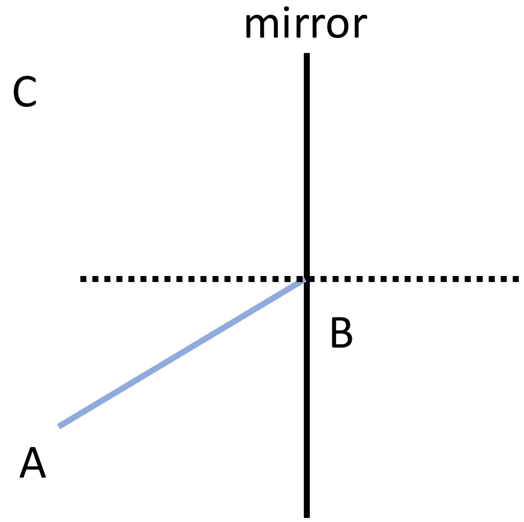
Projection



Pinhole



Reflection from a mirror



The reflection lays in the plane of incidence.

The angle of the reflection the angle of incidence

Snell's law – reflection and refraction at the boundary of two media

At the boundary of two media with n1 and n2 the incident ray is split in two beams:

a *reflected* and a *refracted* beam

$$n1 \sin \theta 1 = n2 \sin \theta 2$$

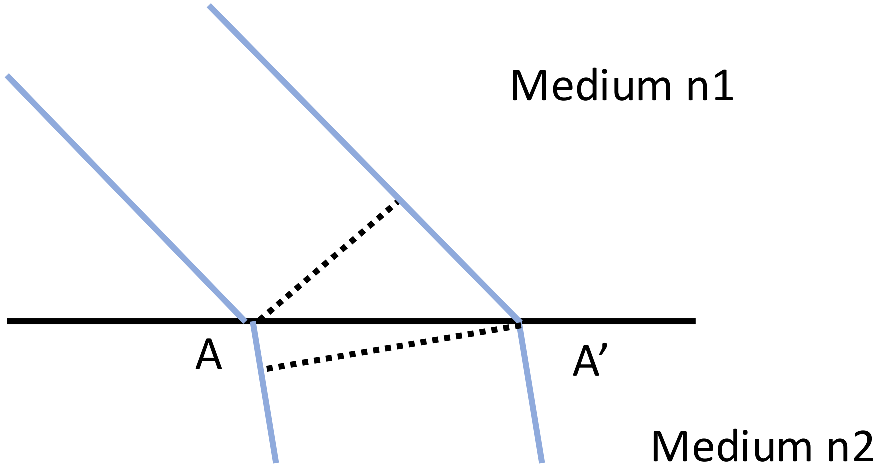
Snell's law

or

$$\frac{n1}{n2} = \frac{\sin \theta 2}{\sin \theta 1}$$

Important note: the proportion of the reflected and refracted light beams are *not* described by Ray optics

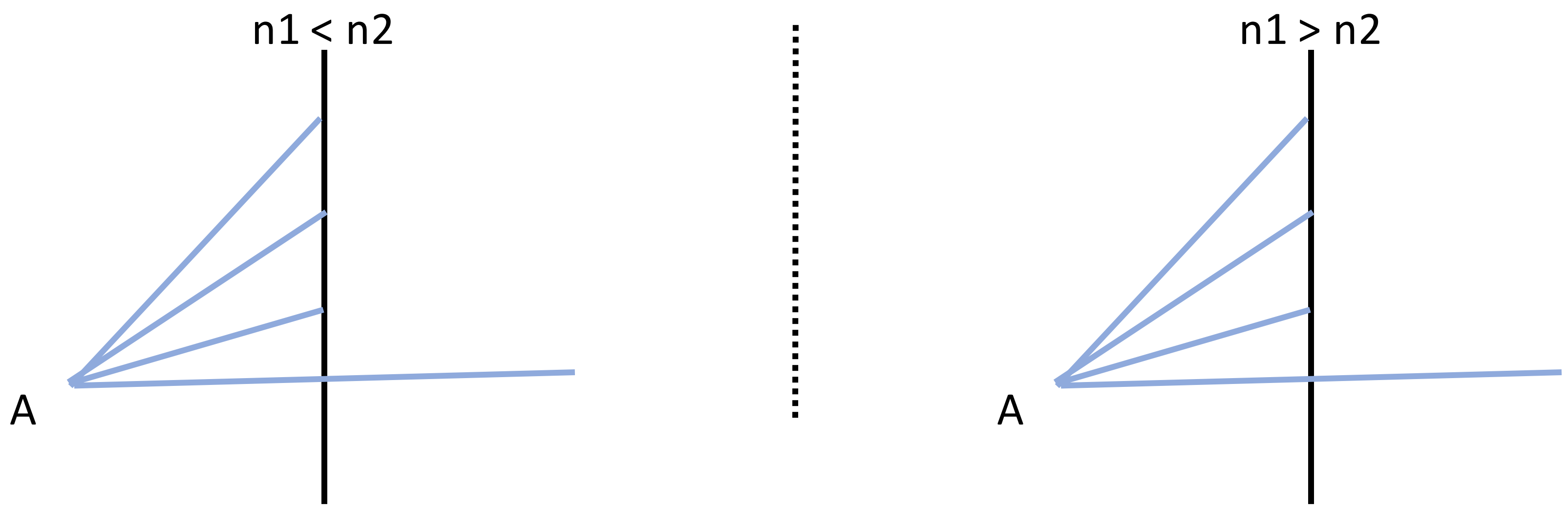
Snell's law based on what we have learned so far



- Same time means same distance travelled, t= const
- From geometry: sin
- Relation:
- Results in Snell's law

Optical boundaries

- External refraction n1<n2 – refracted ray bends away
- Internal refraction n1>n2 – refracted light bends towards boundary



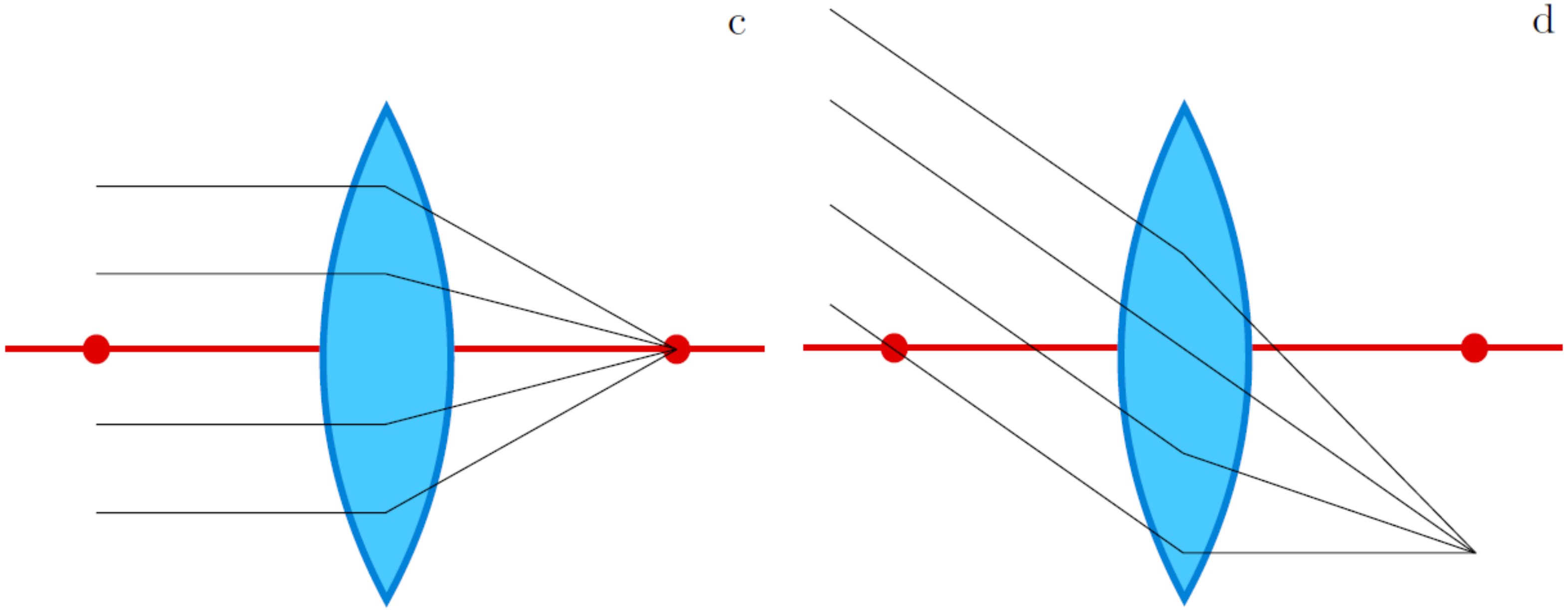
- Total internal reflection
- Use for optical fibers

Some optical components

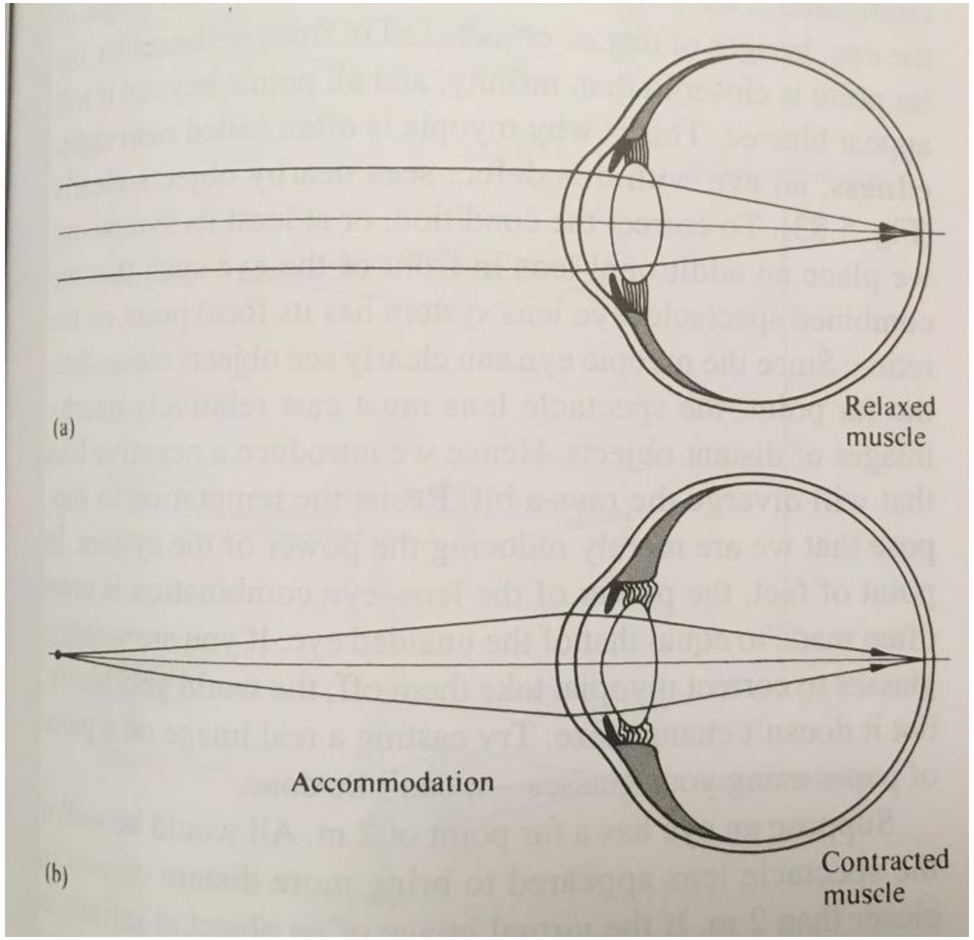
- Ellipse – elliptical mirror reflects all light emitted in one focal point into another focal point

- Parabola – a parabolic mirror focuses parallel light into one point

Recall: Focusing properties of a lens (ray optics)



Reminder: Our eye as an optical system

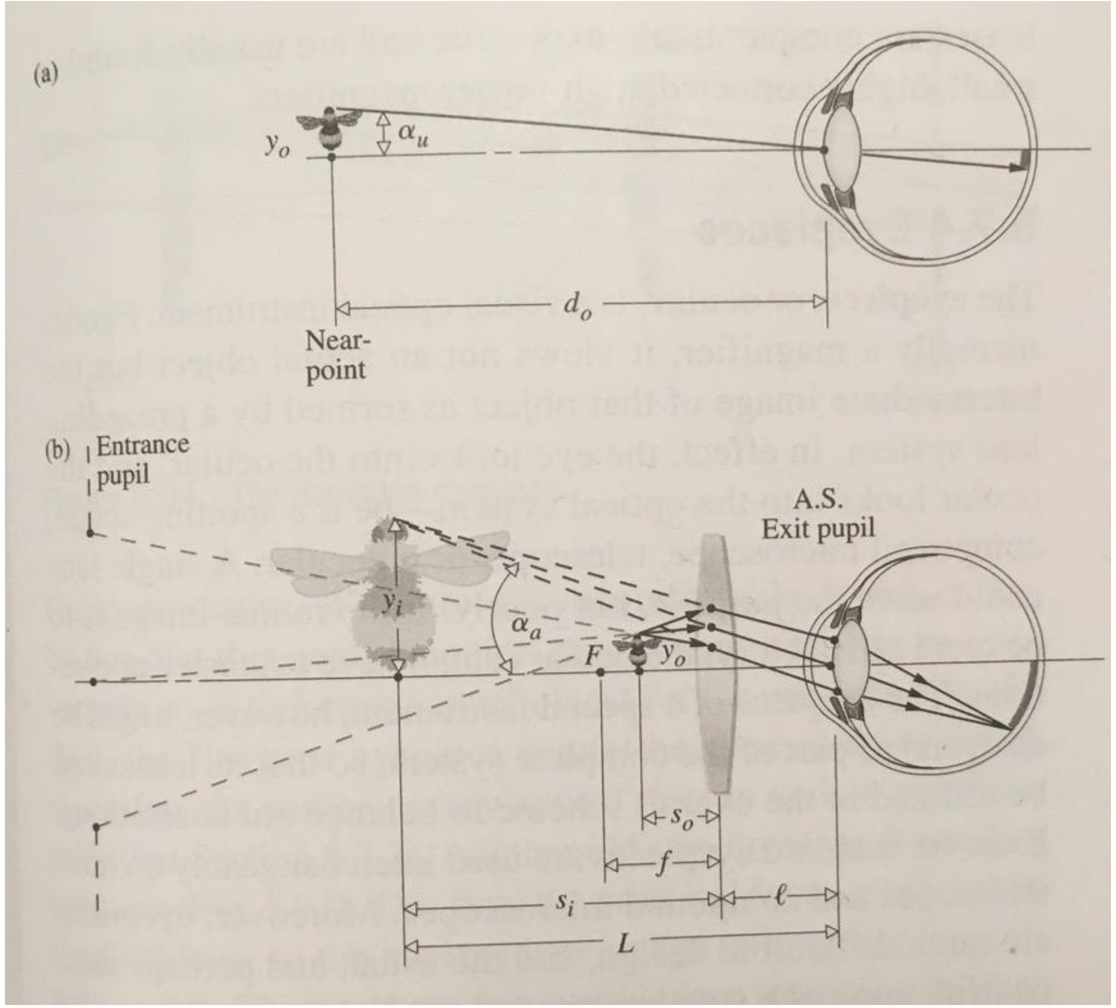


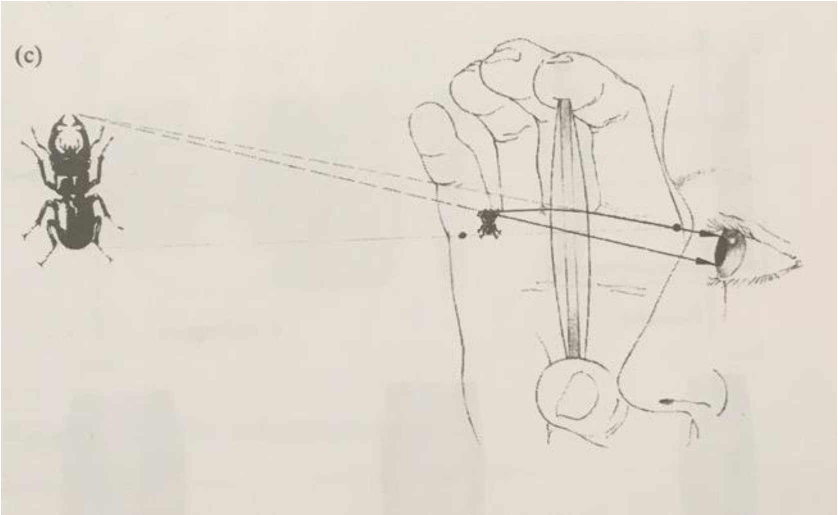
This makes laser radiation so dangerous to eye: parallel beams give perfect focus

When designing optical systems (microscopes) need to consider eye as optical element.

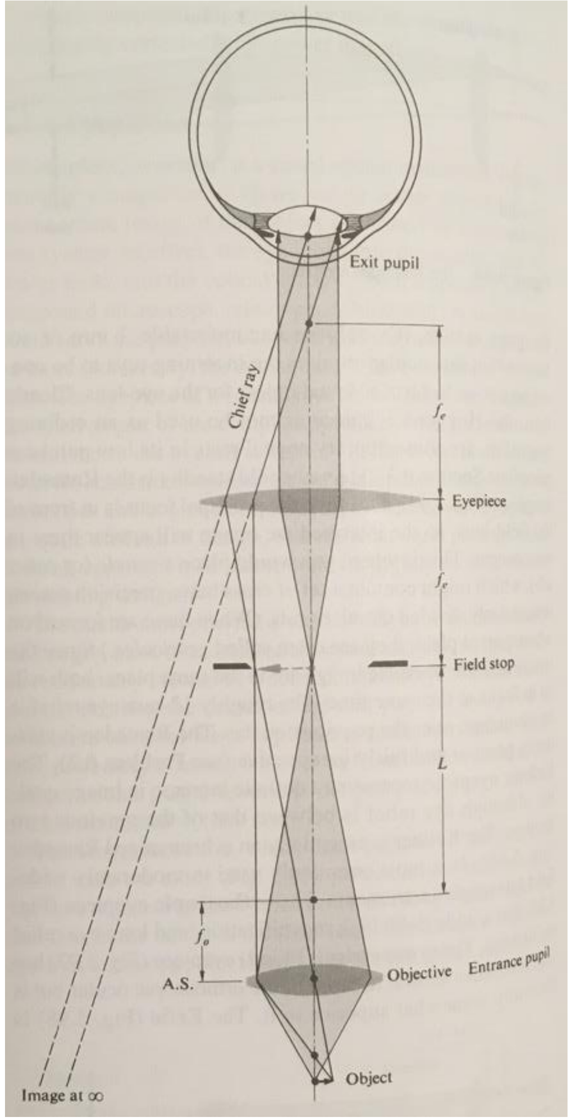
Nowadays eye is typically replaced by camera which is also an imaging system.

Magnifying glas: a simple optical element





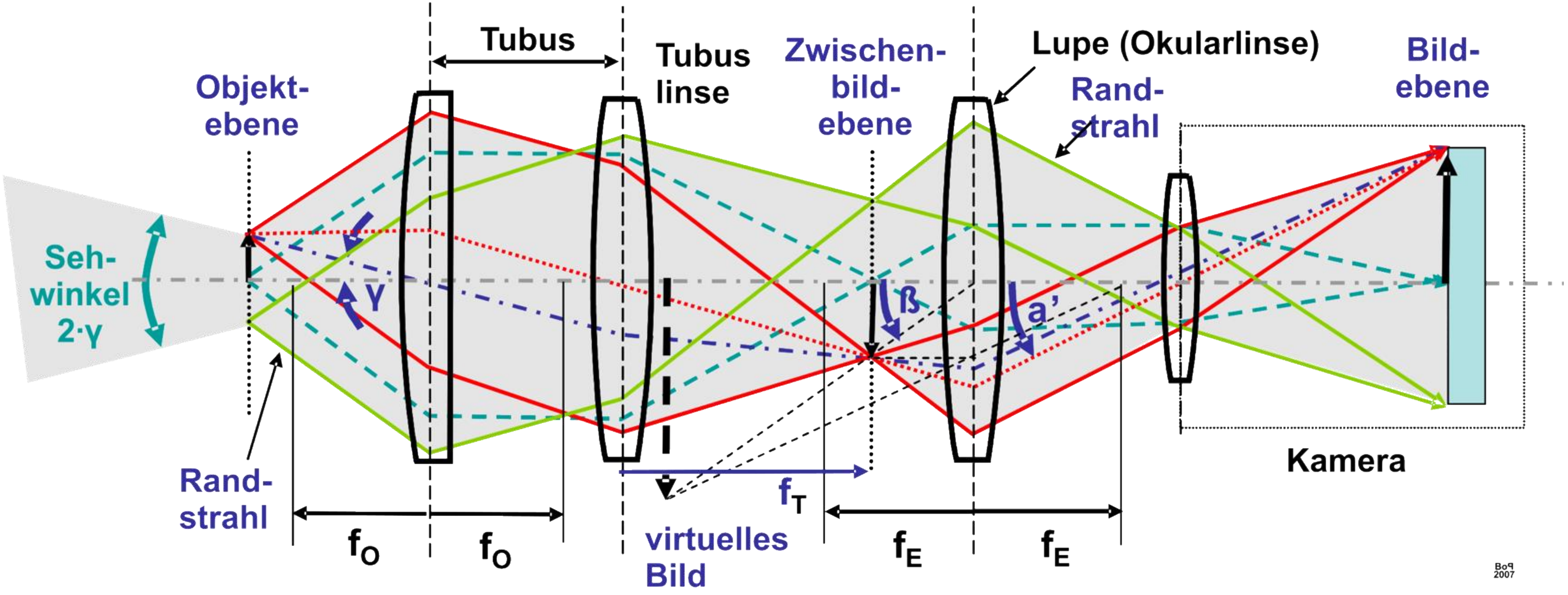
The microscope – a classical view



Principle:
Objective forms intermediate image
Eyepiece looks at and magnifies intermediate image

Magnification:

More extensive and more realistic schematic:



Microscope variations: Confocal microscope

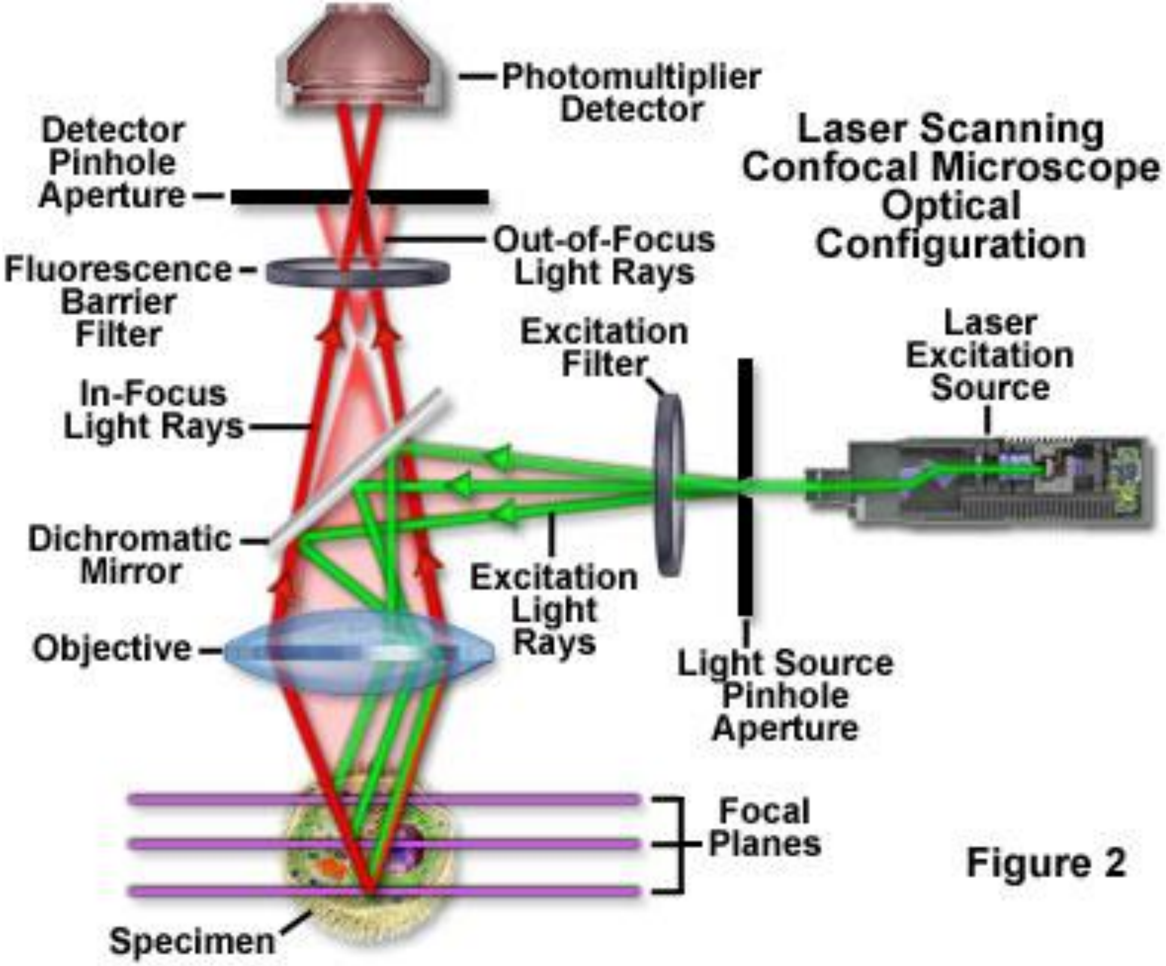


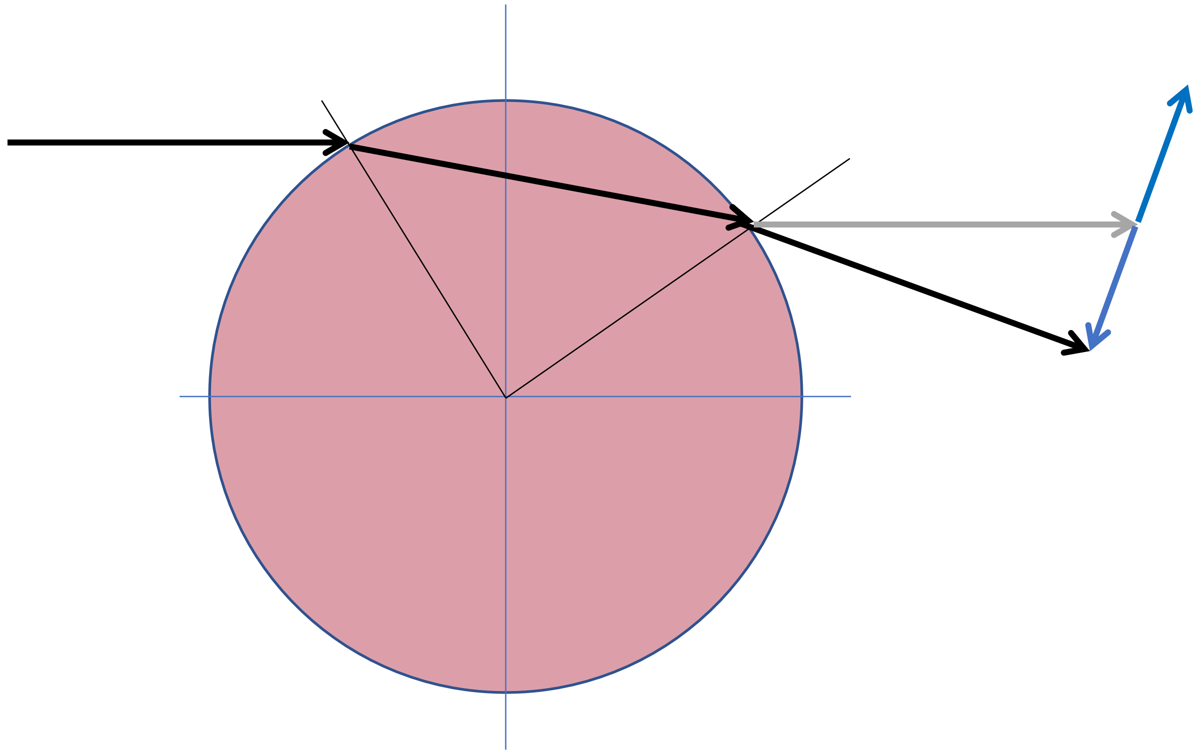
Figure 2

Source: Olympus

Light going through a lens:

- Ray optics
- Momentum vectors

Now: Not a lens but a small particle in a (homogenous) light field



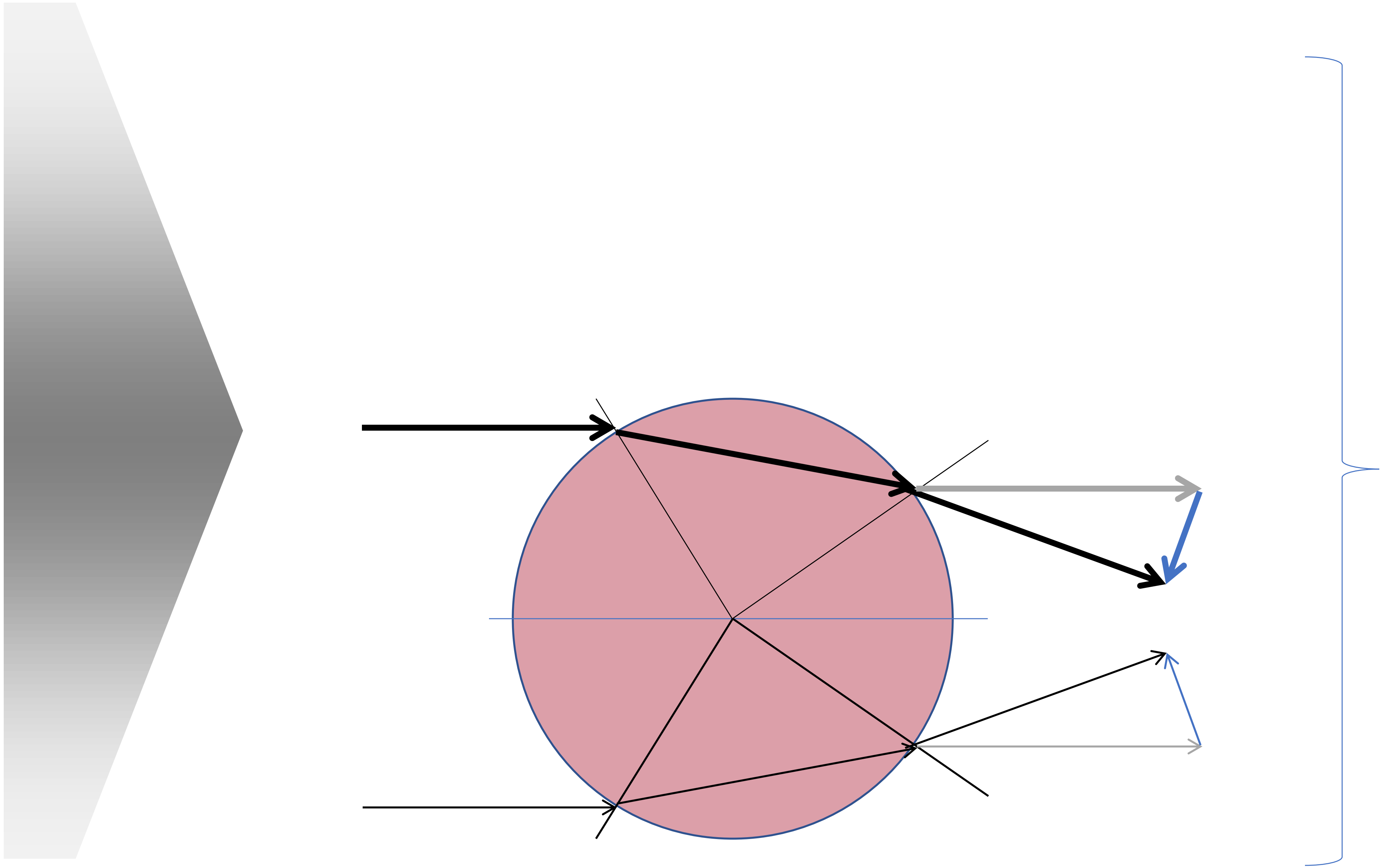
Some boundary conditions:

- Optically thicker sample in optically thinner medium
- Transparent sample, i.e., negligible scattering and reflection compared to transmission

Process:

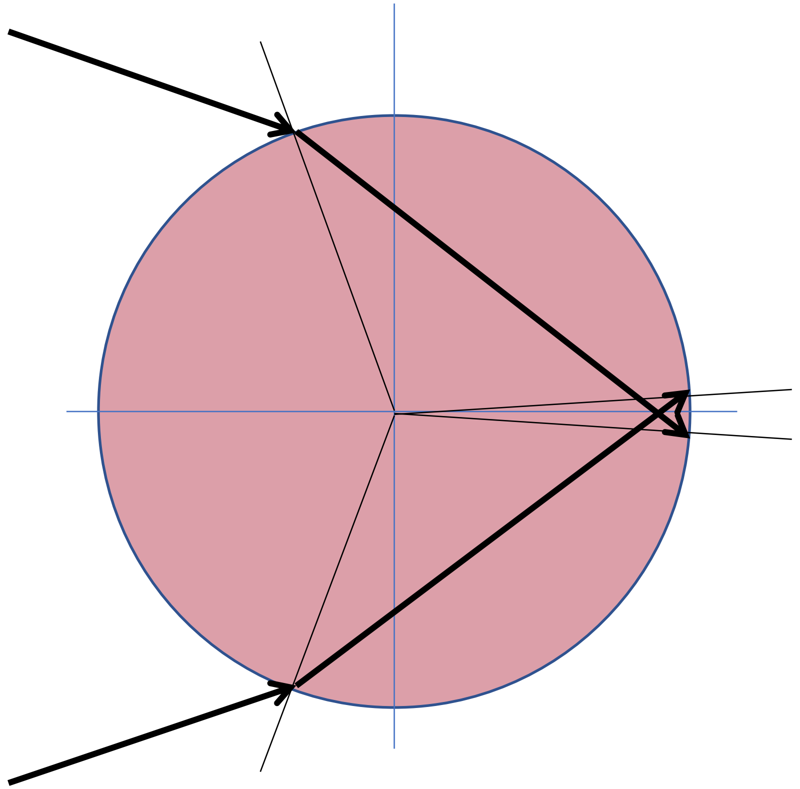
- Rays are refracted, leading to momentum change
- Action equals reaction, sphere is pushed …………wards
- With equal illumination there is……

But we learned: Laser beam has a Gaussian beam profile. More intense in center!

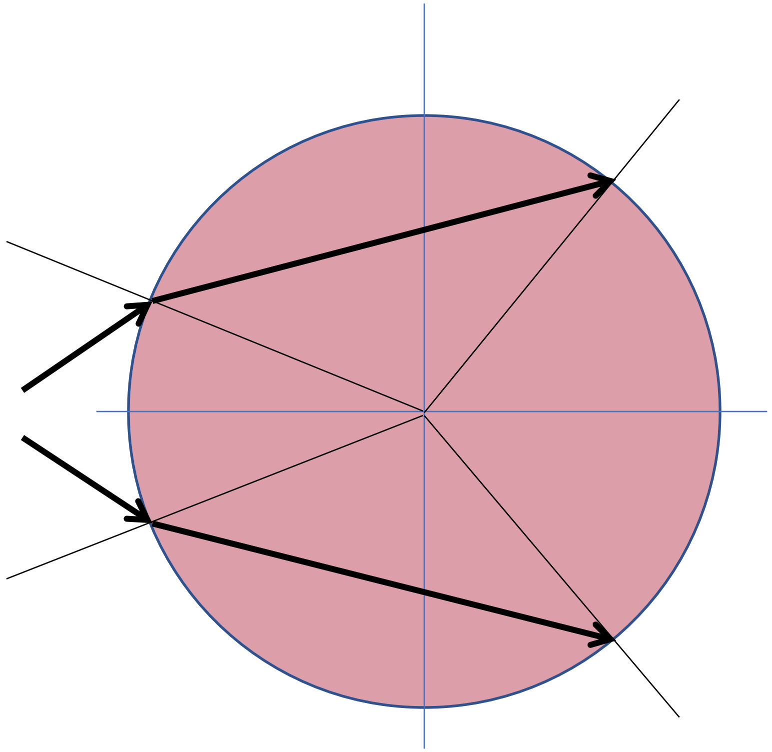


Now before and after focus

Particle before to focus



Particle behind to focus



Waves, wavefronts, interference and diffraction

Postulate of wave optics

- Light propagates in the form of waves, in vacuum light travels with c_o.

- An homogenous transparent medium is characterized by a single constant, the refractive index n>=1. In the medium light travels with reduced speed $c = c_0/n$.

- An optical wave is described by a wave function u(r,t) at position r and time t.

Wave function

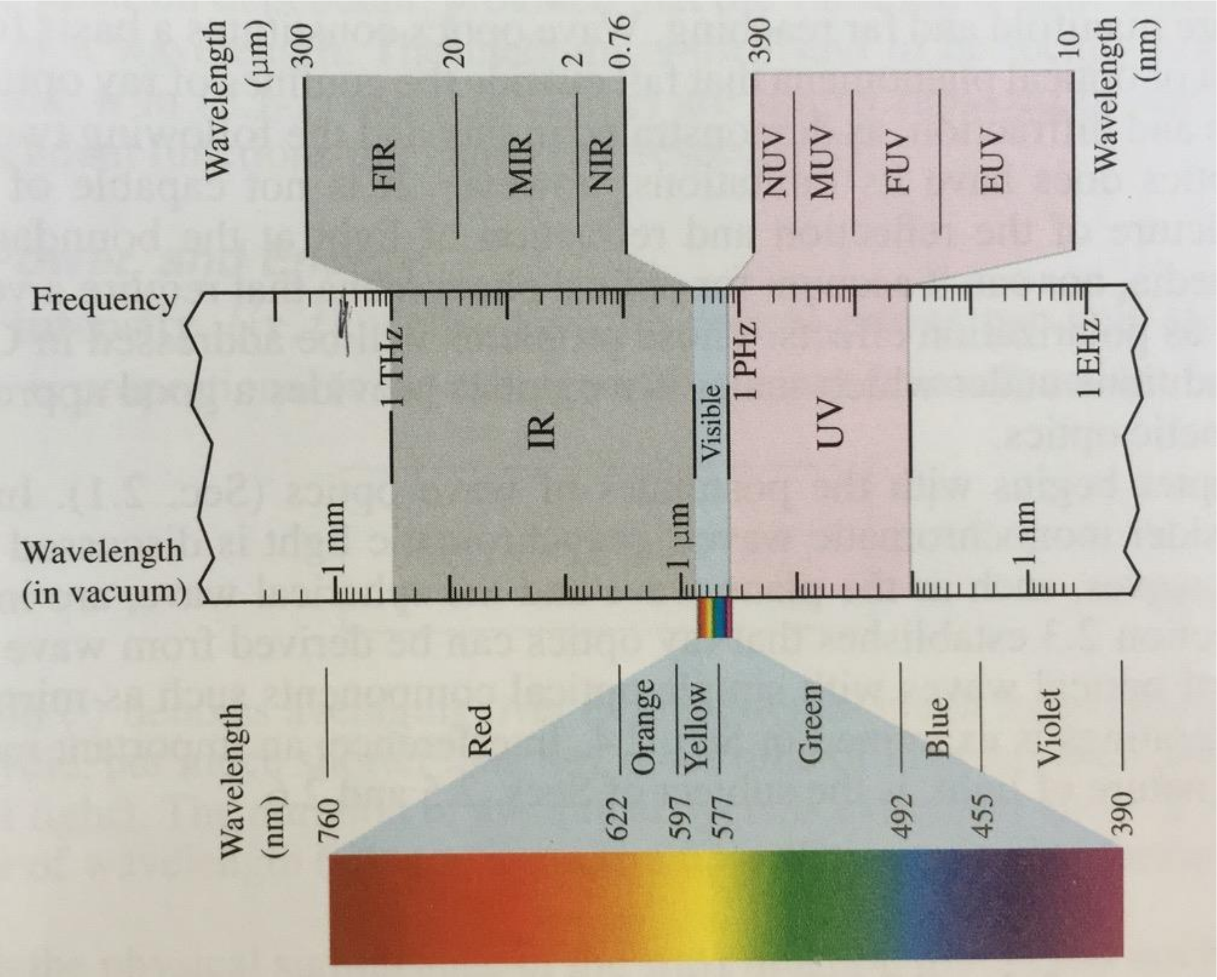
The wave function satisfies the (partial) differential equation

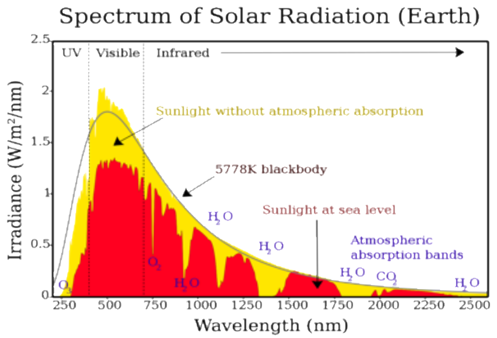
___________ Laplace operator in cartesian coordinates

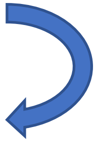
The principle of superposition applies, i.e., if u1 and u2 are optical waves then

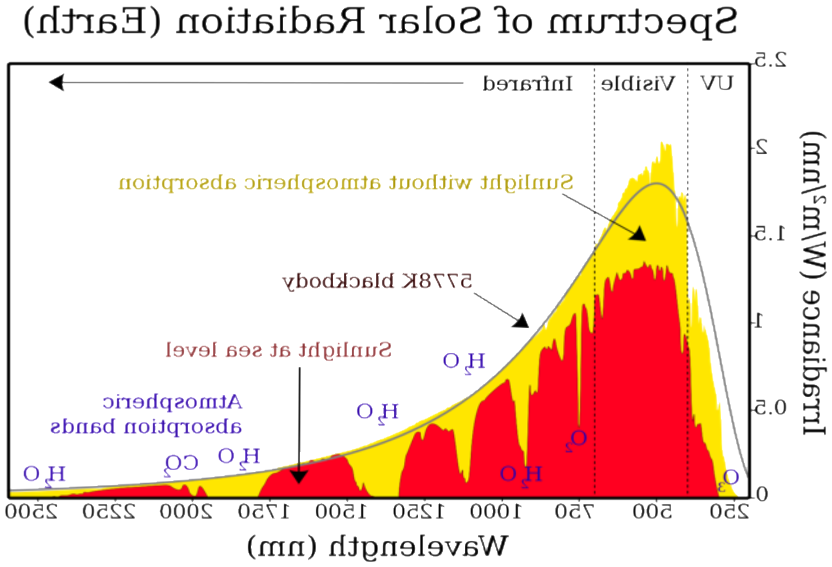
Also represents an optical wave

Optical frequencies and wavelengths









Source: wikipedia

Optical intensity, power, energy

- The optical intensity I(r,t) is the optical power per unit area.
  - The unit is Watts/cm^2
  - average of the squared wave function.

- The optical power (in units of Watts) flowing into an area A normal to the direction of propagation is the integrated intensity

- The optical energy (in units of Joules) in a given time interval is the integral of the optical power over the time interval

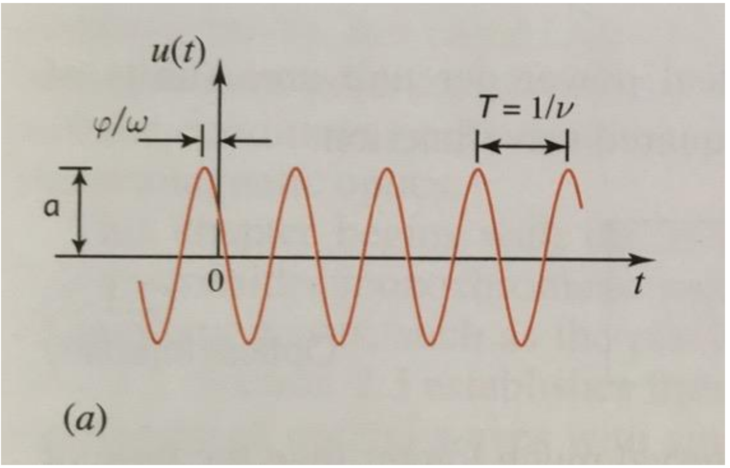
Simple example: Monochromatic wave

- For a monochromatic wave the, the wave function reduces to

With:

- The amplitude and phase are generally position dependent

- Representation of a monochromatic wave



Simple example: Monochromativ wave but as complex wave function

- A monochromatic wave can be explained by complex wave function

- This general description satisfies the

  Helmholtz equation:

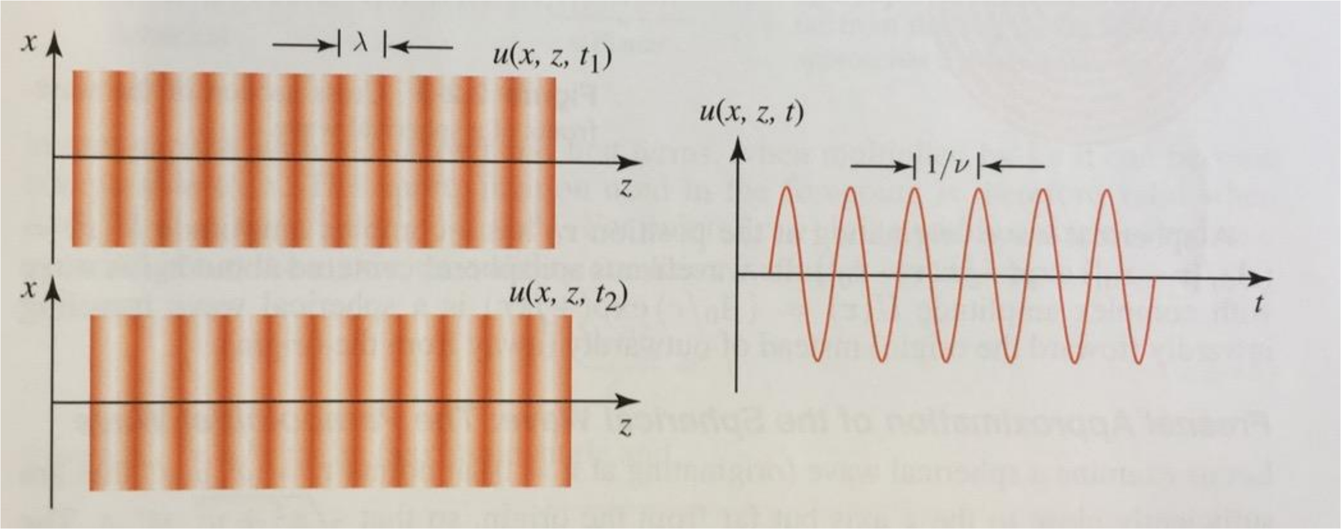
  With wavenumber k =

- Note intensity:

  - Monochromatic wave intensity is (complex amplitude)^2
  - Intensity does not vary in time

- Note: Wavefronts are surfaces of equal phase

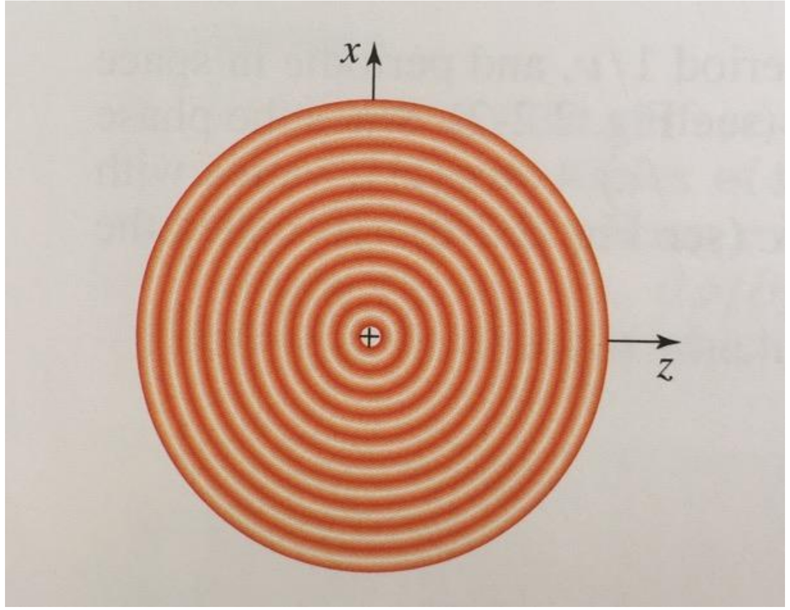
Special case: plane wave



Plane waves: wavefronts are parallel planes perpendicular to k and separated by λ

For graphical animations visit https://en.wikipedia.org/wiki/Sinusoidal_plane_wave

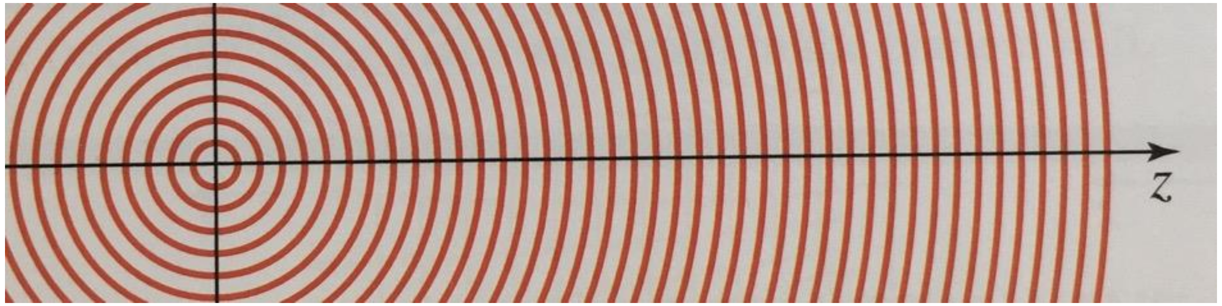
Special case: spherical wave



Spherical waves: wavefronts are concentric spheres separated by $\lambda=2\pi/k$

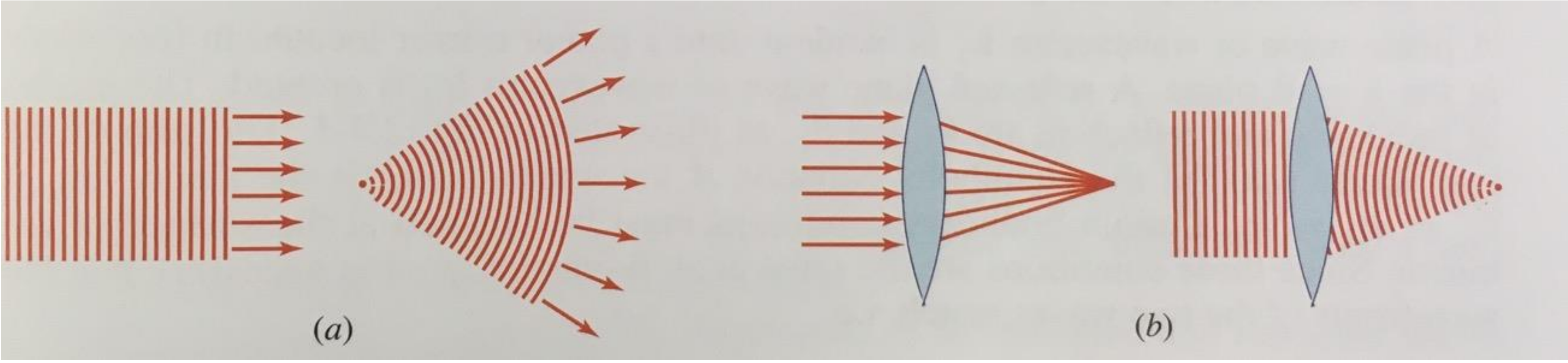
For graphical animations visit https://en.wikipedia.org/wiki/Wave_equation#Spherical_waves

Special case: Fresnel approximation



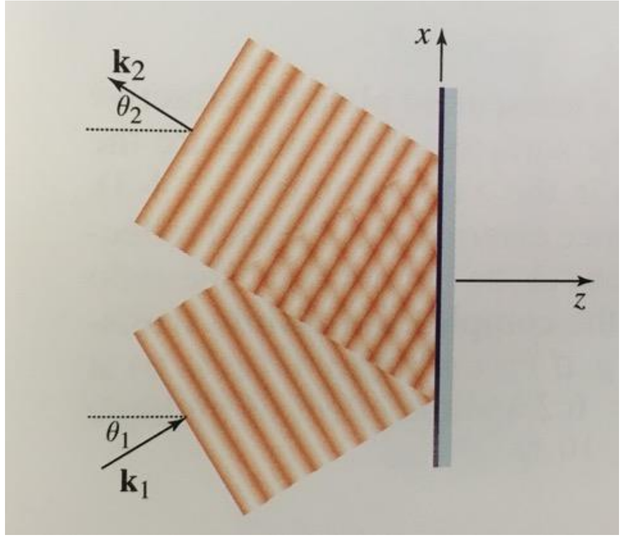
- Spherical wave close to z-axis but far away from origin

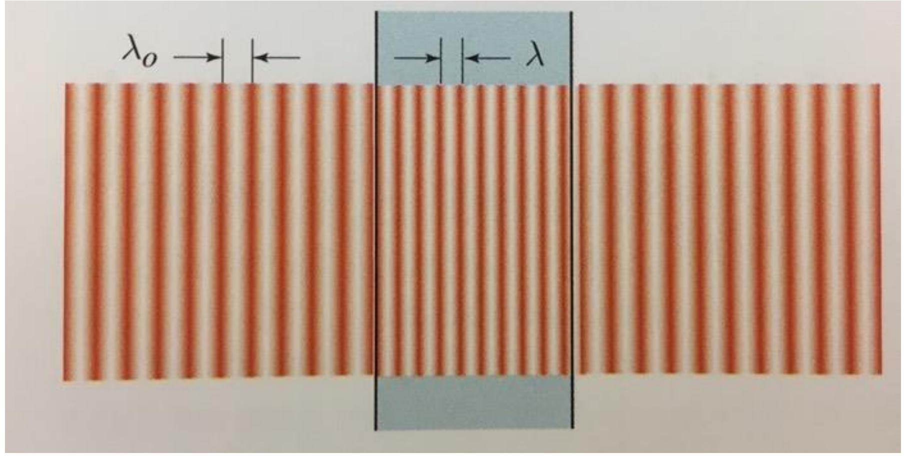
From ray to wave optics

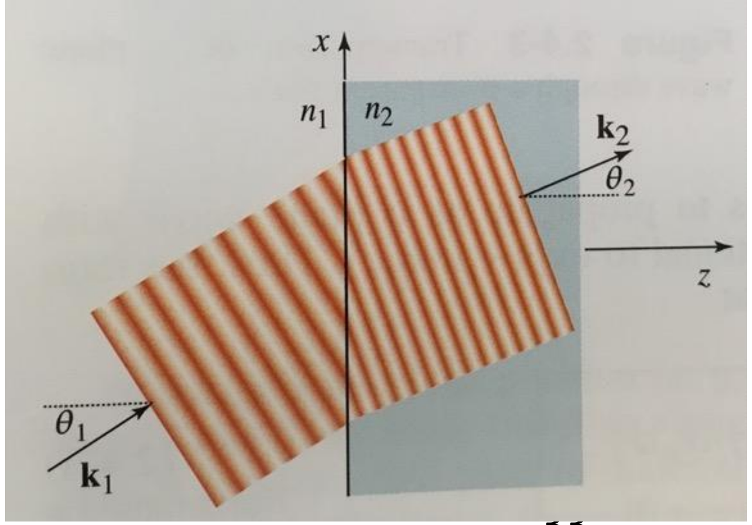


What happens after focal point?

Wave optics and simple optical components







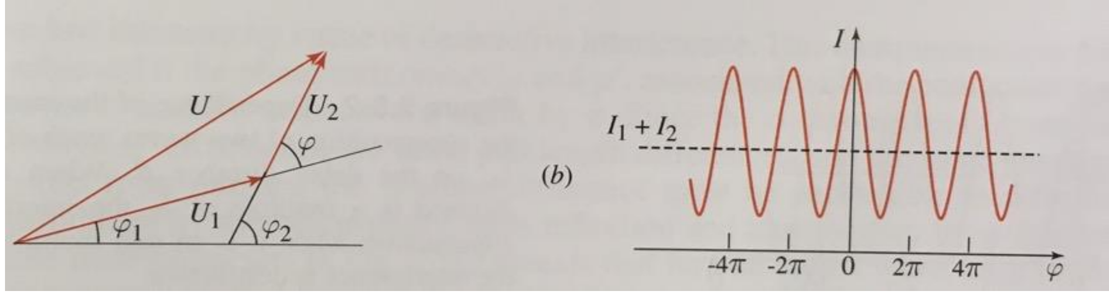
Interference of two waves

When two monochromativ waves with complex amplitudes U_1 and U_2 are superimposed, the result ia a monochromatic wave of the same frequency that has a complex amplitude

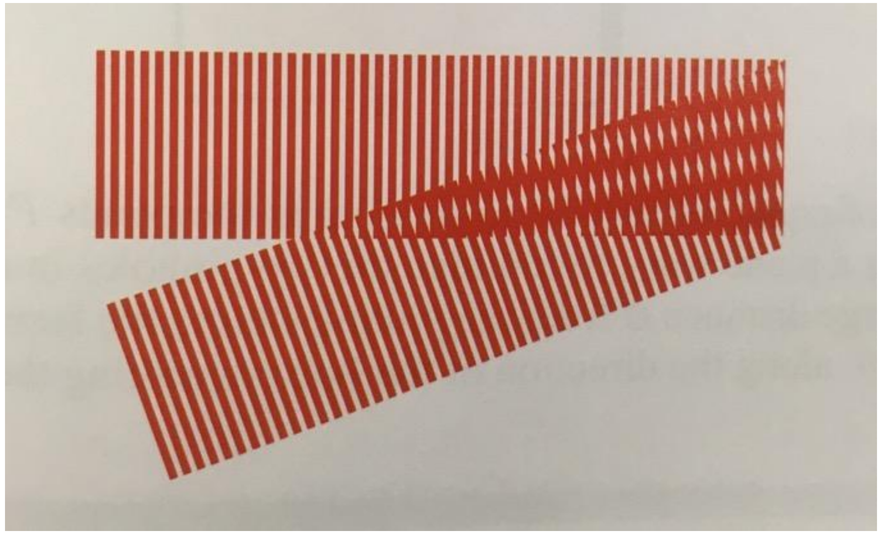
$$U(r) = U_1(r) + U_2(r)$$

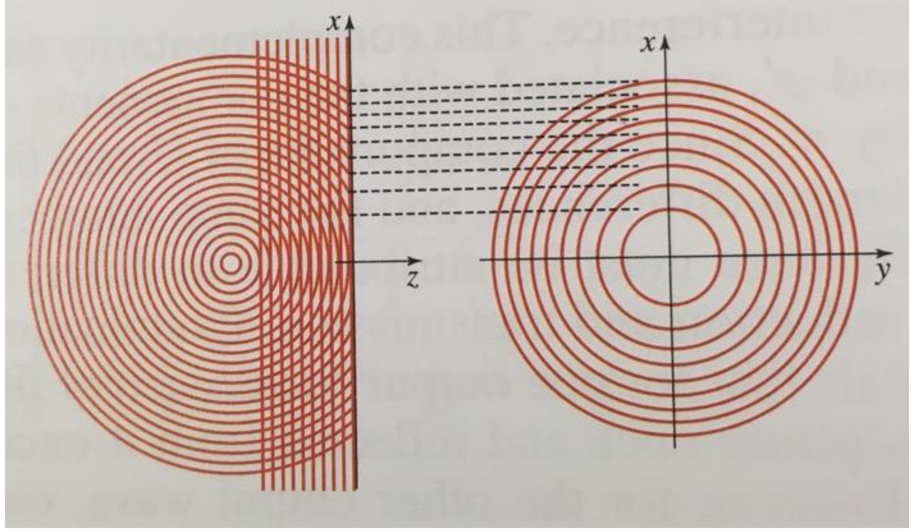
The intensity of the resulting wave is:

Resulting in the interference equation:

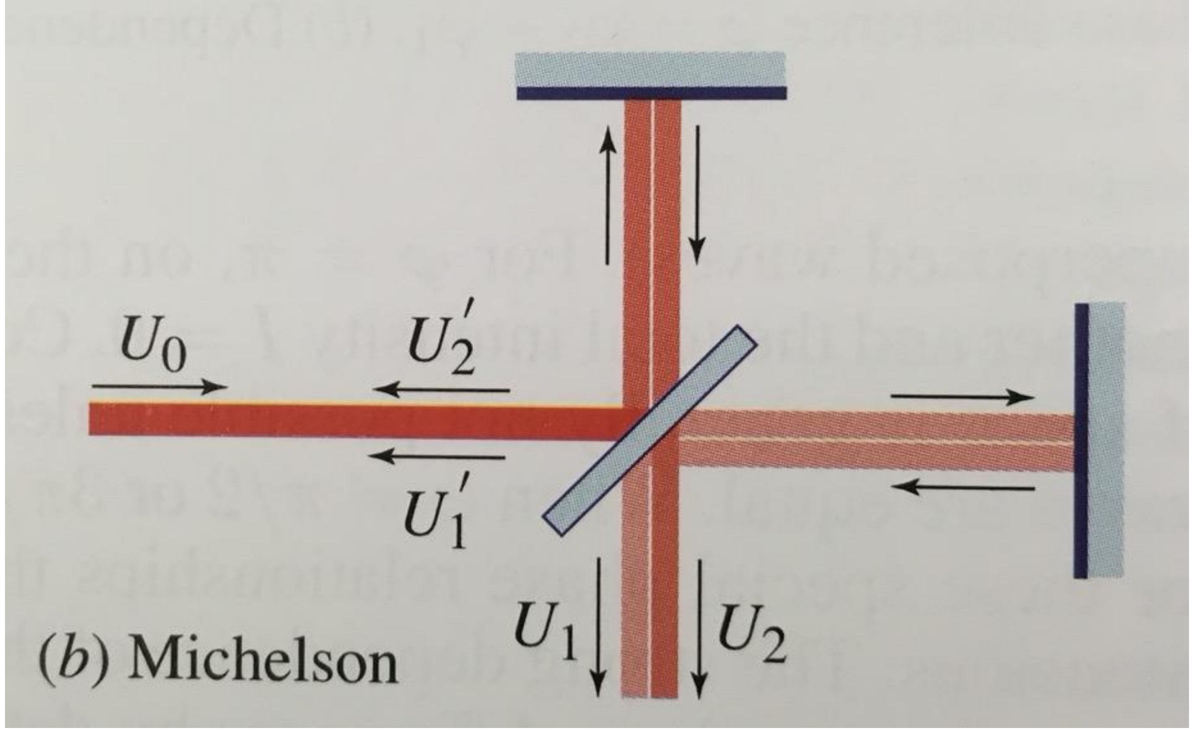


Interference: Some examples





Interferometer, example Michelson



(b) Michelson

Nice demonstration: https://www.youtube.com/watch?v=j-u3IEgcTiQ

The Huygens-Fresnel Principle

- Hugens: 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)

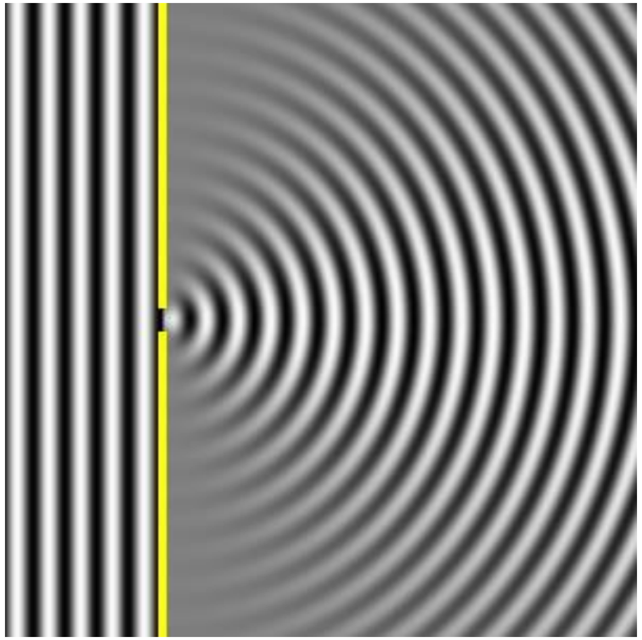
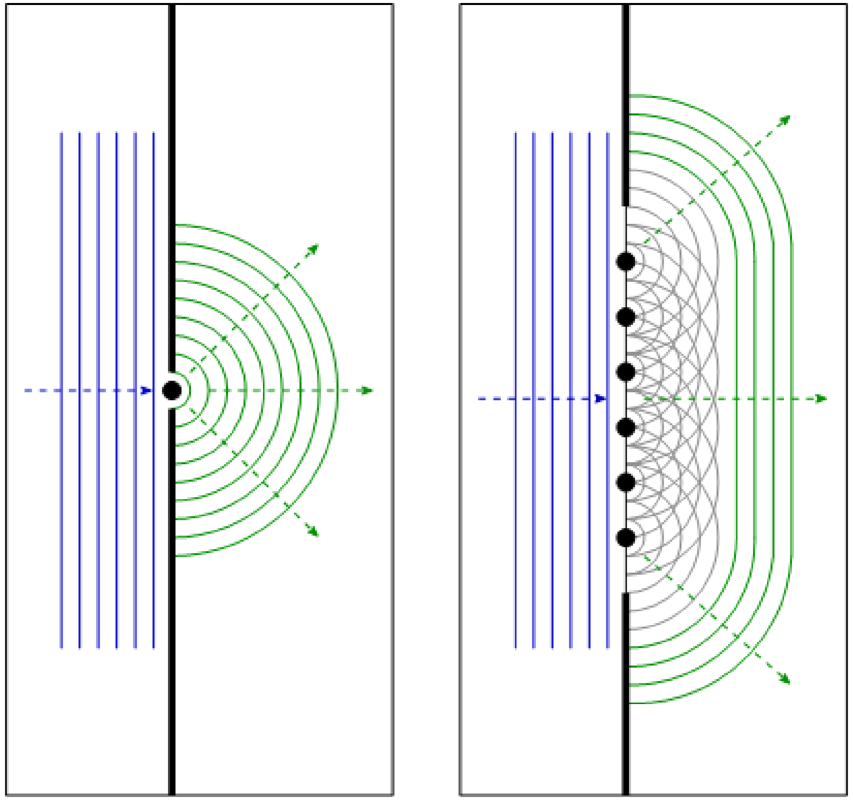


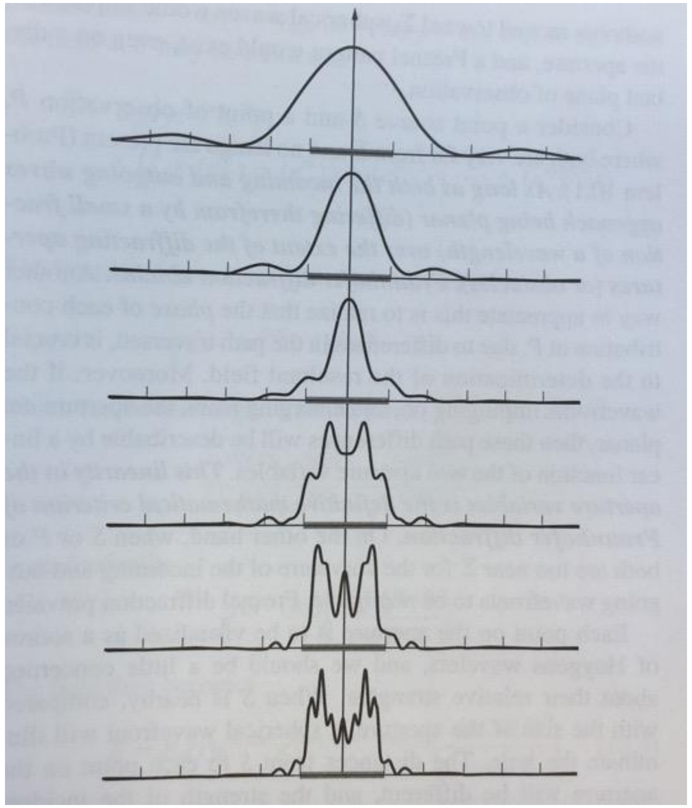
Image credits: By Lookangmany thanks to Fu-Kwun Hwang and author of Easy Java Simulation = Francisco Esquembre - Own work, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=16981632

Wavefronts behind slit

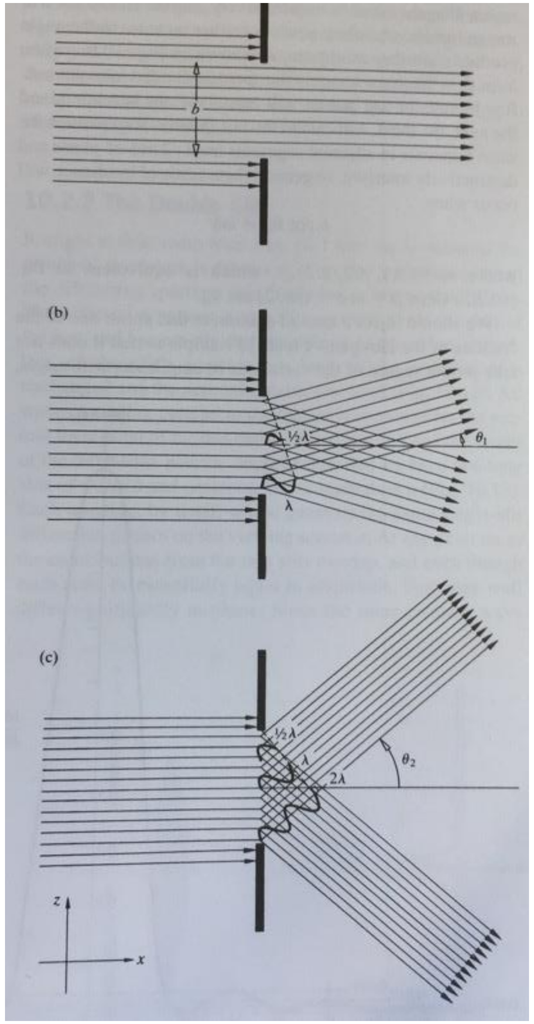
Small vs. real slit



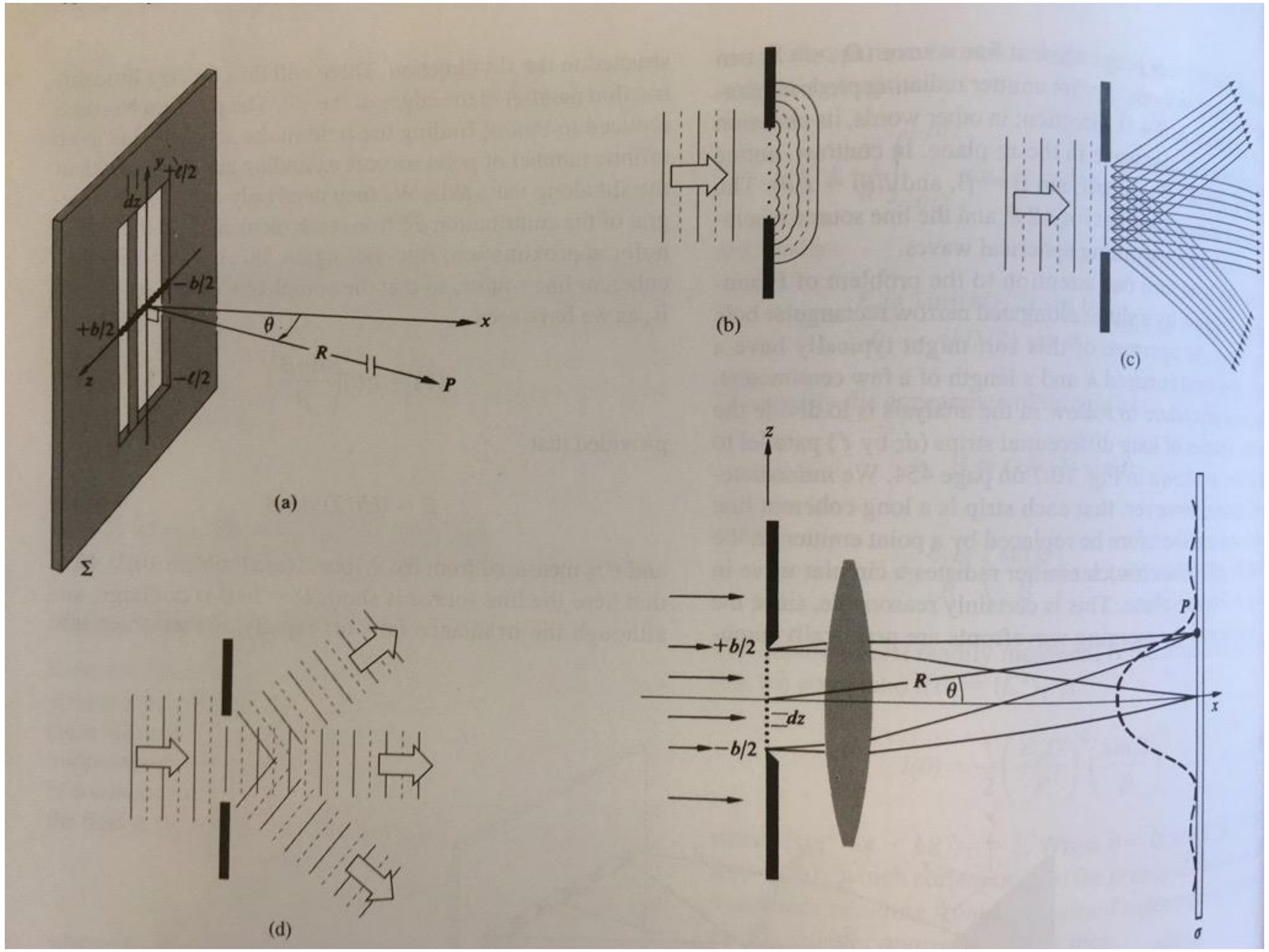
Fresnel and Fraunhofer regime



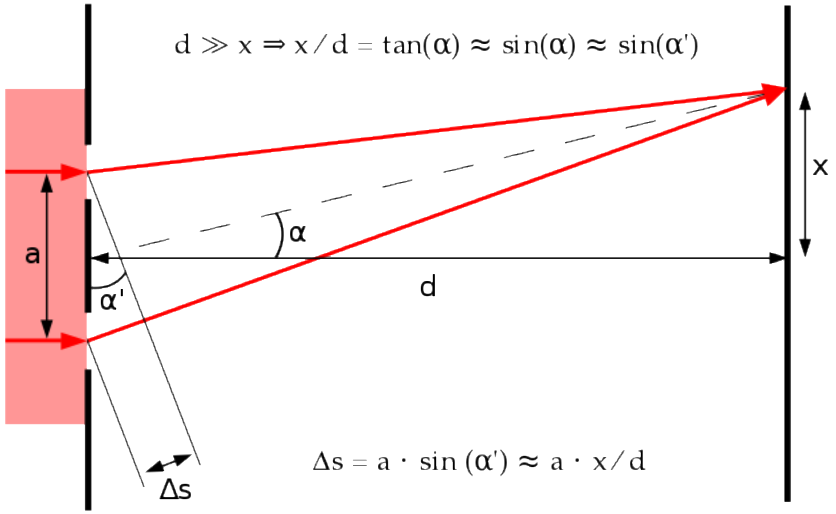
Different views on Fraunhofer Diffraction (R>>D) for single slit



Different views on Fraunhofer Diffraction (R>>D) for single slit



Now the double slit



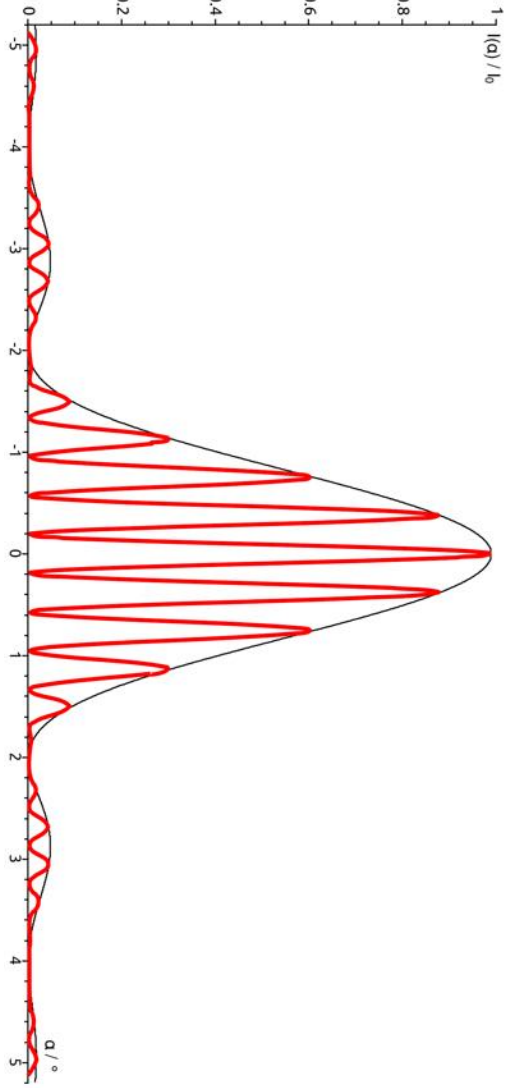
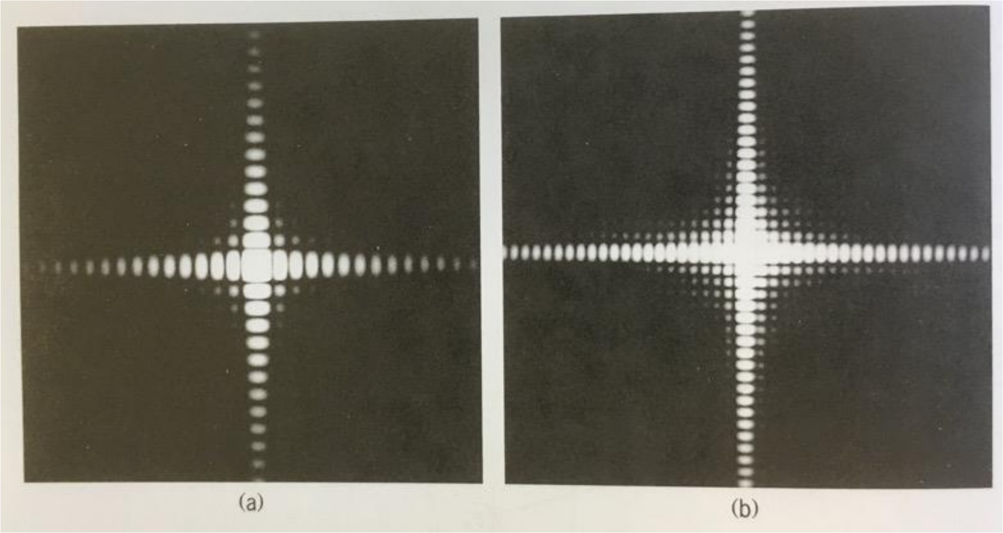


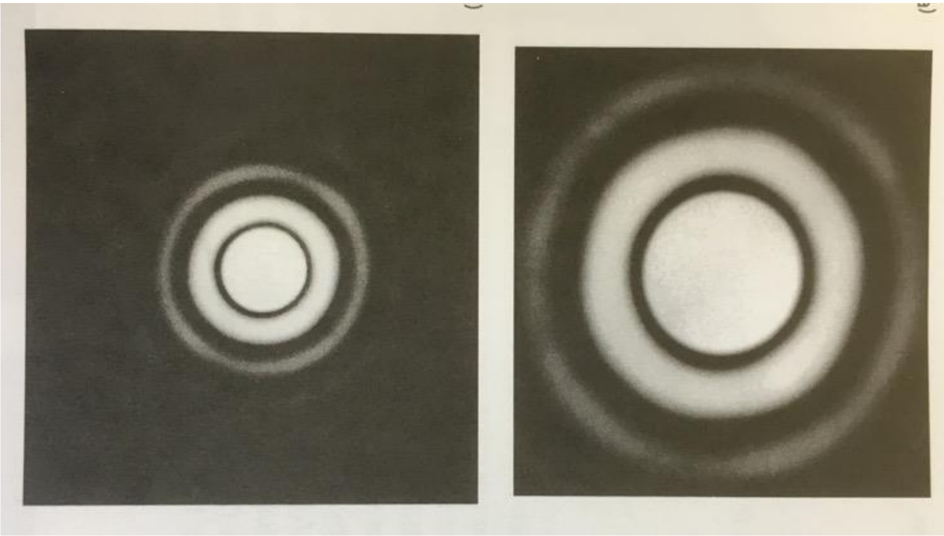
Image source: wikipedia

Diffraction pattern of 2D objects – 2 examples

Square aperture



Round aperture



Note: Babinets 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:

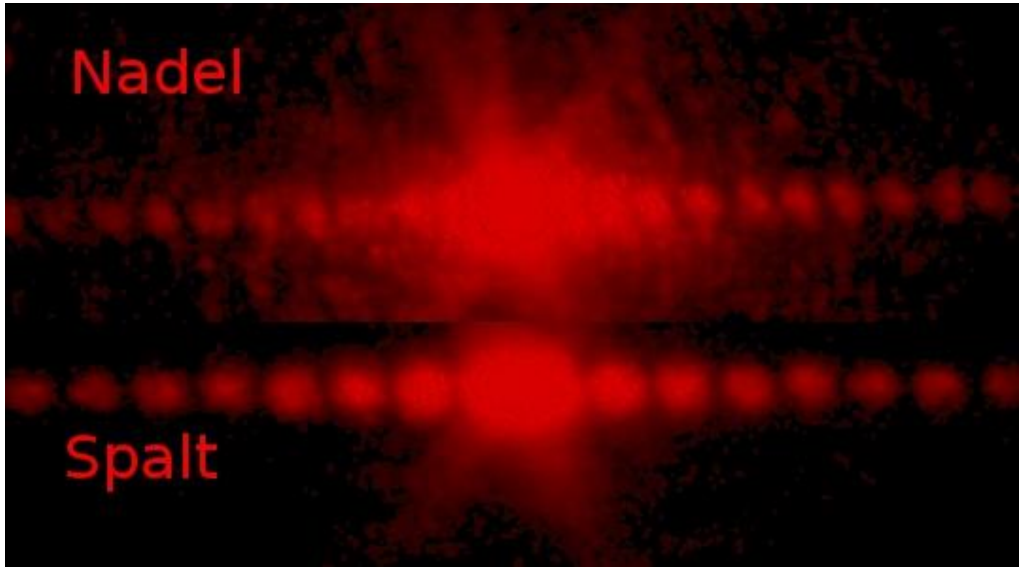
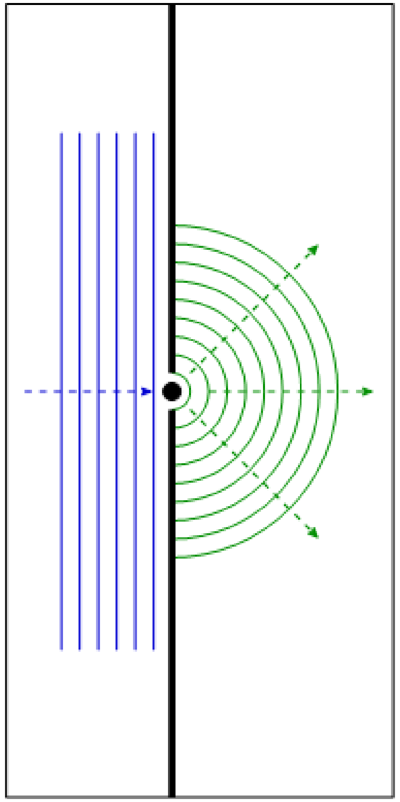


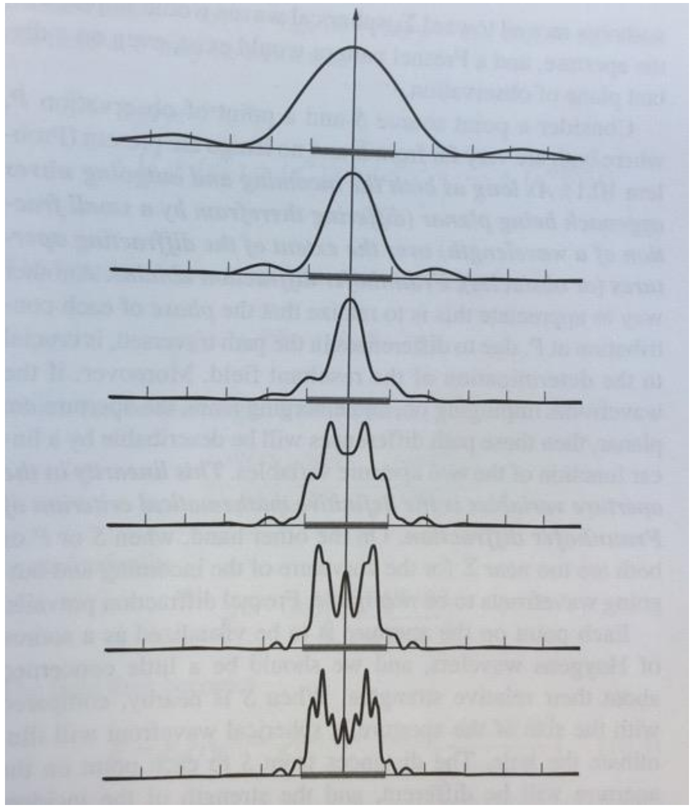
Image: wikipedia

Resolution limit of a classical optical apparatus: Remember Huygens Fresnel principle, diffraction at a slit, Airy rings

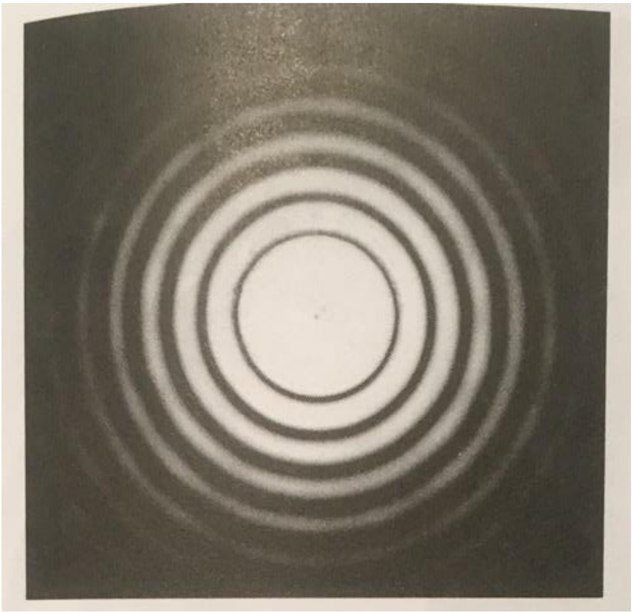
Diffraction at slit / aperture



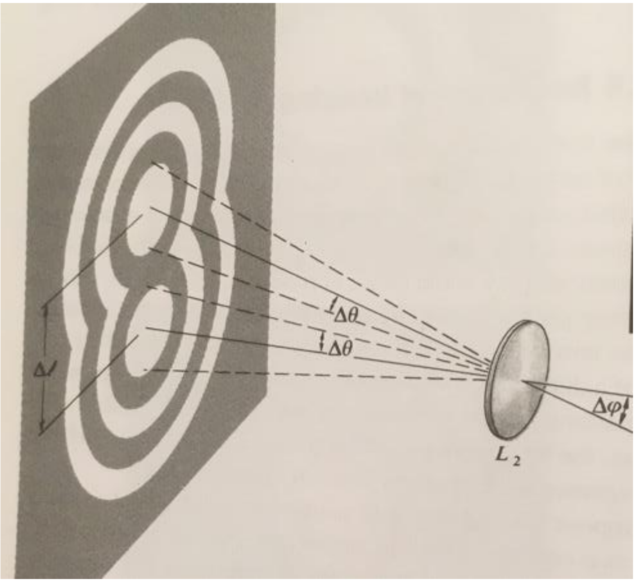
Fresnel and Fraunhofer regime

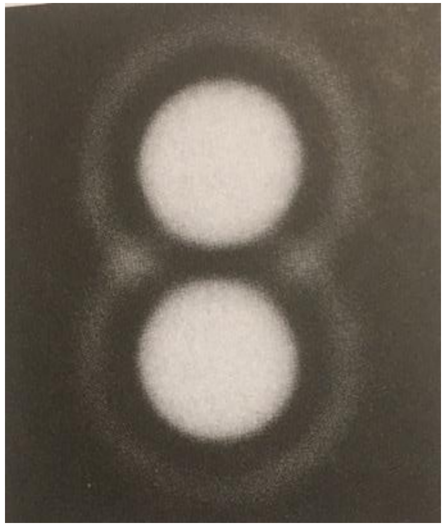


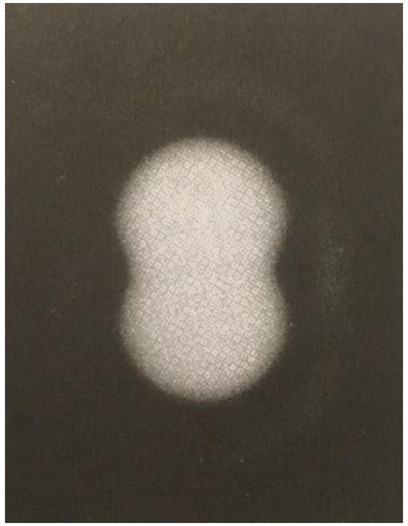
Airy rings of circular aperture

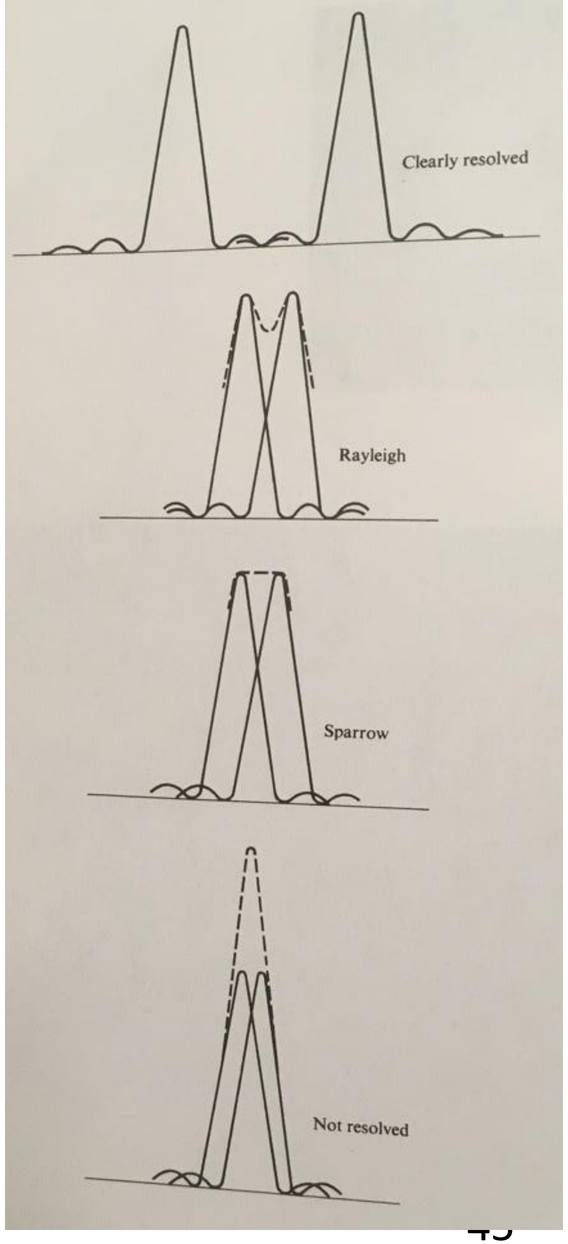


Resolution limit of a classical optical apparatus









Beam optics

Gaussian beam III

- U(r) is called a Gaussian beam

$$U(\mathbf{r}) = A_0 \frac{W_0}{W(z)} \exp\left[-\frac{\rho^2}{W^2(z)}\right] \exp\left[-jkz - jk\frac{\rho^2}{2R(z)} + j\zeta(z)\right]$$

- With the following parameters

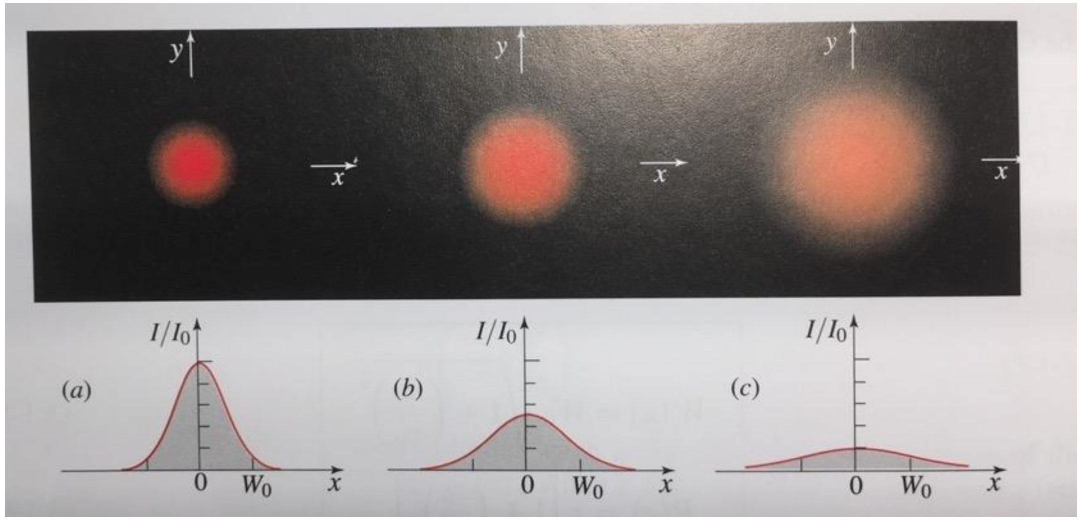
$$W(z) = W_0 \sqrt{1 + \left(\frac{z}{z_0}\right)^2}$$

$$R(z) = z\left[1 + \left(\frac{z_0}{z}\right)^2\right]$$

$$\zeta(z) = \tan^{-1}\frac{z}{z_0}$$

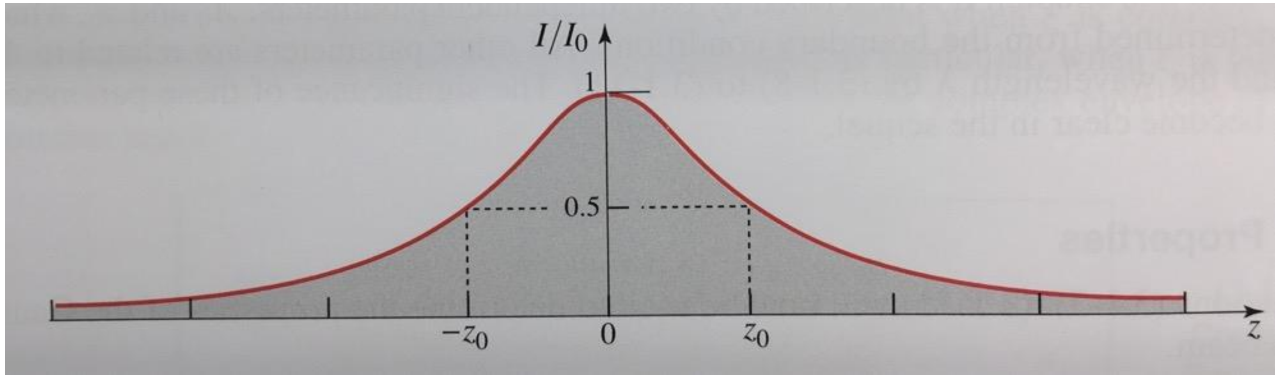
$$W_0 = \sqrt{\frac{\lambda z_0}{\pi}}.$$

Parameter: Intensity as function of radial distance

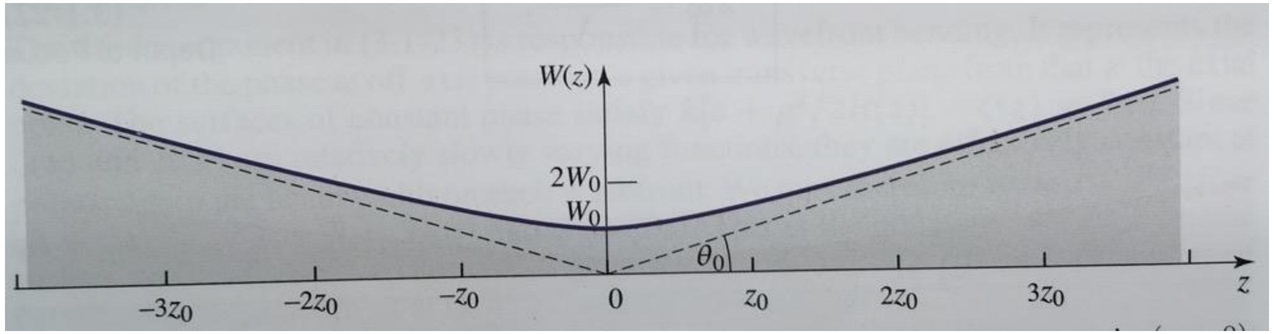


Once a Gaussian – always a Gaussian!

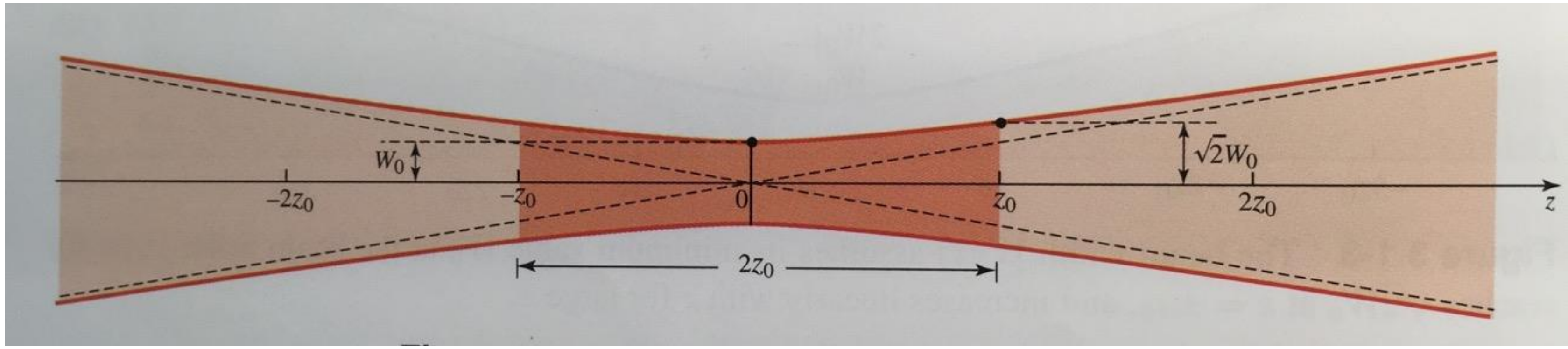
Parameter: Intensity on beam axis



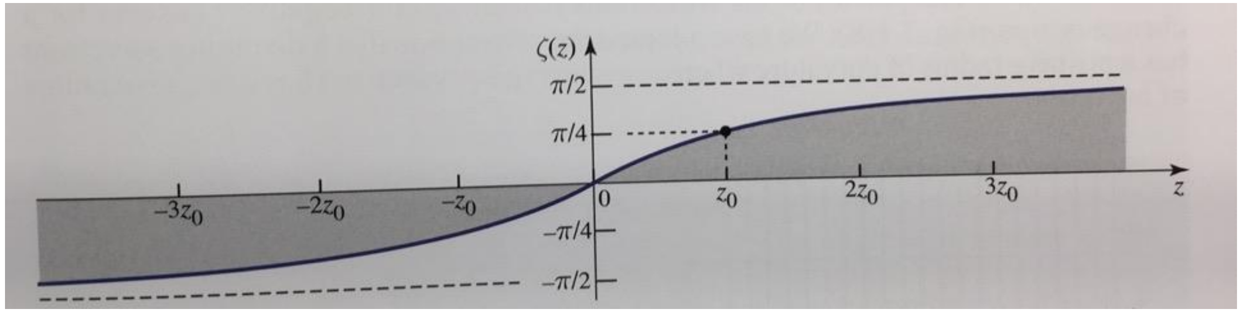
Parameter: Beam waist



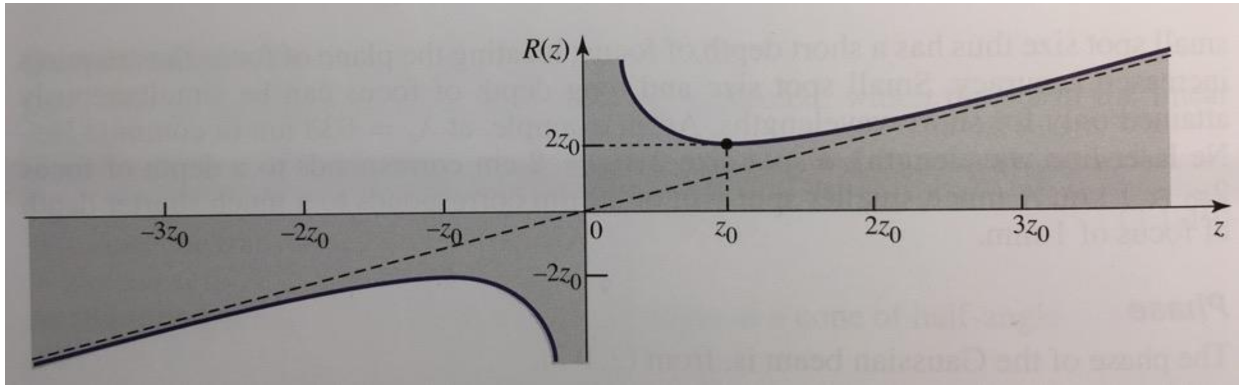
Parameter: Depth of focus

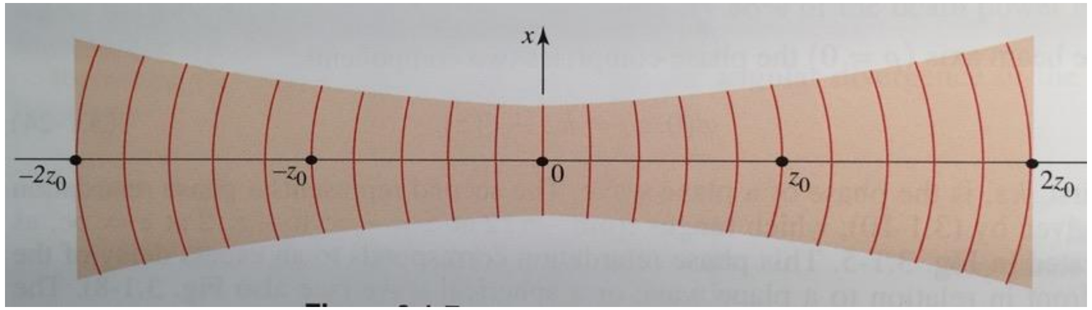


Parameter: Phase

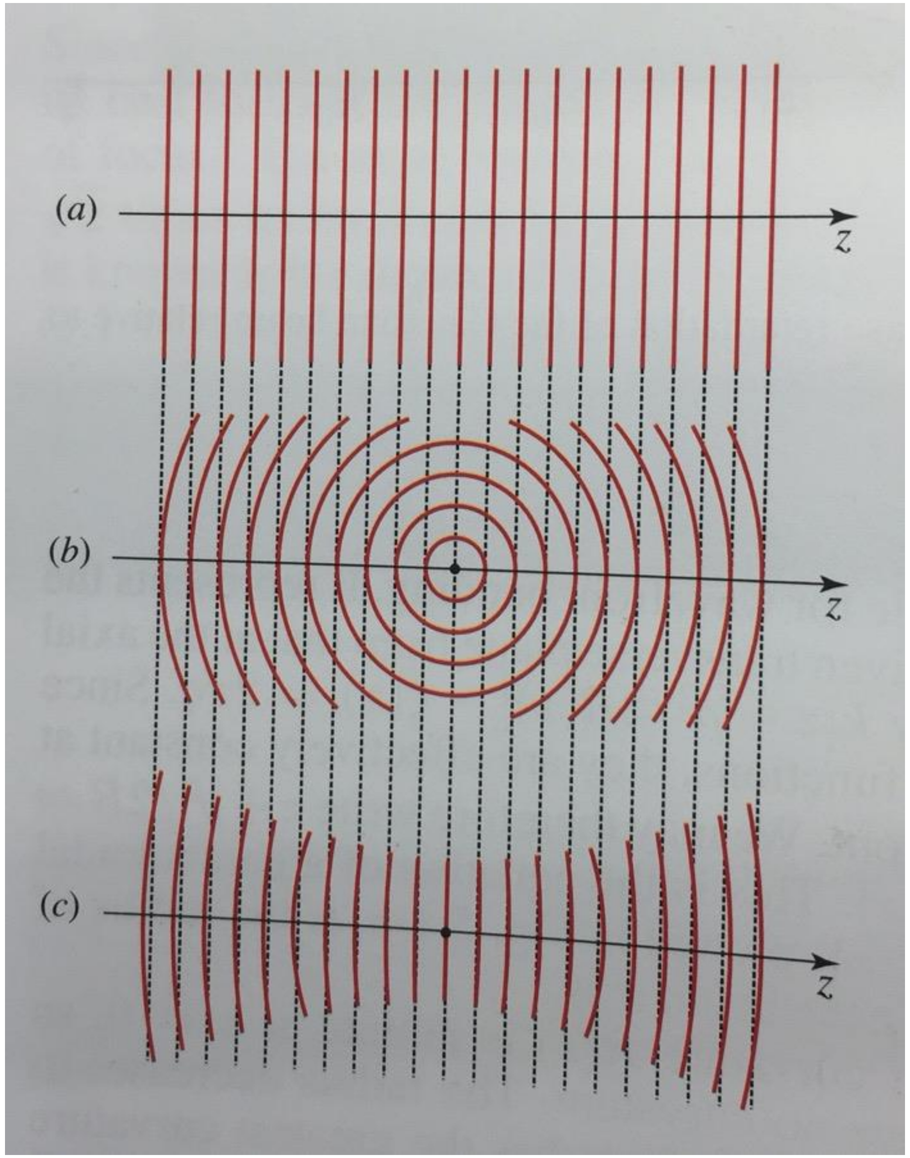


Parameter: Curvature of wavefront





Comparison: plance wave, spherical wave, Gaussian beam

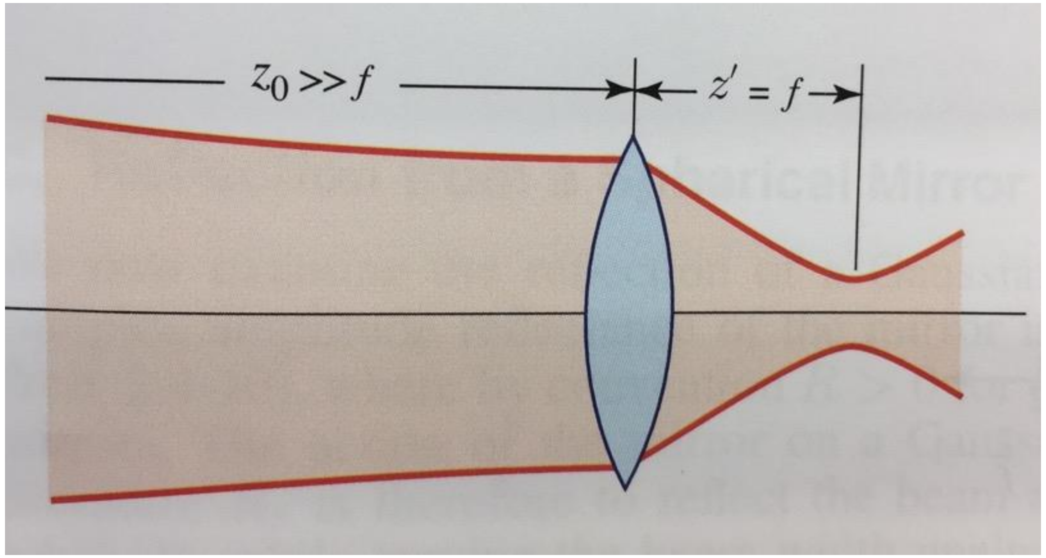


Some statements to remember

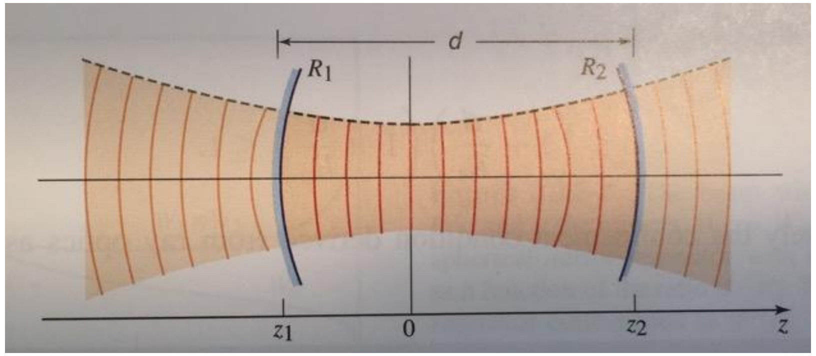
- A Gaussian beam transmitted through a circularly symmetric optical component remains a Gaussian beam

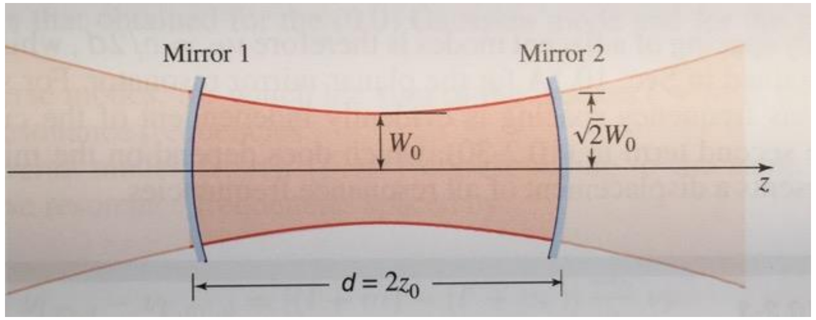
- Such optical components reshape the beam, i.e., its waist and curvature

- Focusing a collimated Gaussian beam:

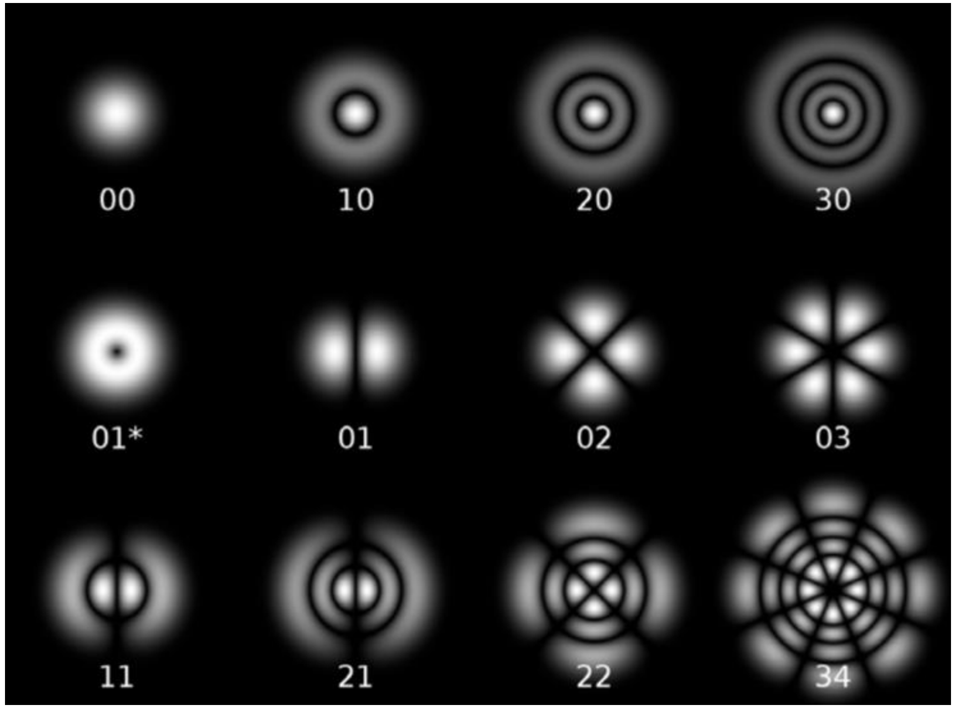


Gaussian Beam Resonator



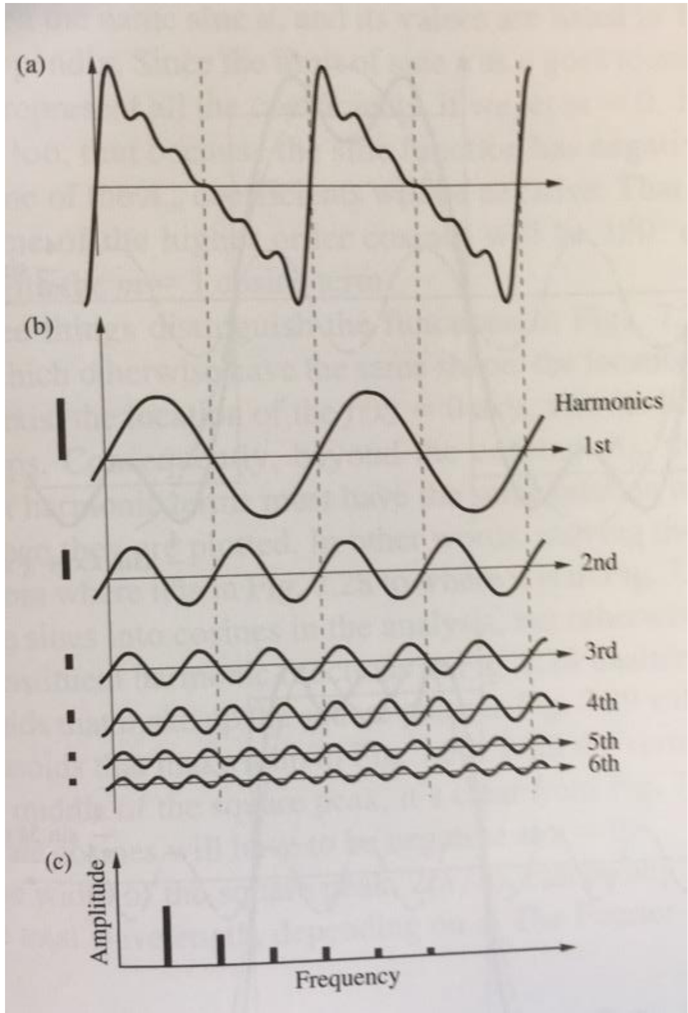


Laguerre-Gaussian modes



Fourier transforms and Fourier optics

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

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

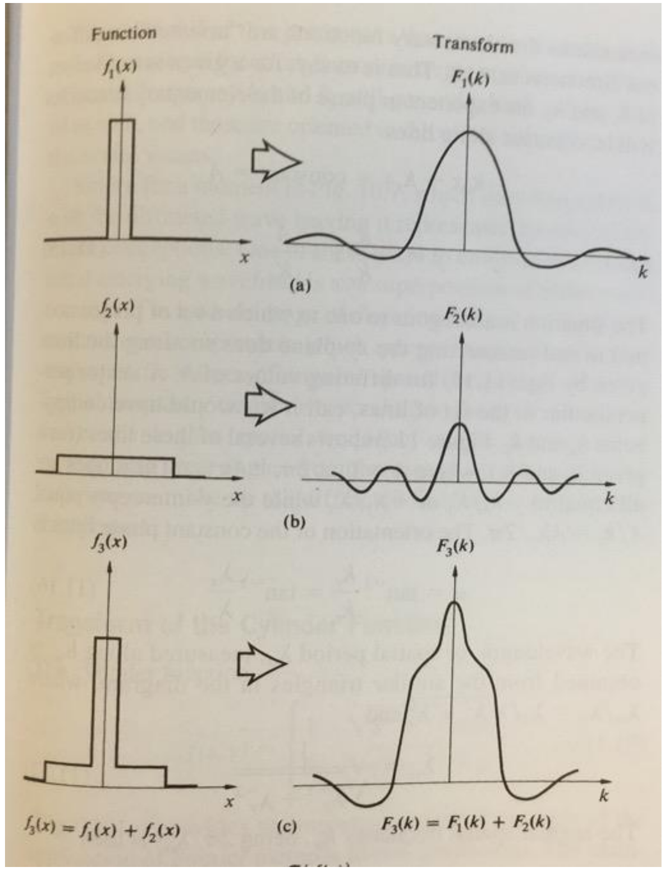
provided that

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

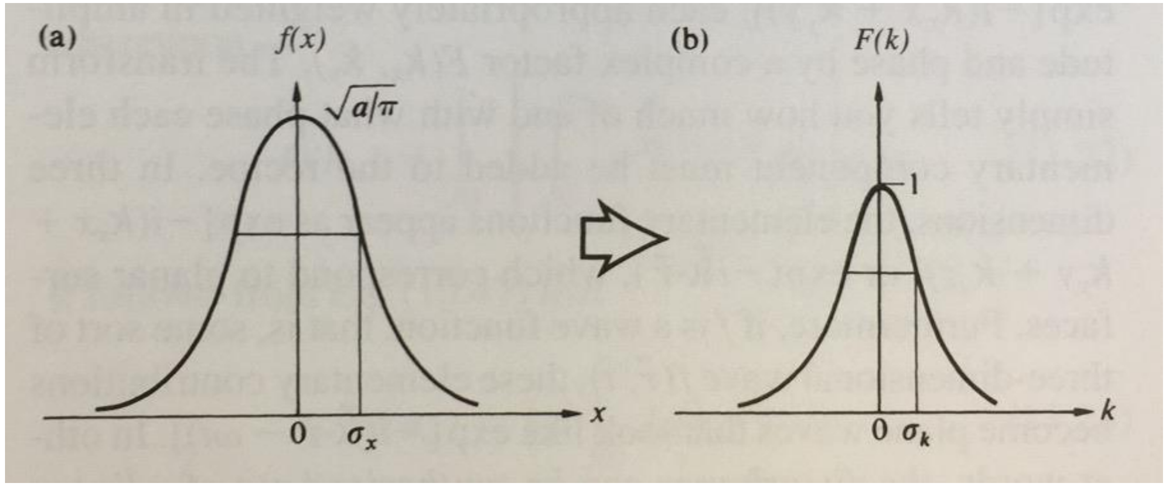
Hecht chapter 11

Examples

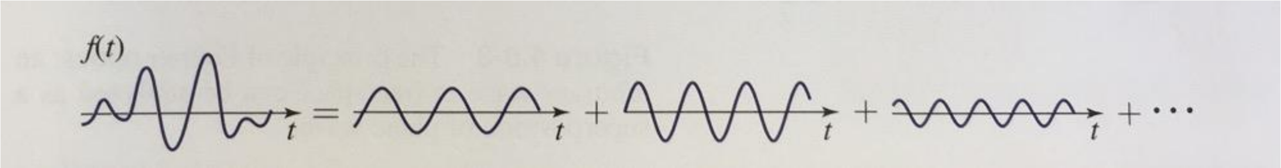
Squares and composite

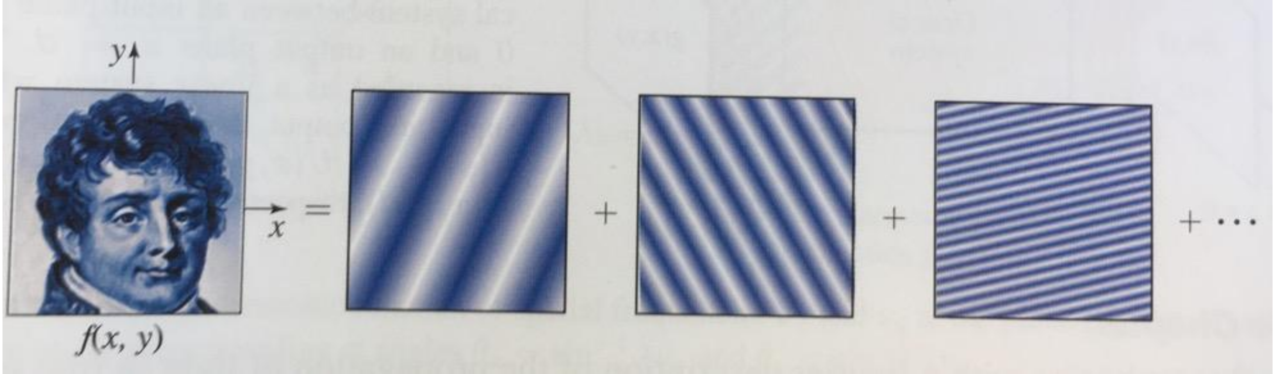


Gauss function

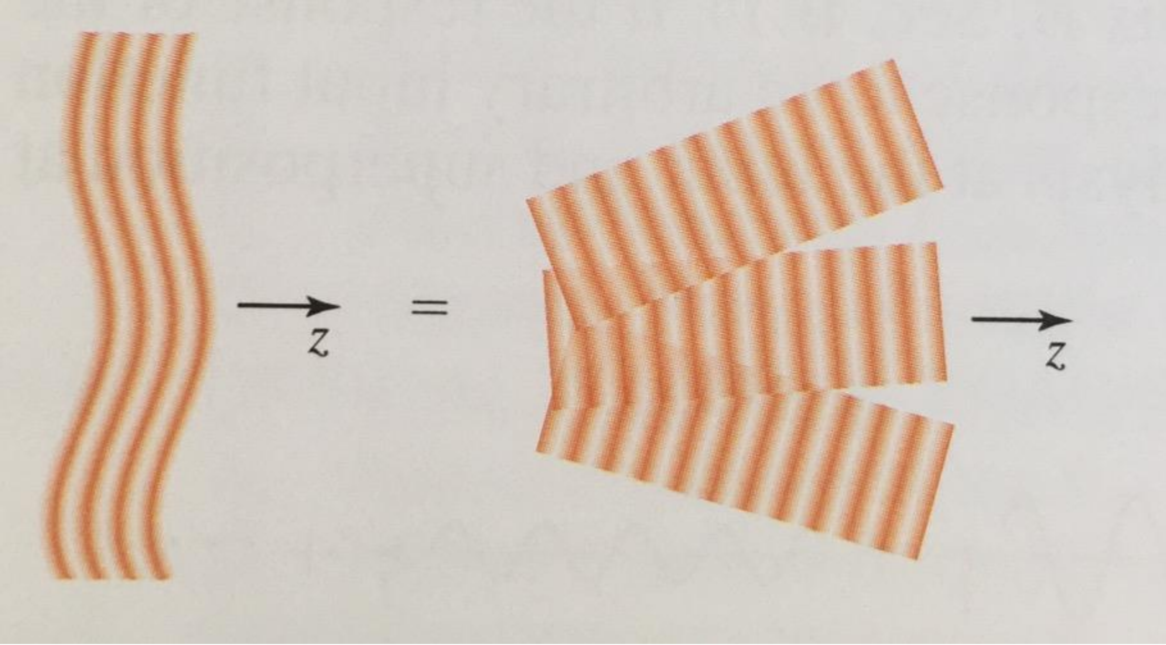


Expansion 2D





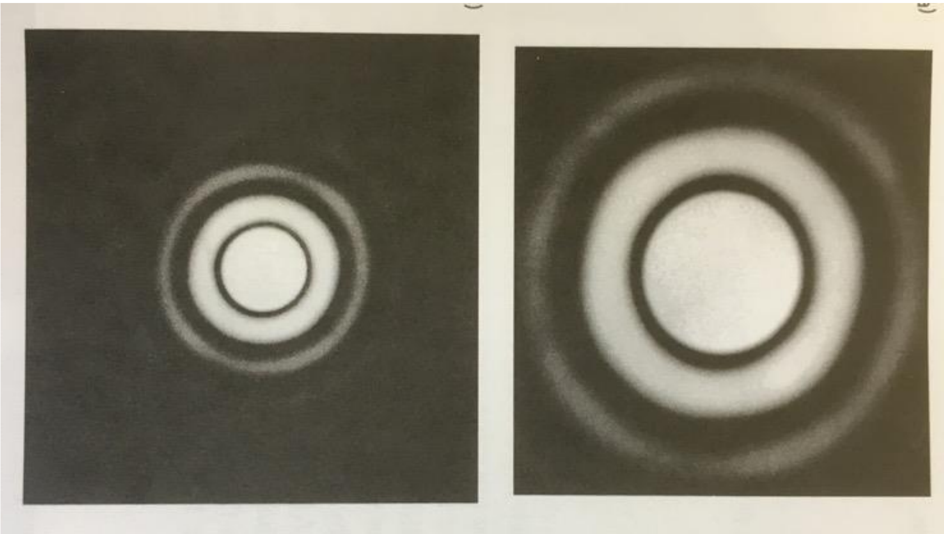
Principle of Fourier Optics: Any wavefront can be analyzed as superposition of plane waves



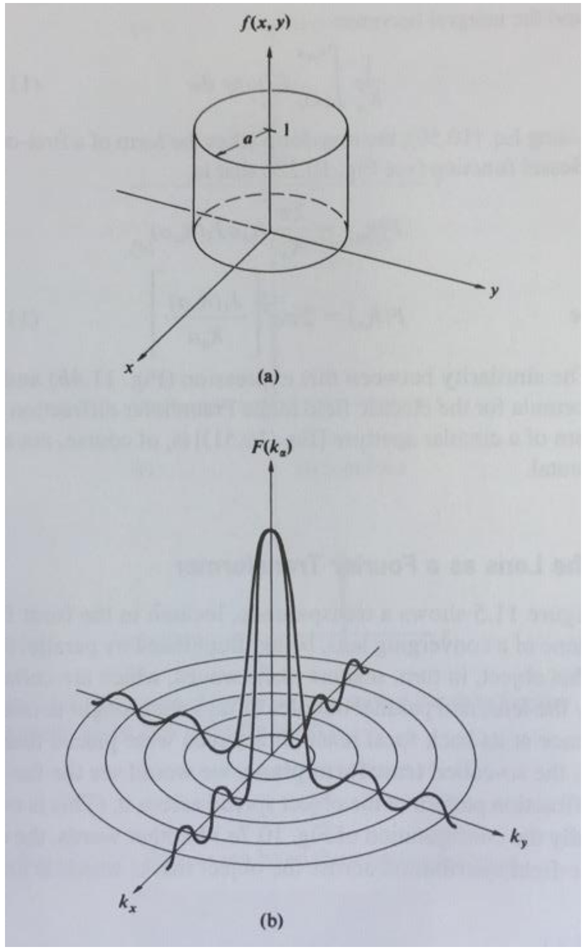
Implications

Fourier transform of round aperture and airy pattern

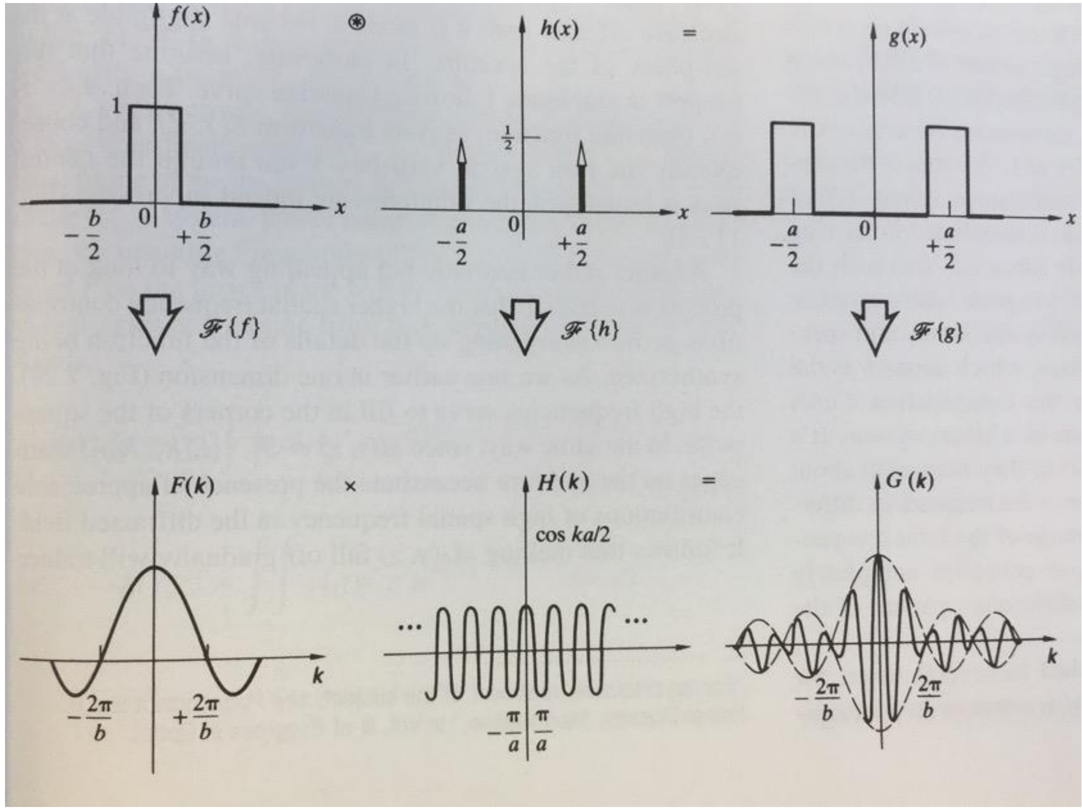
Experiment: Diffraction pattern of circular aperture, Airy pattern



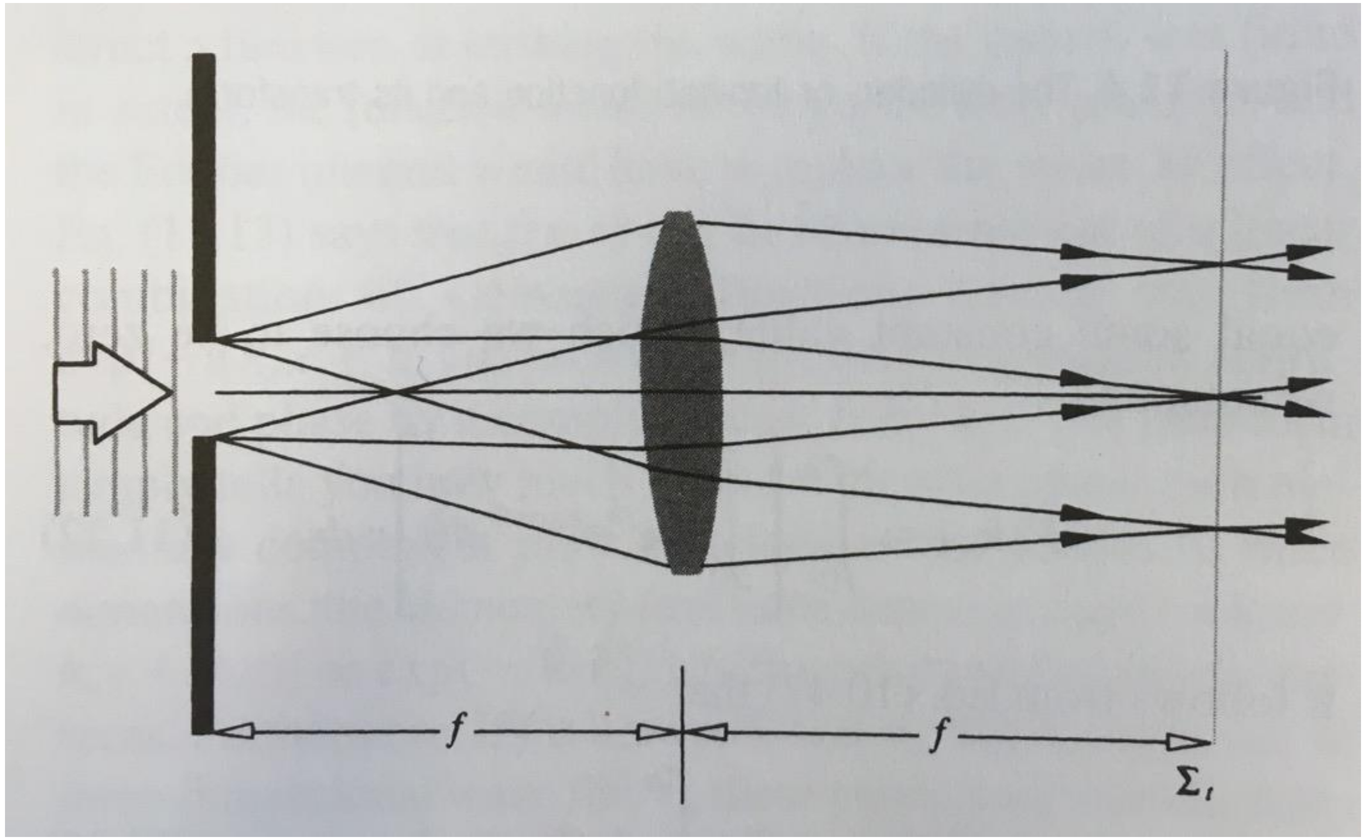
Theory: Fourier transform of cylinder or “top-hat” function



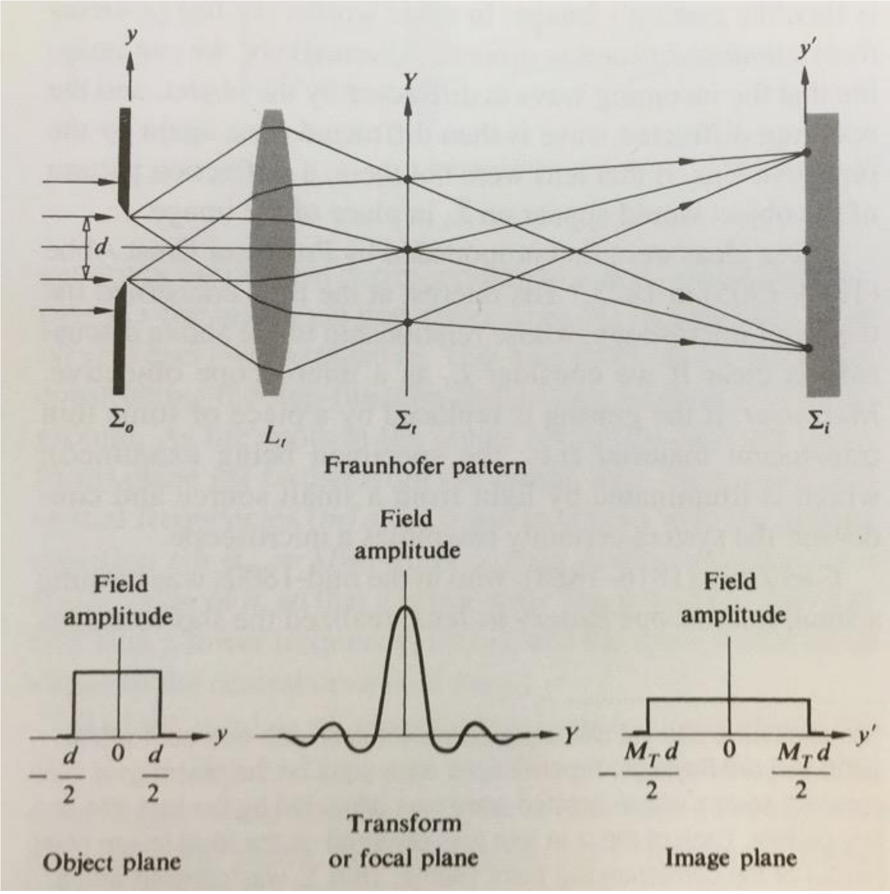
Diffraction as Fourier transform:



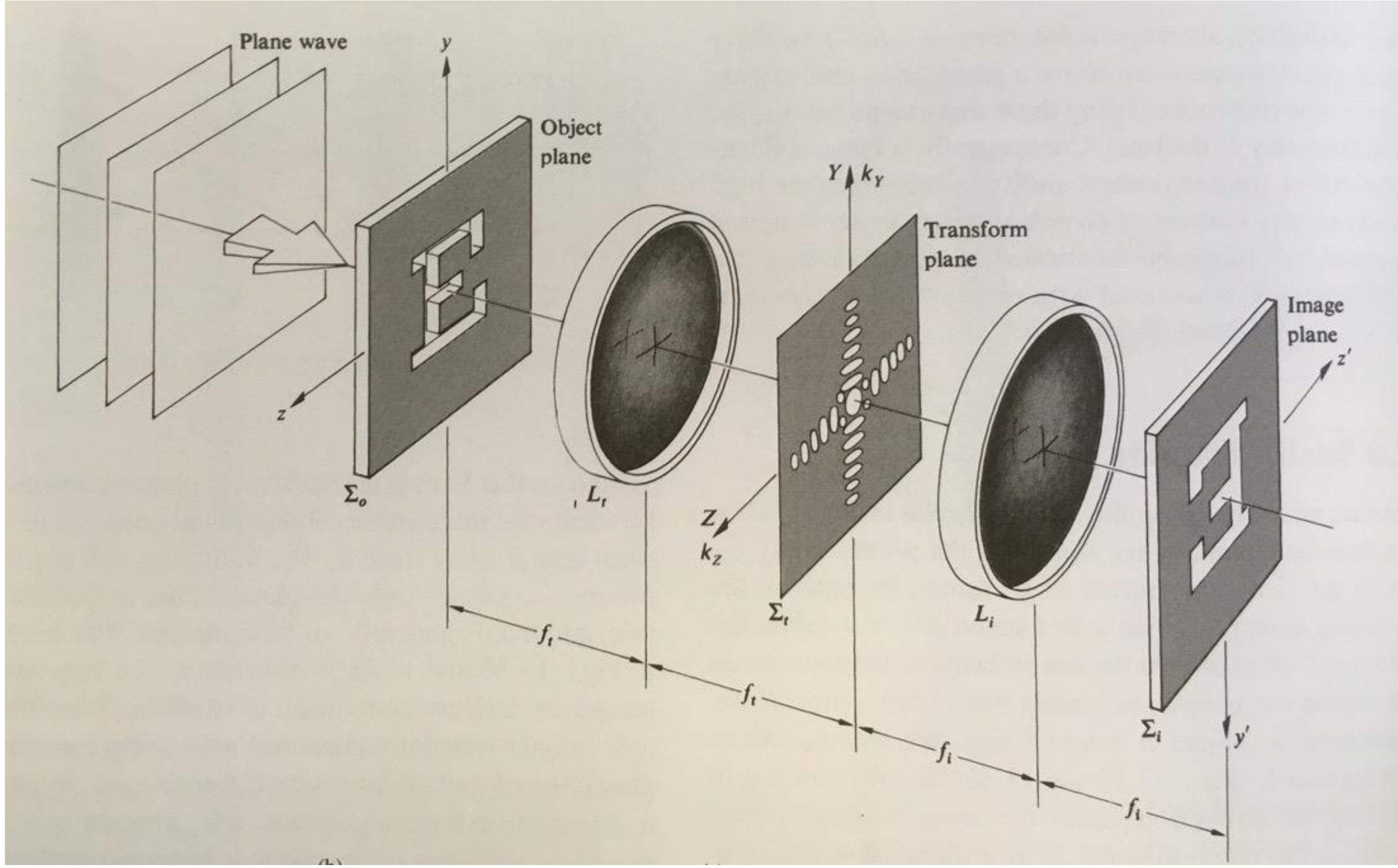
Lens as Fourier transformer



Abe image formation



4f imaging setup



Phase contrast microscopy

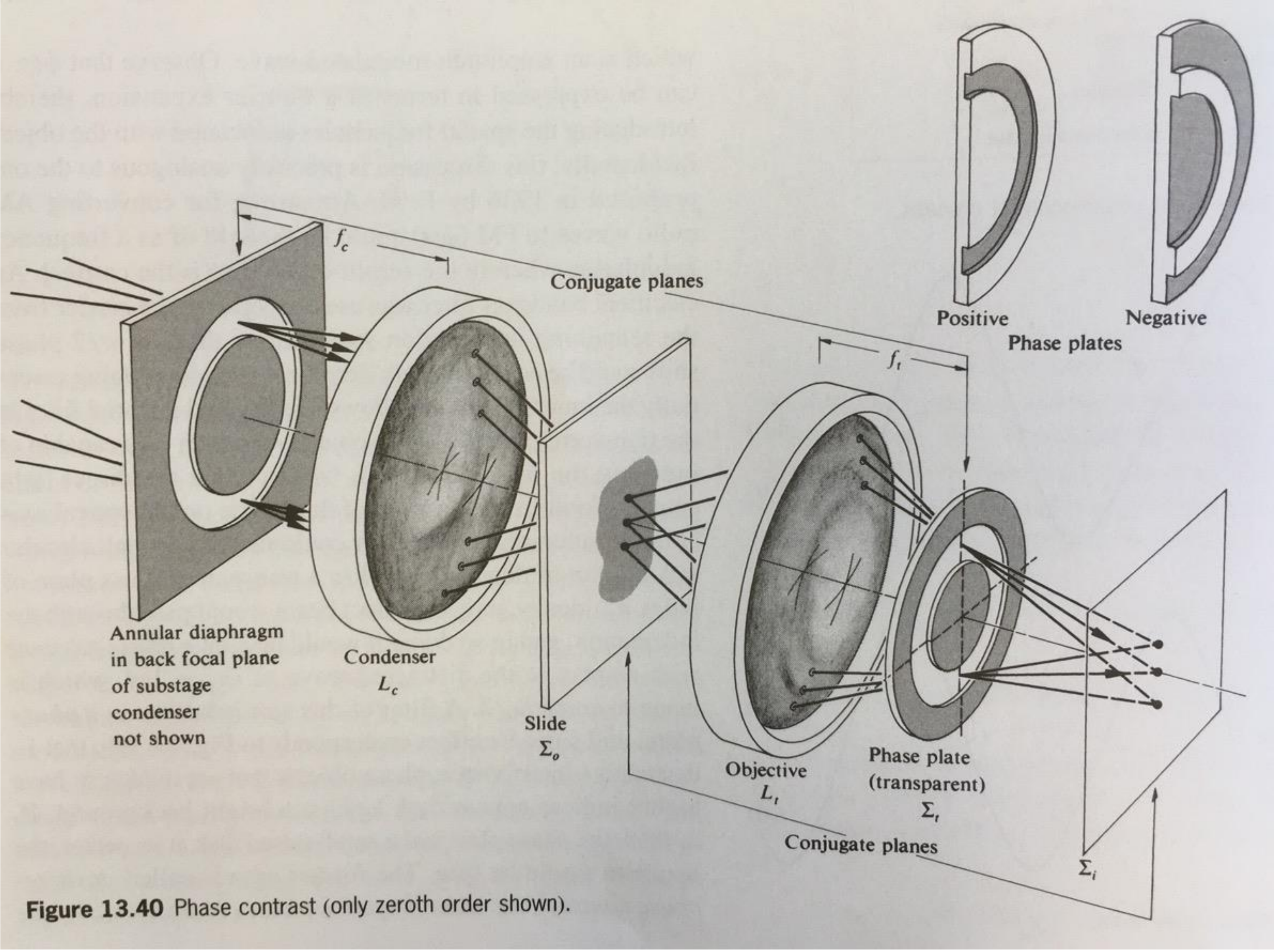


Figure 13.40 Phase contrast (only zeroth order shown).

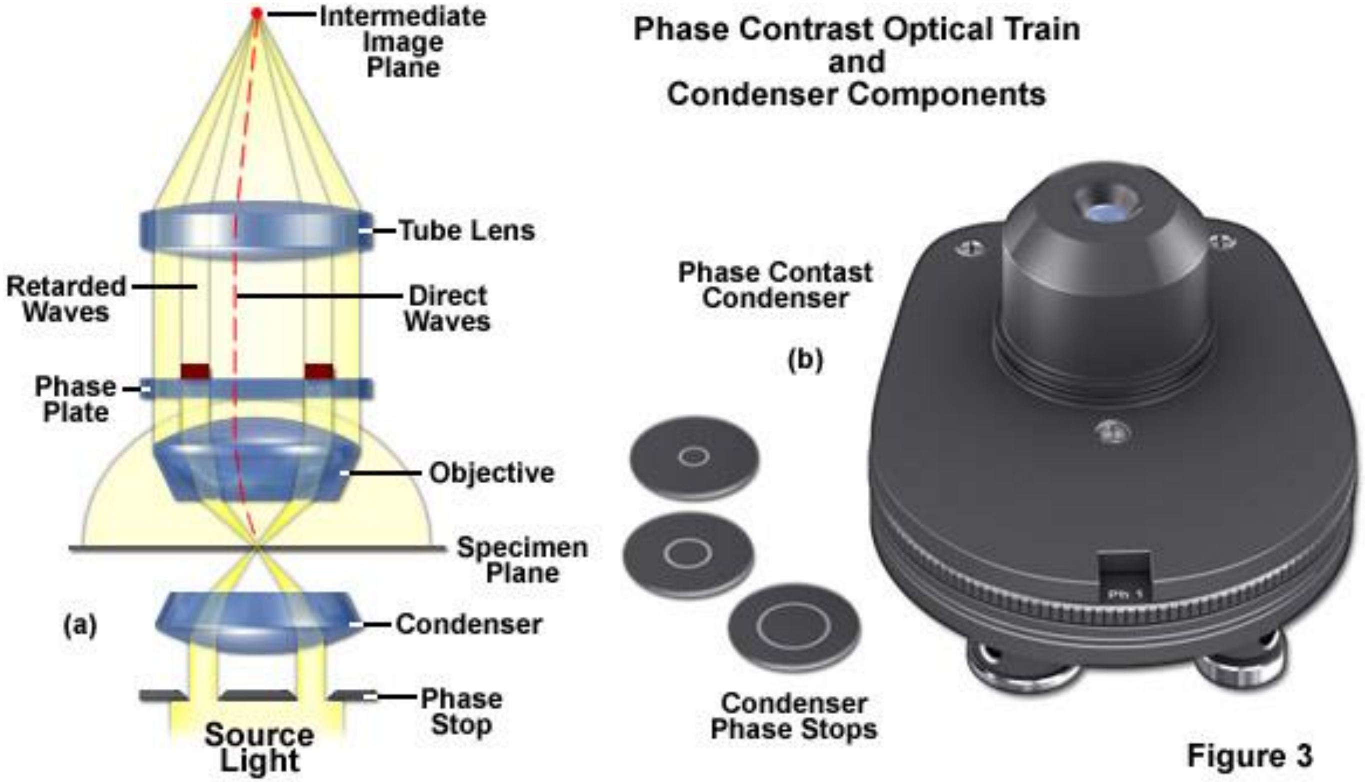
The Nobel Prize in Physics 1953

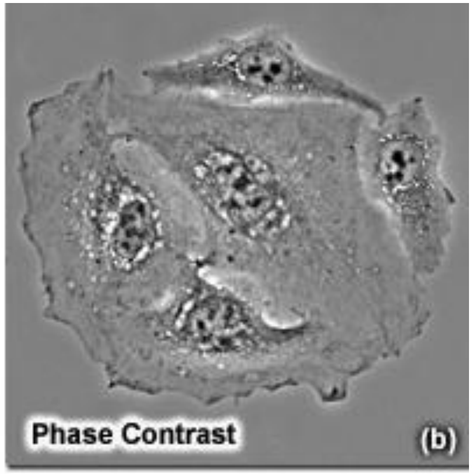
Photo from the Nobel Foundation archive.

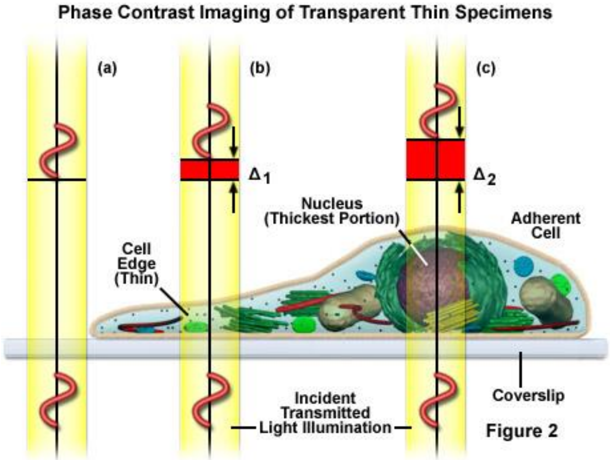
Frits Zernike

Prize share: 1/1

Phase contrast microscopy

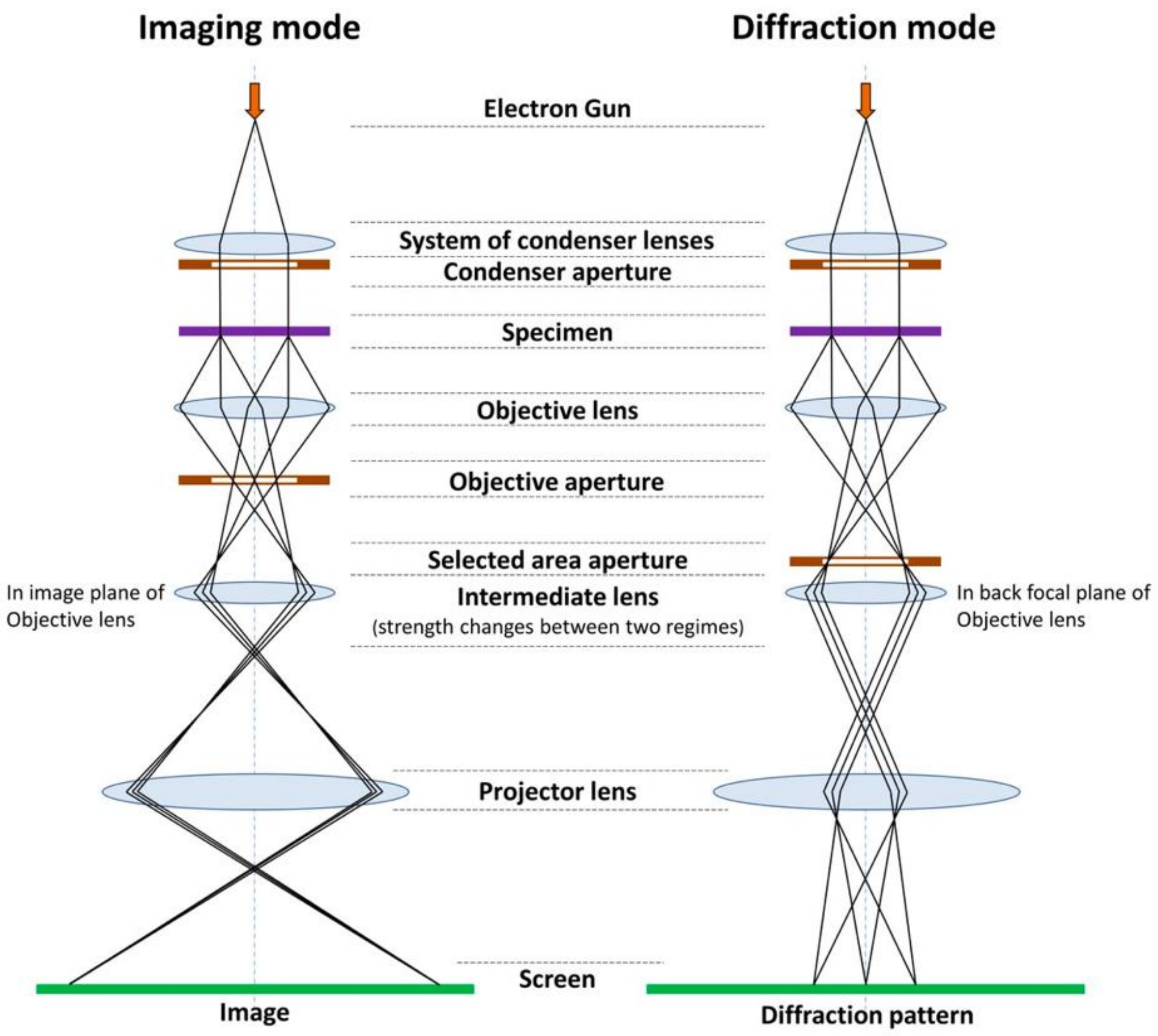




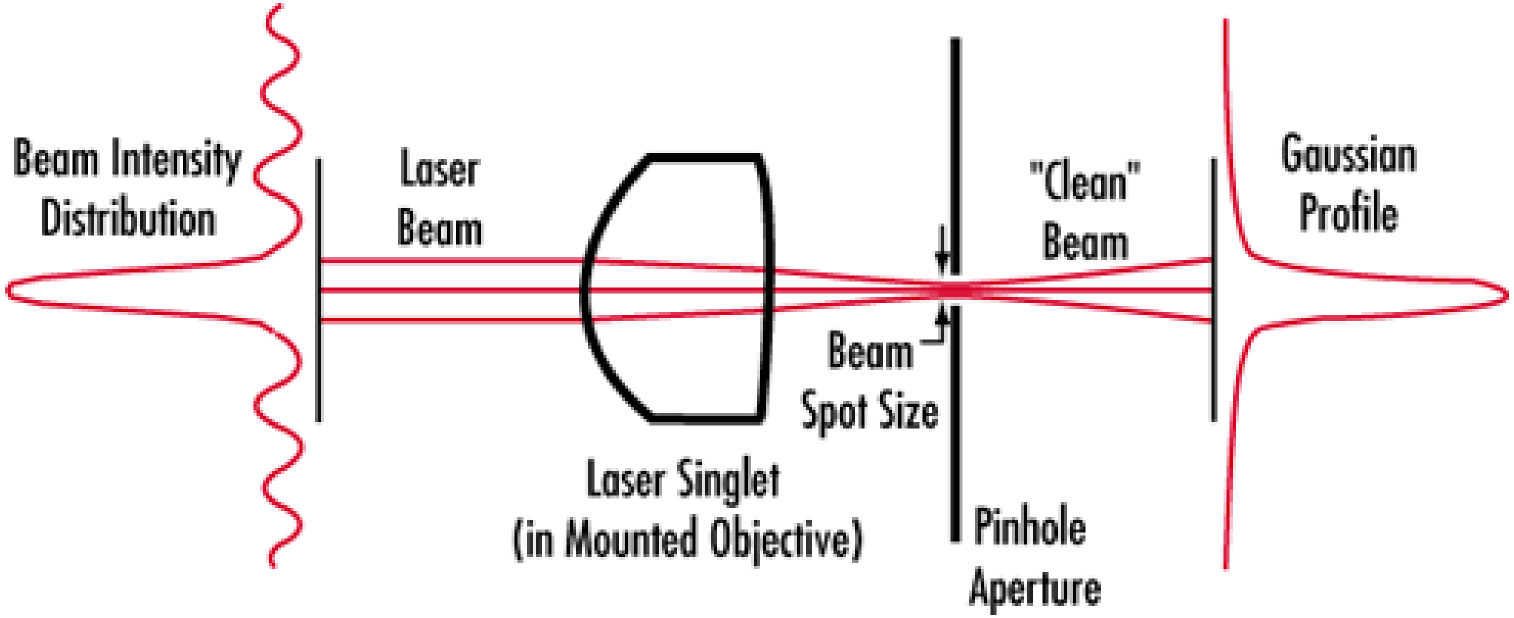


Source: Zeiss Campus

Note: Electron microscopy



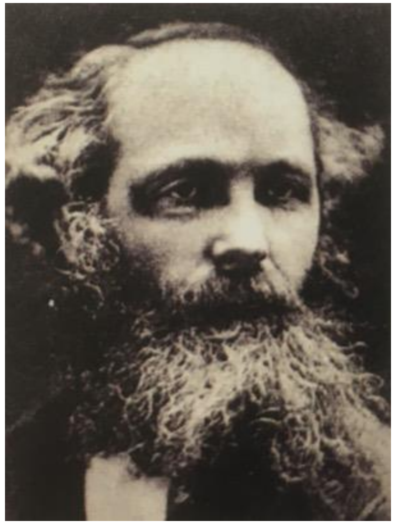
Note on optical tricks: How to make a Gaussian beam or “Spatial Filtering”



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

Light as electromagnetic waves

Welcome to EM description of light!



James Maxwell
1831 - 1879

$$\nabla \times \mathcal{H} = \epsilon_o \frac{\partial \mathcal{E}}{\partial t}$$

$$\nabla \times \mathcal{E} = -\mu_o \frac{\partial \mathcal{H}}{\partial t}$$

$$\nabla \cdot \mathcal{E} = 0$$

$$\nabla \cdot \mathcal{H} = 0,$$

Familiar wave equation:

Maxwell equation in medium

$$\nabla \times \mathcal{H} = \frac{\partial \mathcal{D}}{\partial t}$$

$$\nabla \times \mathcal{E} = -\frac{\partial \mathcal{B}}{\partial t}$$

$$\nabla \cdot \mathcal{D} = 0$$

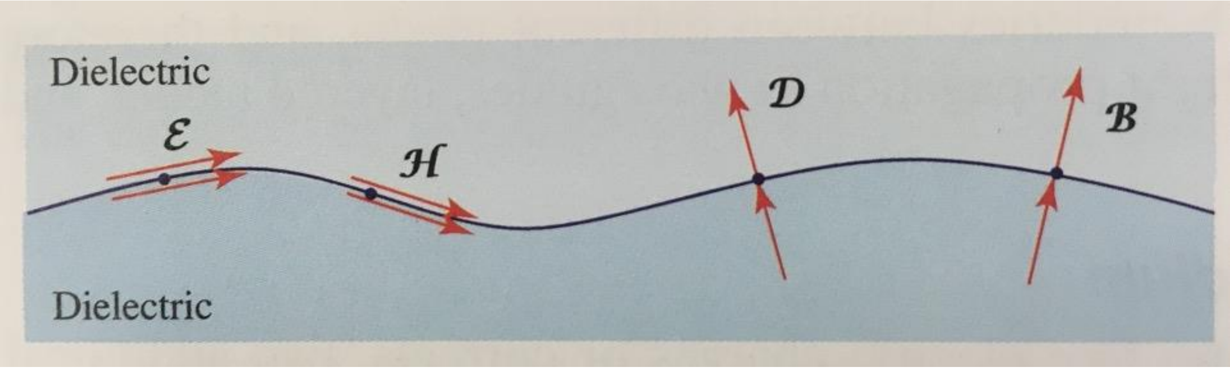
$$\nabla \cdot \mathcal{B} = 0.$$

$$\mathcal{D} = \epsilon_o \mathcal{E} + \mathcal{P}$$

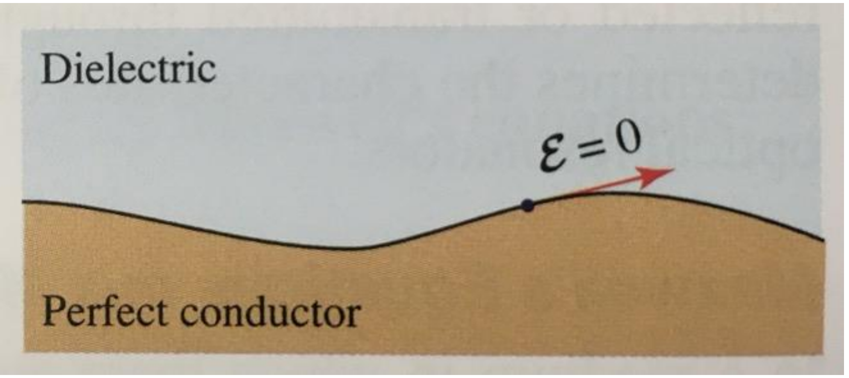
$$\mathcal{B} = \mu_o \mathcal{H} + \mu_o \mathcal{M}.$$

Boundary conditions at interfaces

Two dielectric media

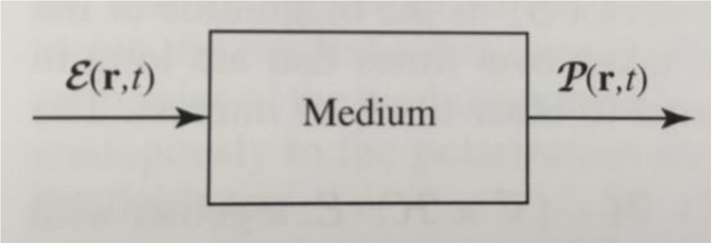


Dielectric and conducting media



Electromagnetic waves in dielectric media

General



But stick with linear, nondispersive, homogenous, and isotropic media right now:

$$\mathcal{P} = \epsilon_o \chi \mathcal{E},$$

This leads to the following Maxwell and wave equations wave equations

$$\nabla \times \mathcal{H} = \epsilon \frac{\partial \mathcal{E}}{\partial t}$$

$$\nabla \times \mathcal{E} = -\mu \frac{\partial \mathcal{H}}{\partial t}$$

$$\nabla \cdot \mathcal{E} = 0$$

$$\nabla \cdot \mathcal{H} = 0.$$

Complex refractive index

General:

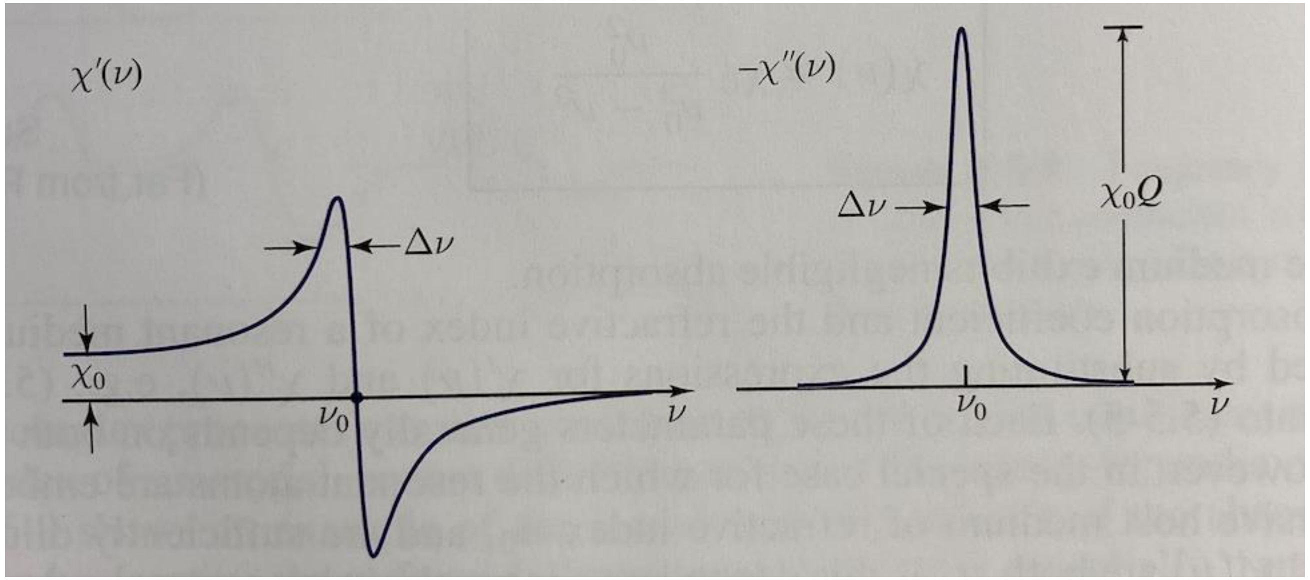
$$n - j\frac{1}{2}\frac{\alpha}{k_o} = \sqrt{\epsilon/\epsilon_o} = \sqrt{1 + \chi' + j\chi''}.$$

Weakly absorbing media:

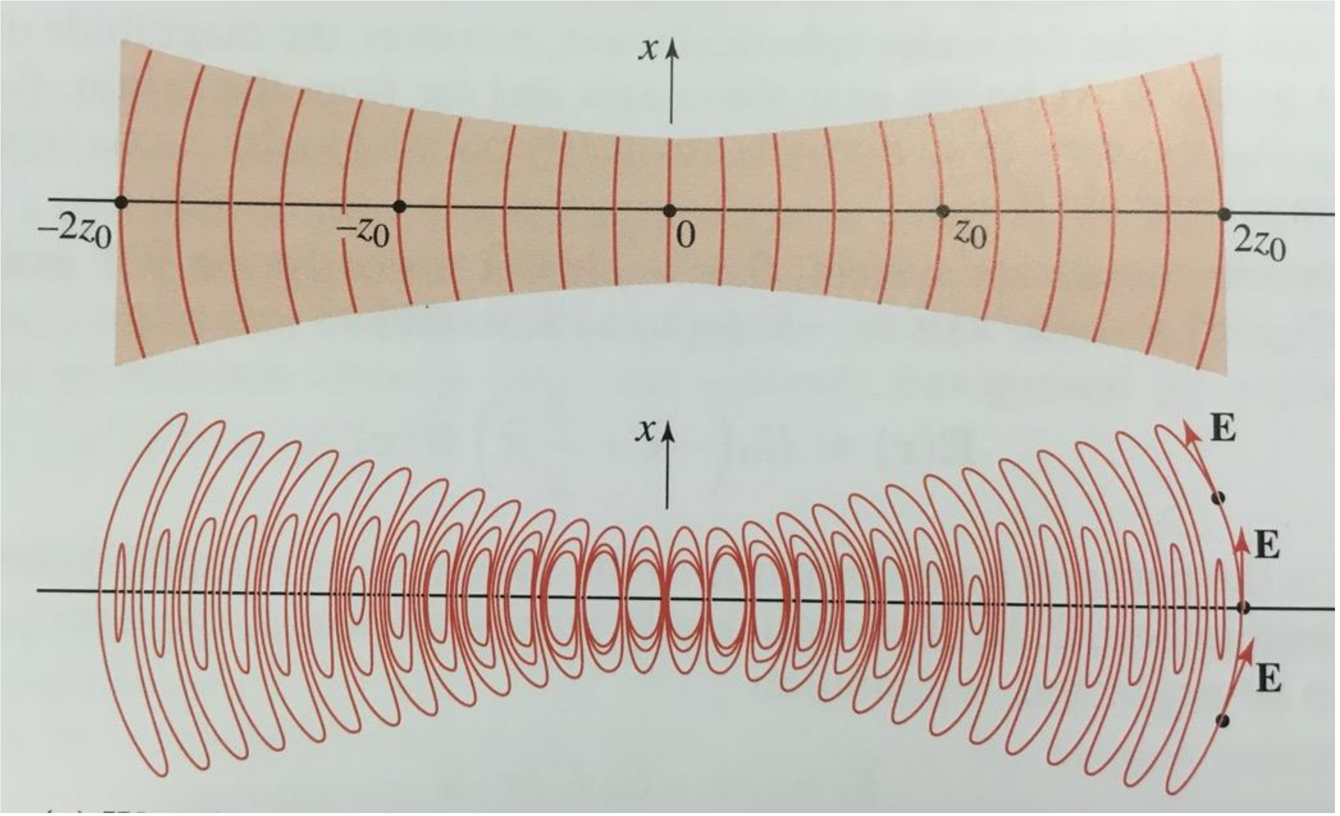
$$n \approx \sqrt{1 + \chi'}$$

$$\alpha \approx -\frac{k_o}{n}\chi''.$$

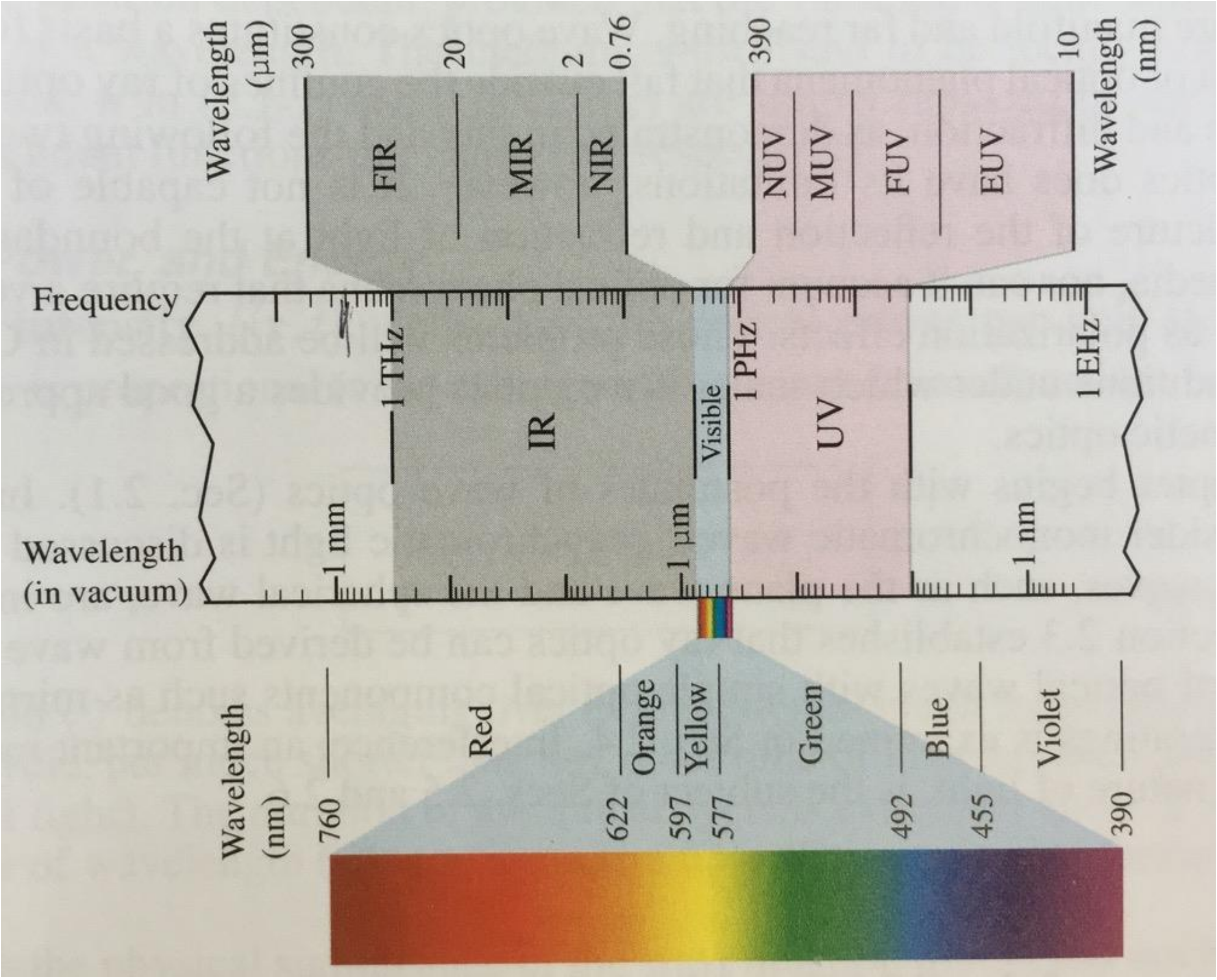
Resonances and refractive index



A note on wavefronts



Characteristic fingerprints of a molecule: rotational, virbrational, electronic transitions



Spectroscopy – different approaches

The “classic approach” to spectroscopy

Version 1

Version 2

Grating spectrometer

Common use in (far) infrared spectroscopy not restricted to this regime
Note strong absorption of water, work in “dry conditions”
Excitation source can be mercury discharge lamp

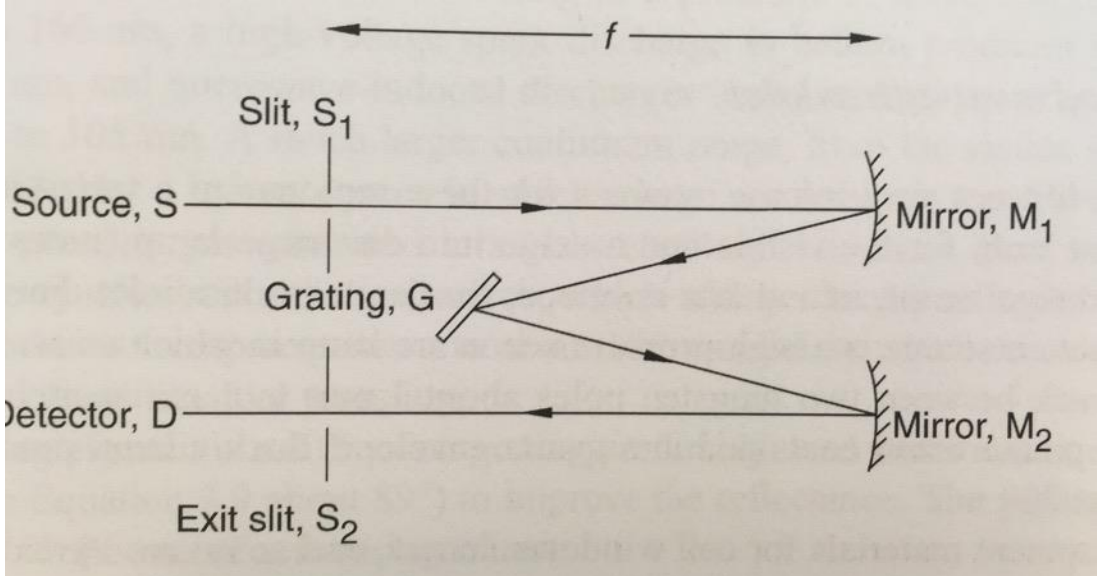


Figure 3.17 The Czerny–Turner grating mounting

Spectrophotometer

Depending on excitation source from IR to visible to near-uv

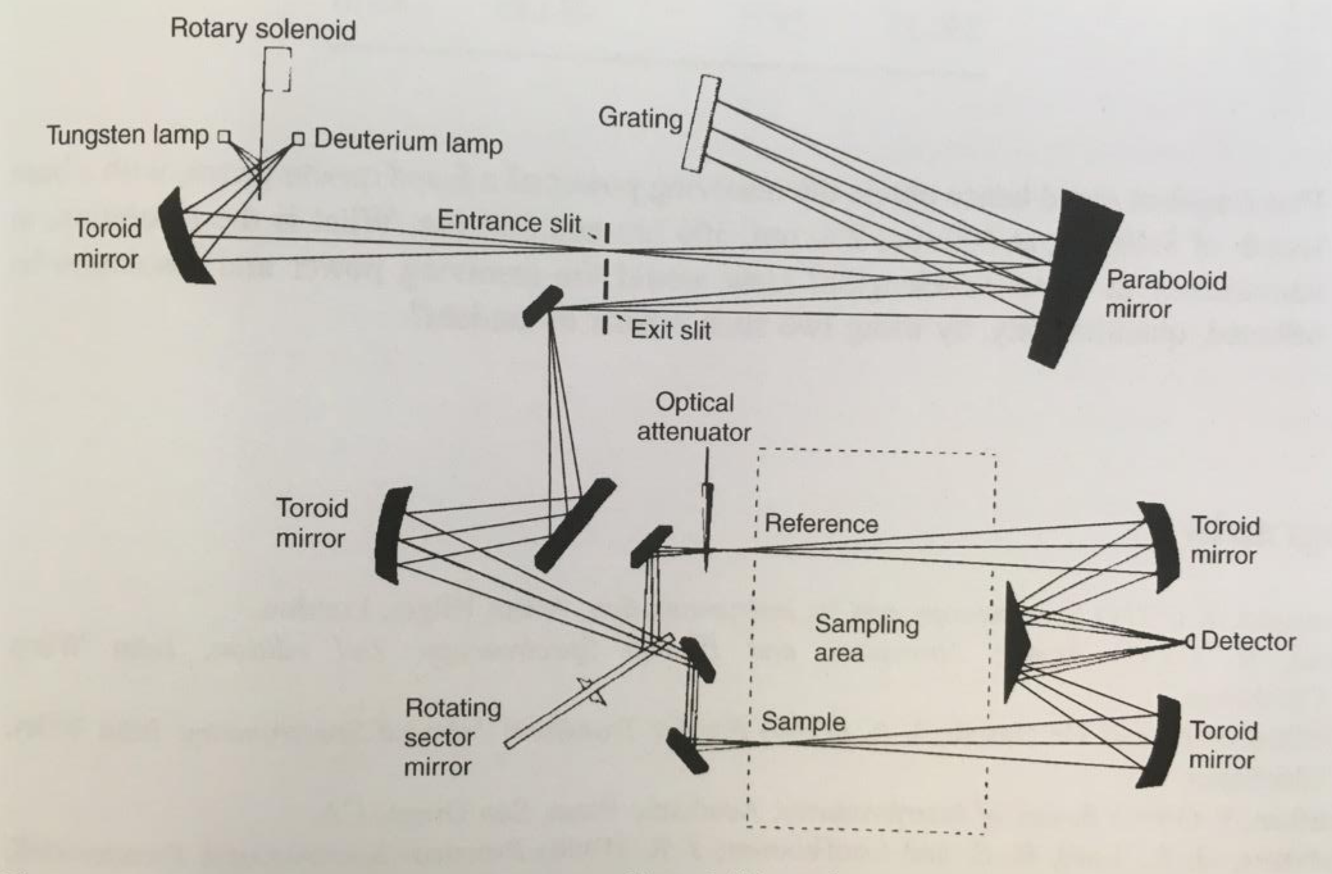


Figure 3.24 A typical double-beam recording visible and near-ultraviolet spectrophotometer

Basics of Michelson interferometer (mono)

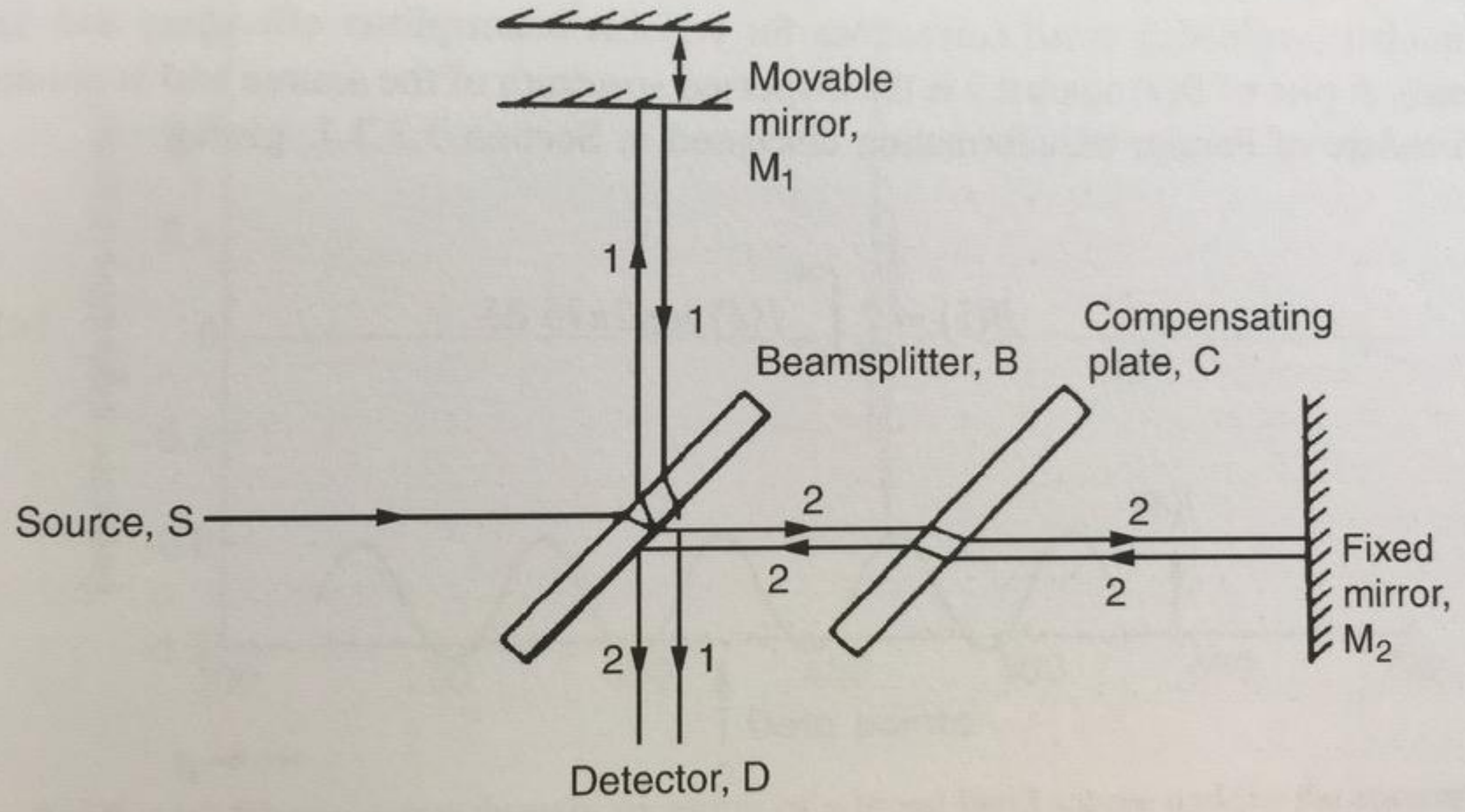
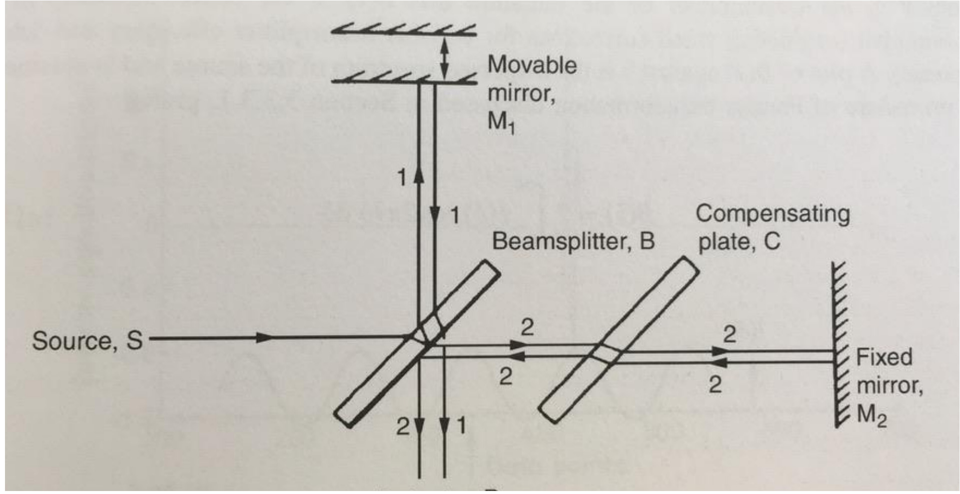


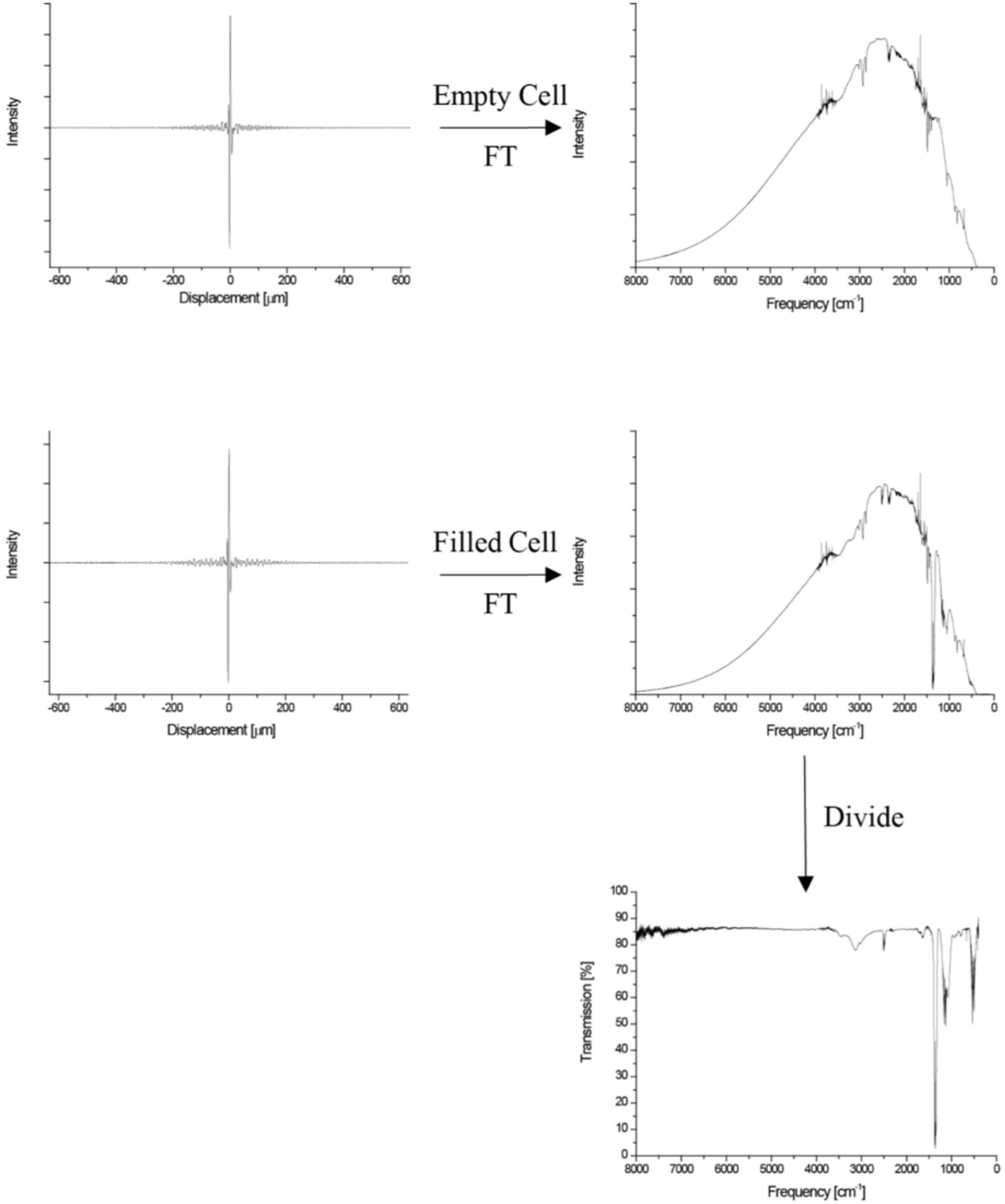
Figure 3.11 Michelson interferometer

Measuring an interferogram

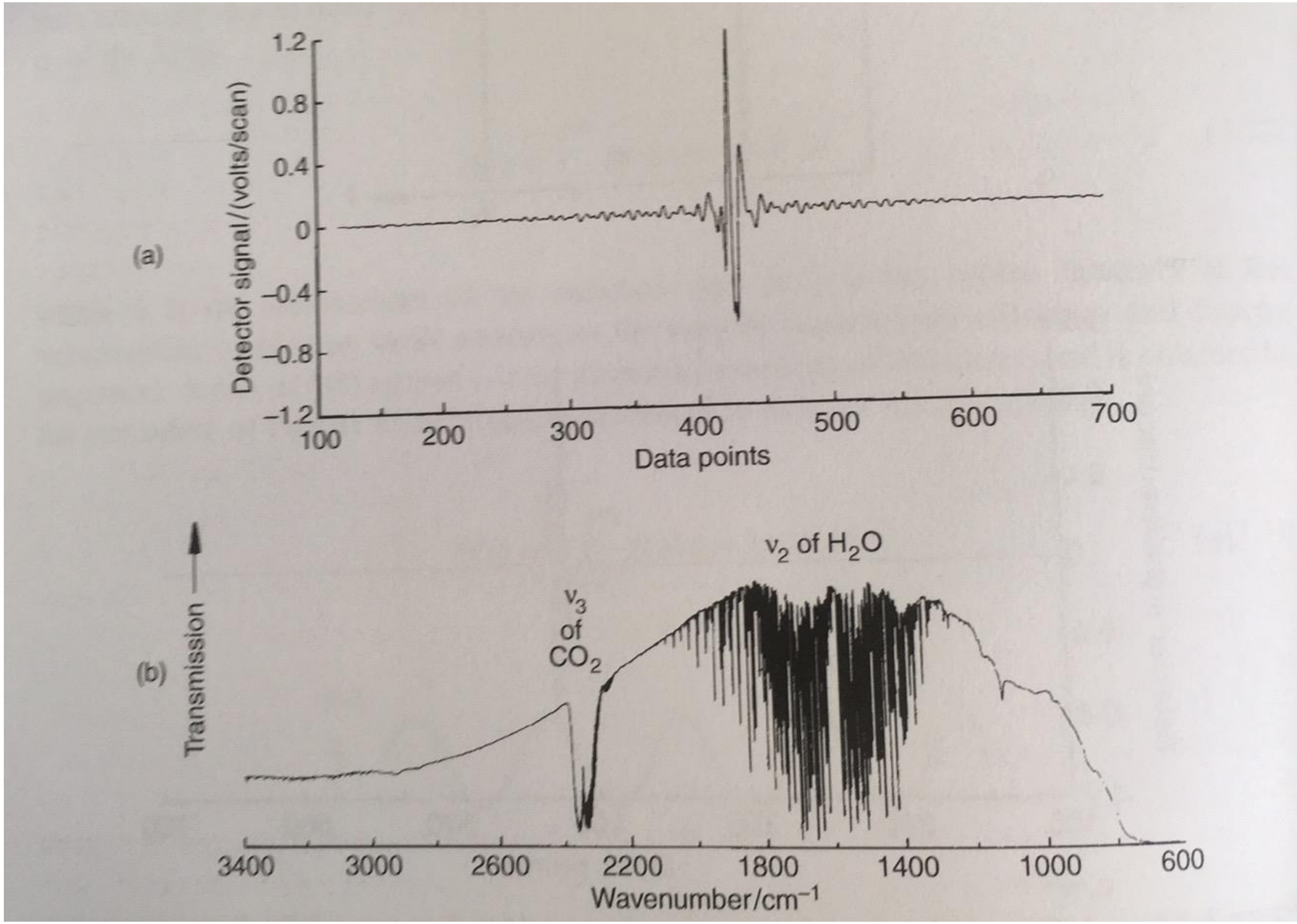


Sample

Detector



Example: Interferogram and spectrum of air



Fourier spectroscopy

- Advantages
  - Higher overall transmission through interferometer compared to spectrometer
  - Multiplexing through use of all frequencies
  - Faster acquisition times and better signal to noise ratio
  - Higher accuracy for measuring mirror travel

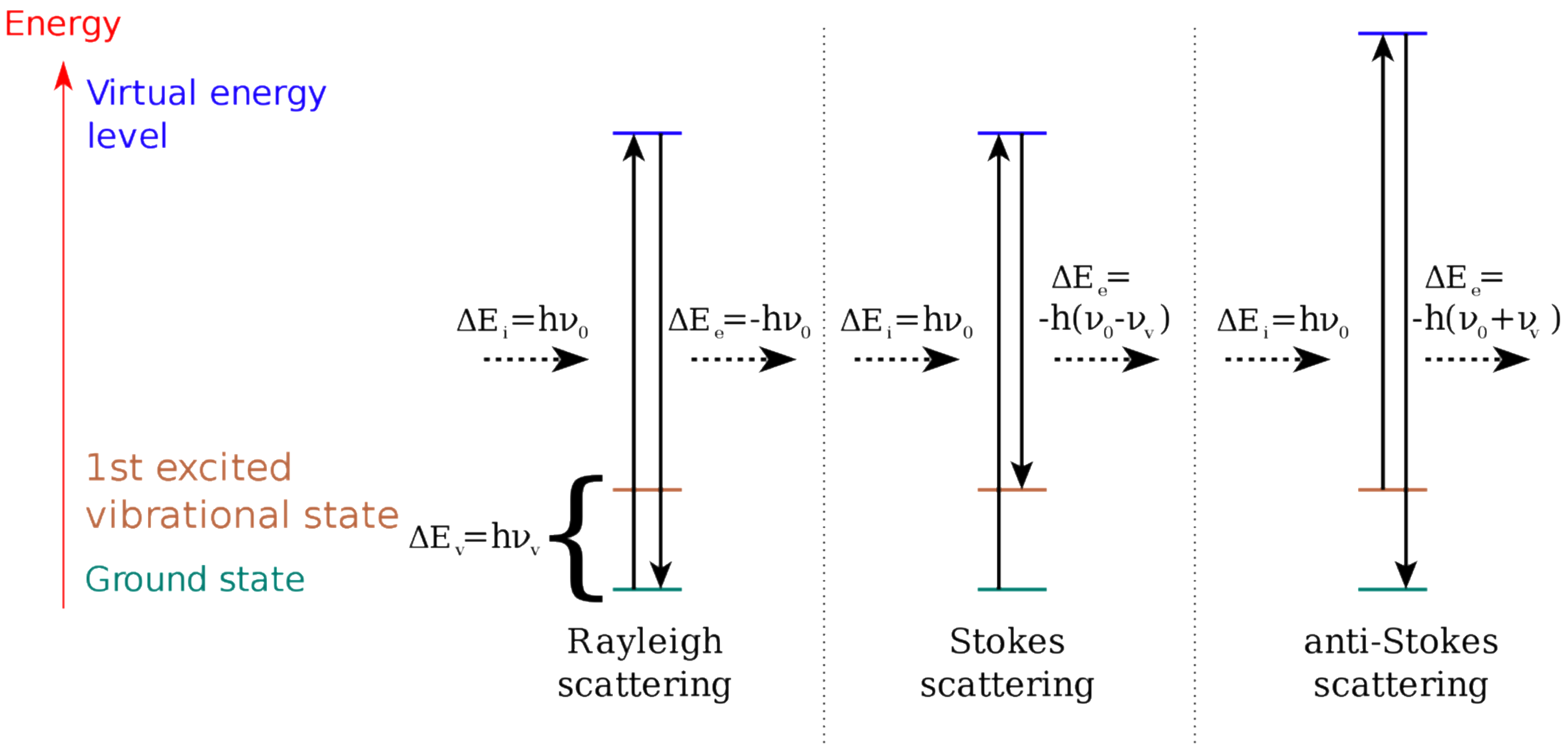
- Limitations
  - Tyipcally restricted to IR measurements
  - Accuracy determined by mirror travel distance

- Video by Brooker company for modern apparatus

https://www.facebook.com/bruker.corp/videos/o.712956095479376/10152856330318129/?type=2&theater

Raman spectroscopy (short introduction)

Raman process: Inelastic scattering of light

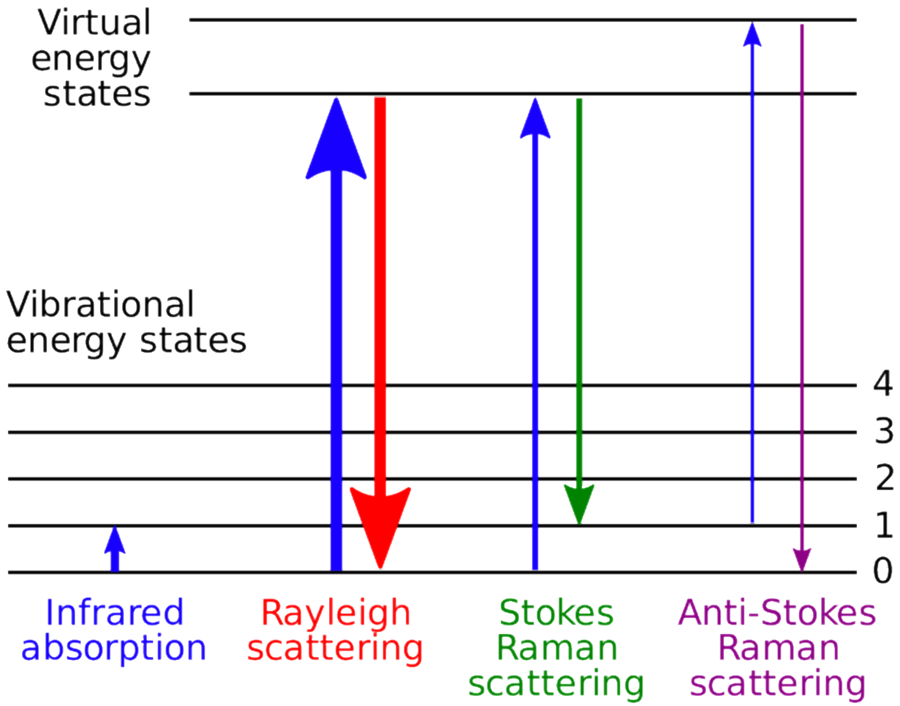


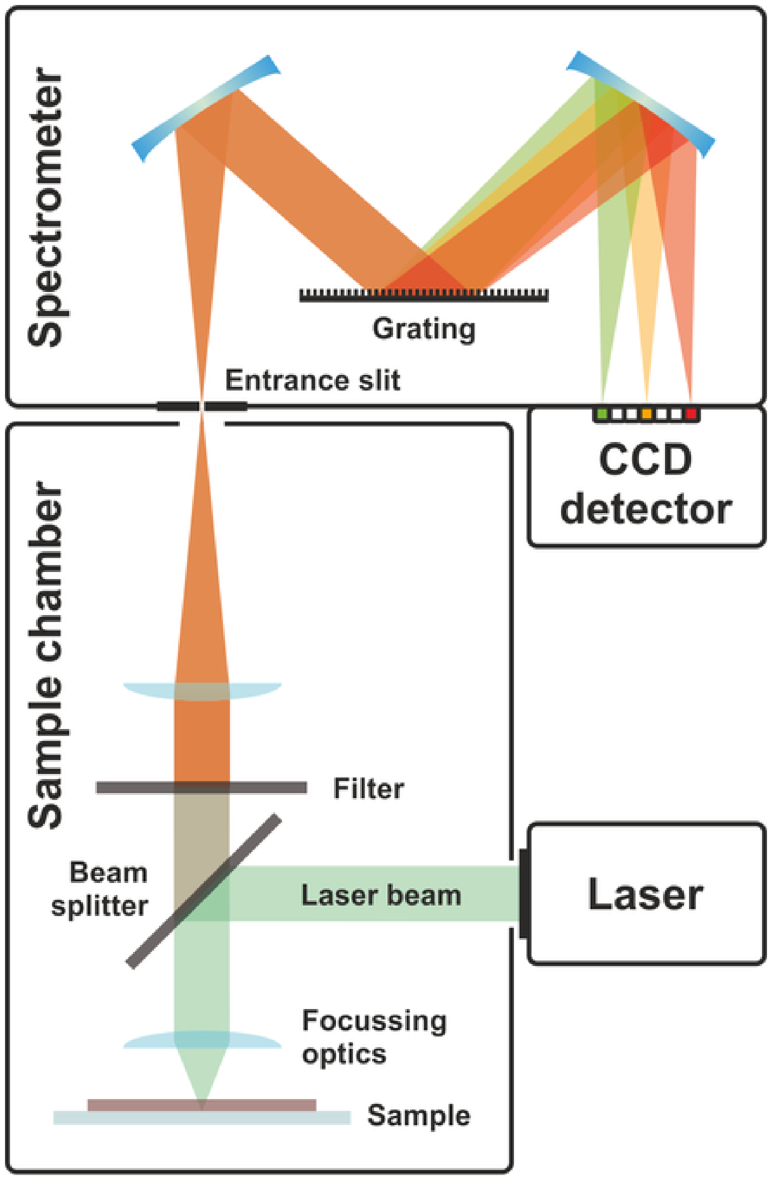
The Nobel Prize in Physics 1930

Photo from the Nobel Foundation archive.

Sir Chandrasekhara Venkata Raman

Raman spectroscopy

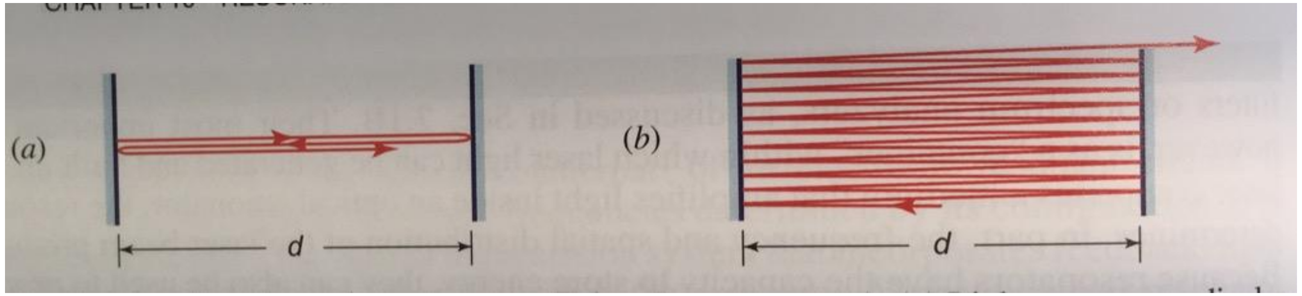




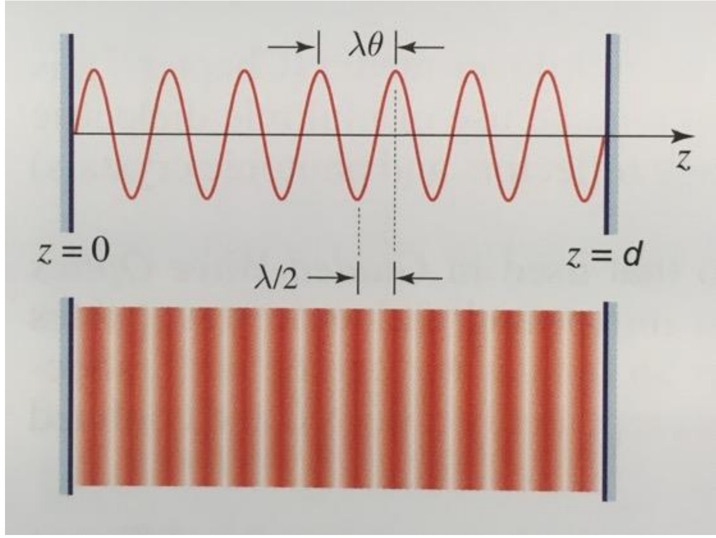
Optical resonators, cavities

Fabry-Perot Resonator

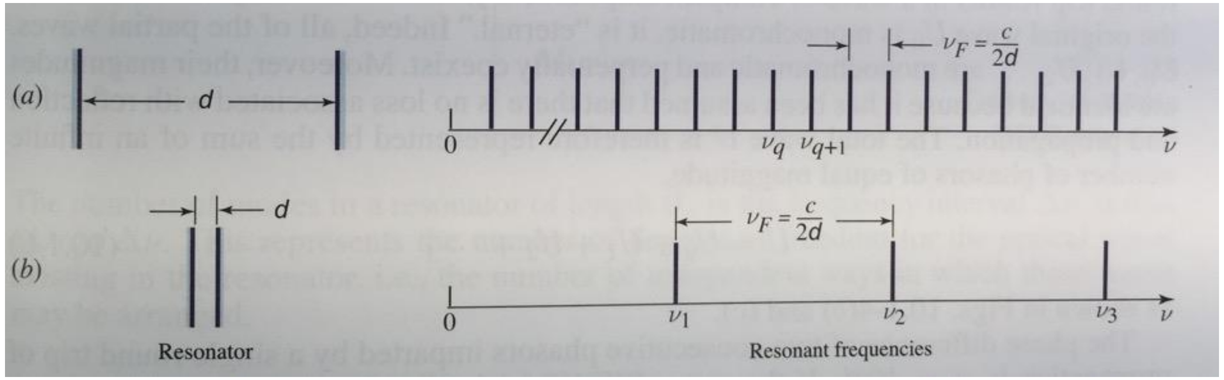
Idea: Trap light between highly reflective mirrors



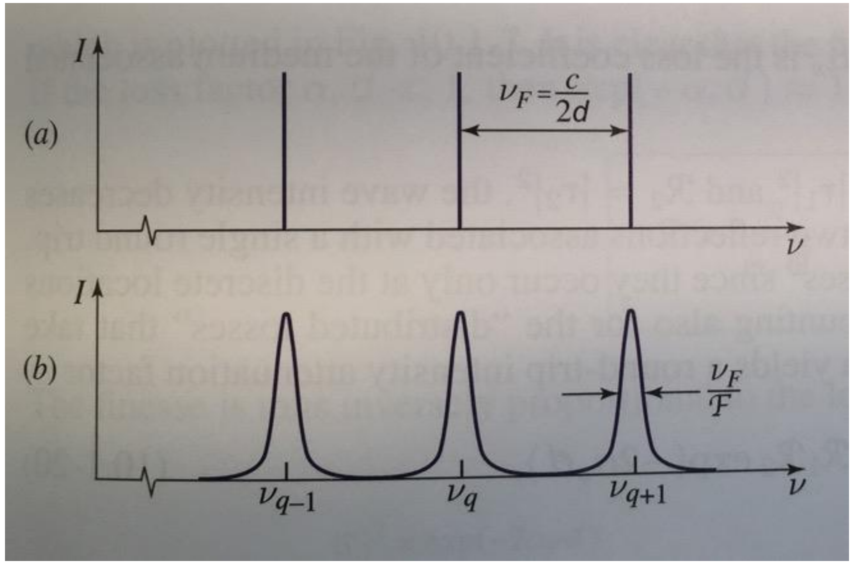
Standing waves represent resonator modes



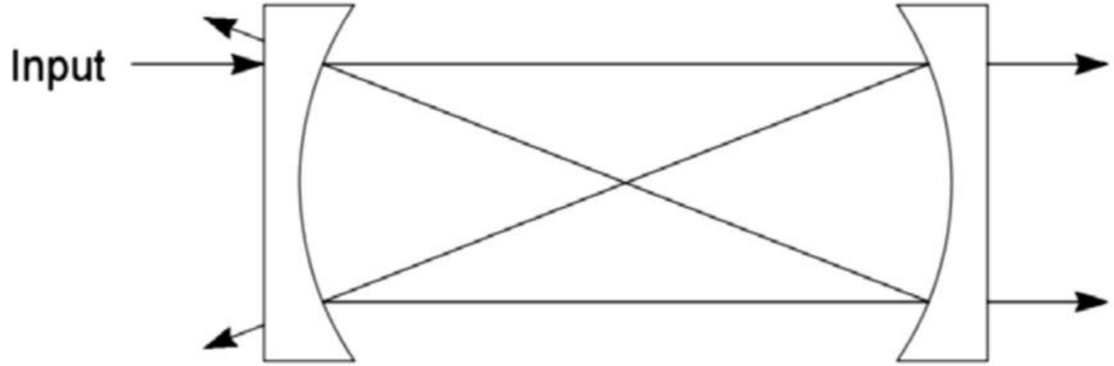
Properties of the Fabry Perot Resonator

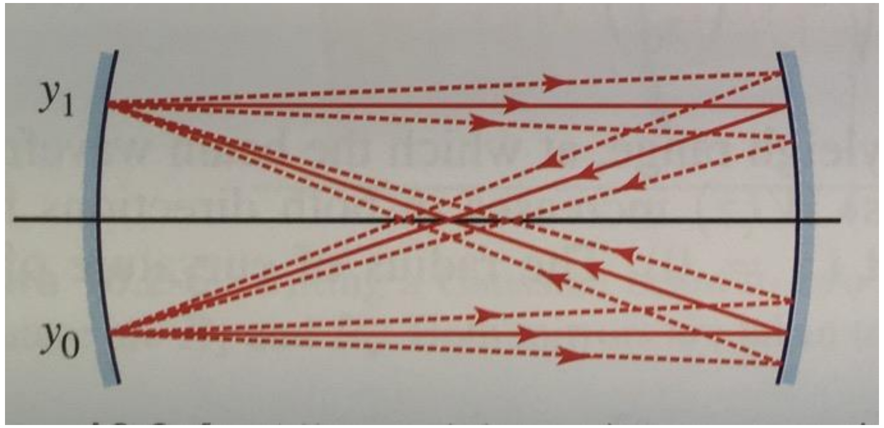


Ideal vs real resonator – real is with losses



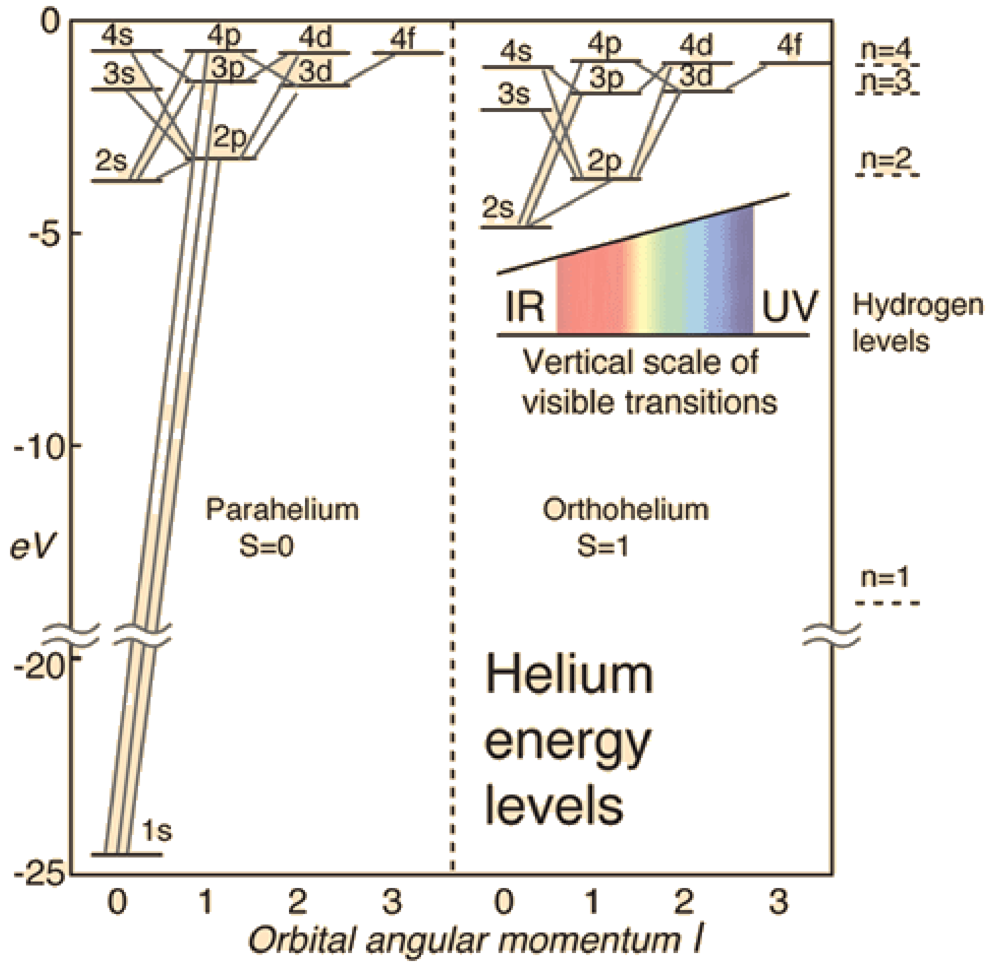
Spherical Resonator





Lasers

Absorption, energy level diagram



Absorption, emission, stimulated emission - overview

Spontaneous emission

Stimulated Emission

(Stimulated) absorption

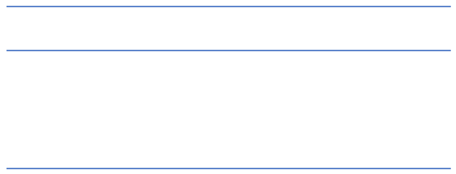
Fundamental concept of laser

Note: The gain must always be higher than the losses!

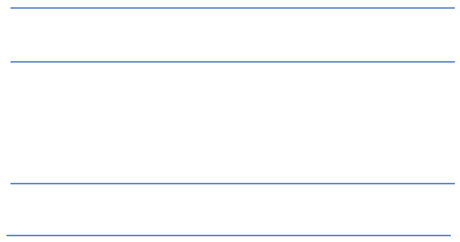
2, 3, 4 level systems

2 level system

3 level system



4 level system

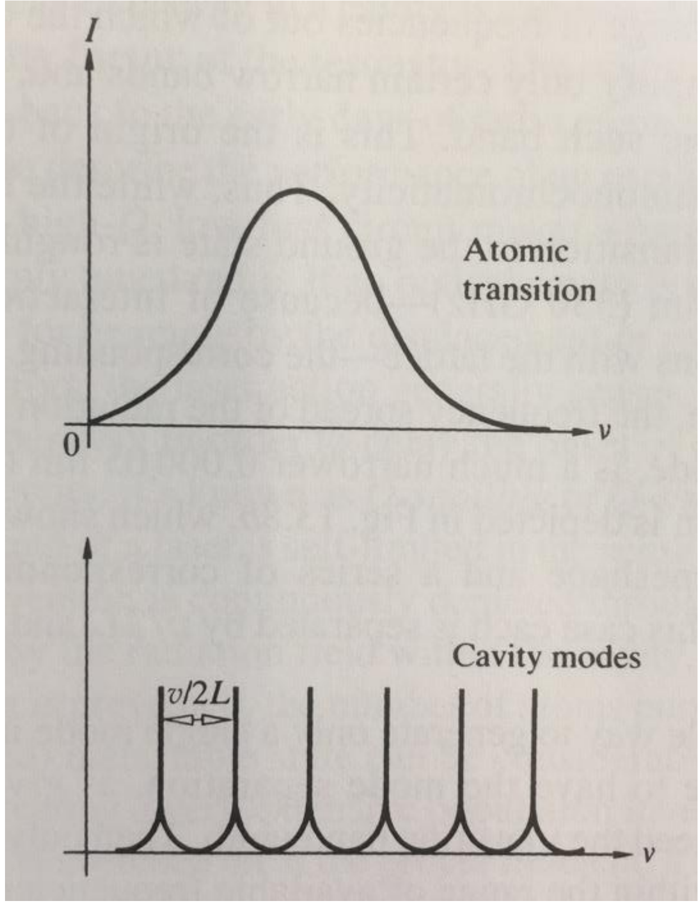


Fundamental concept of laser laser oscillator:

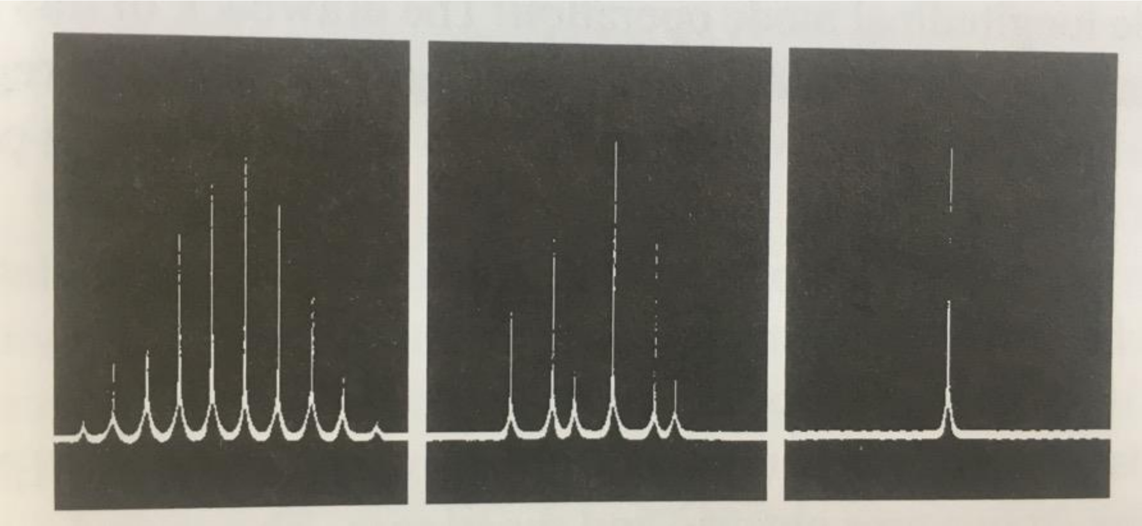
Note: The gain must always be higher than the losses!

Lasers and laser cavities

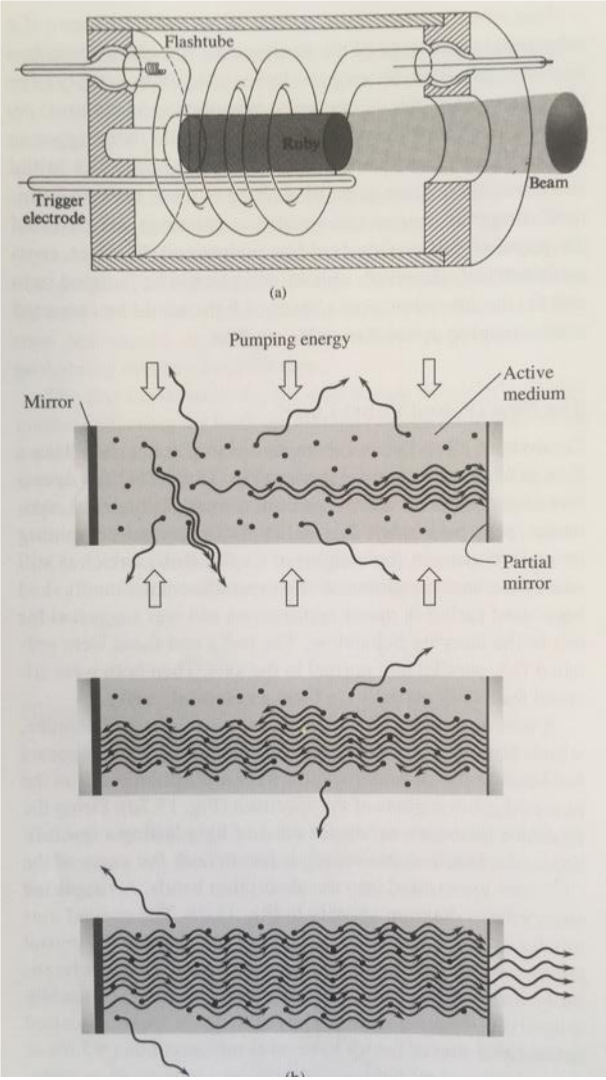
Atomic lines vs cavity modes

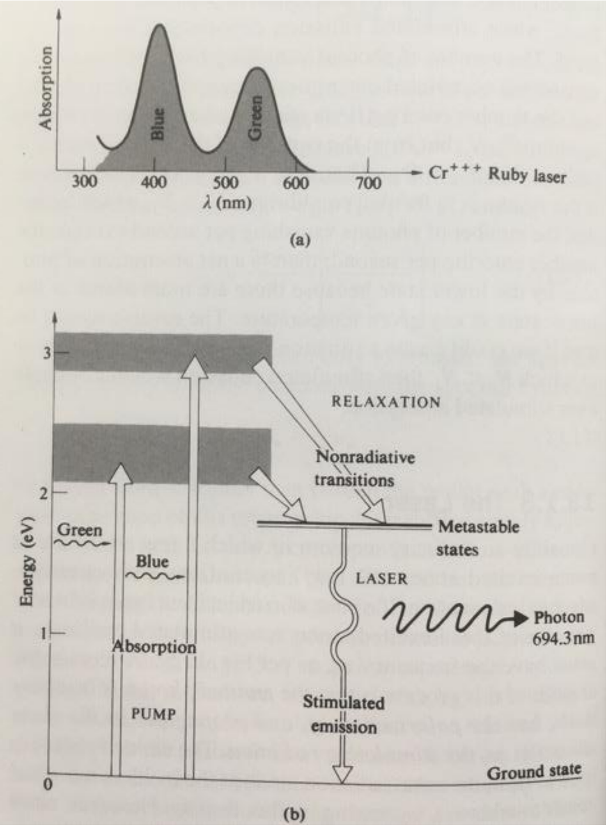


Mode selection



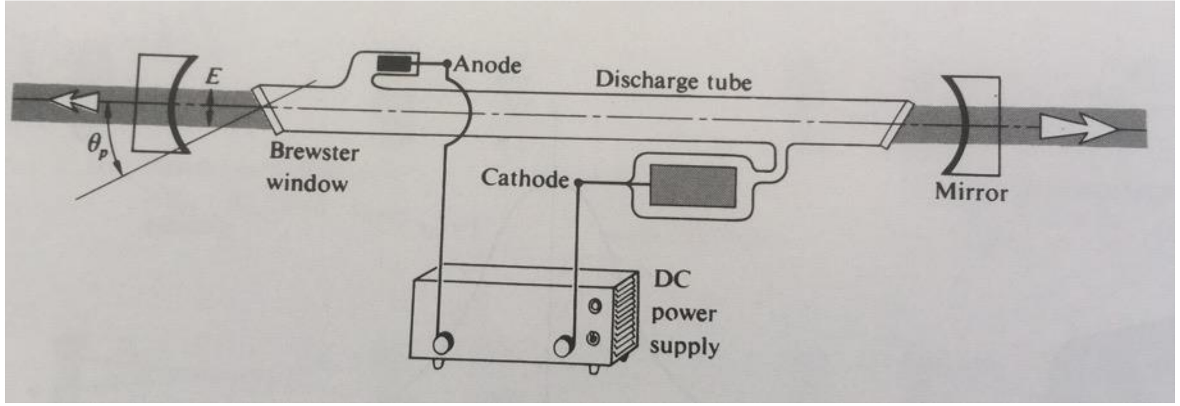
The Ruby laser

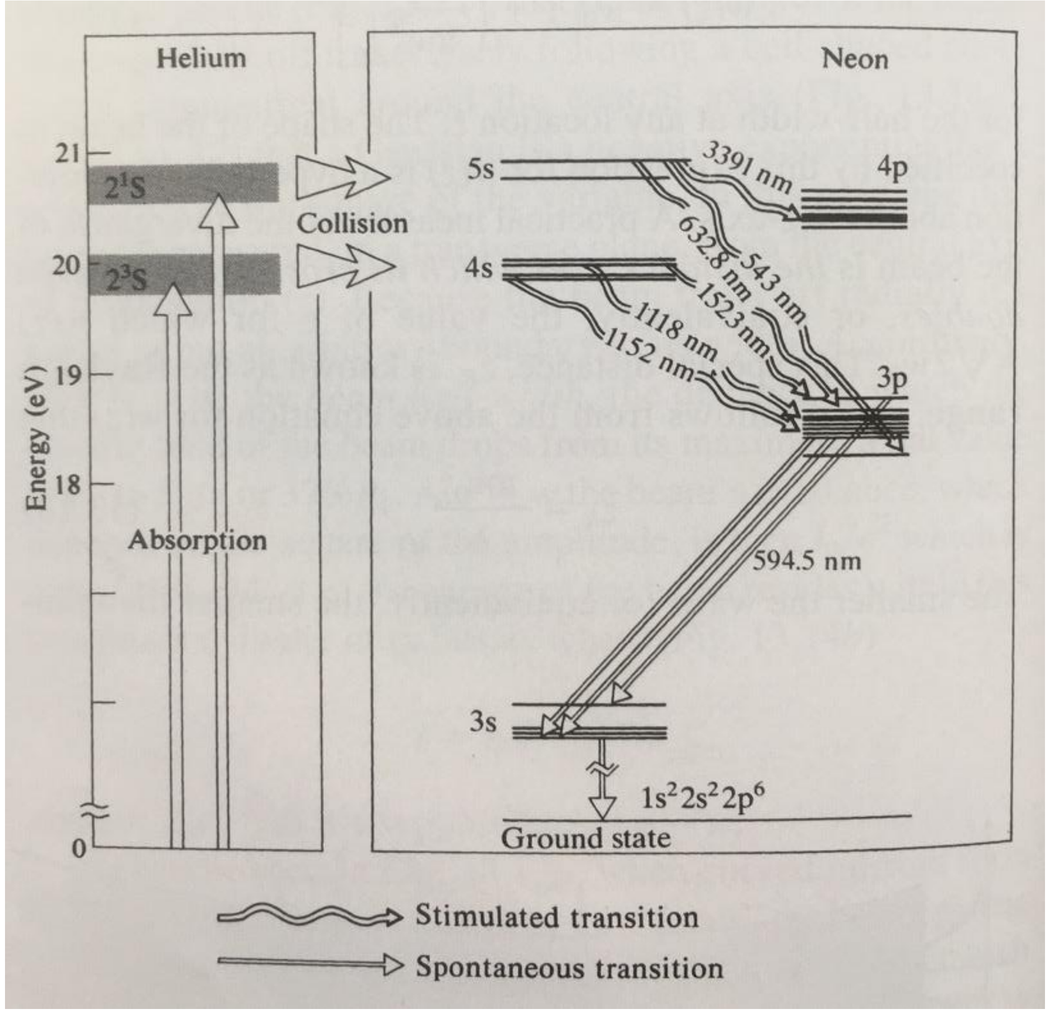




For fun https://www.youtube.com/watch?v=yV09p5LY7GA

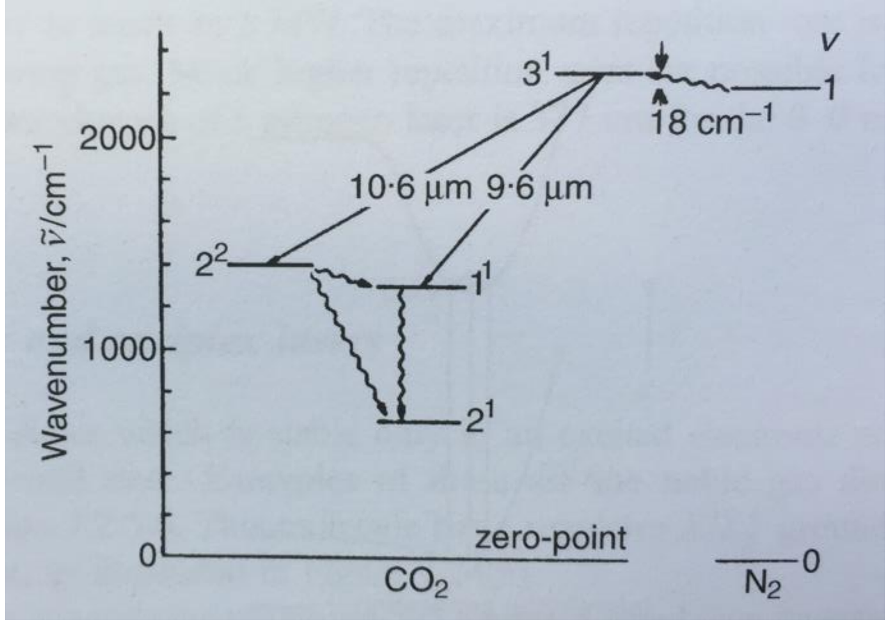
The Helium Neon Laser - HeNe





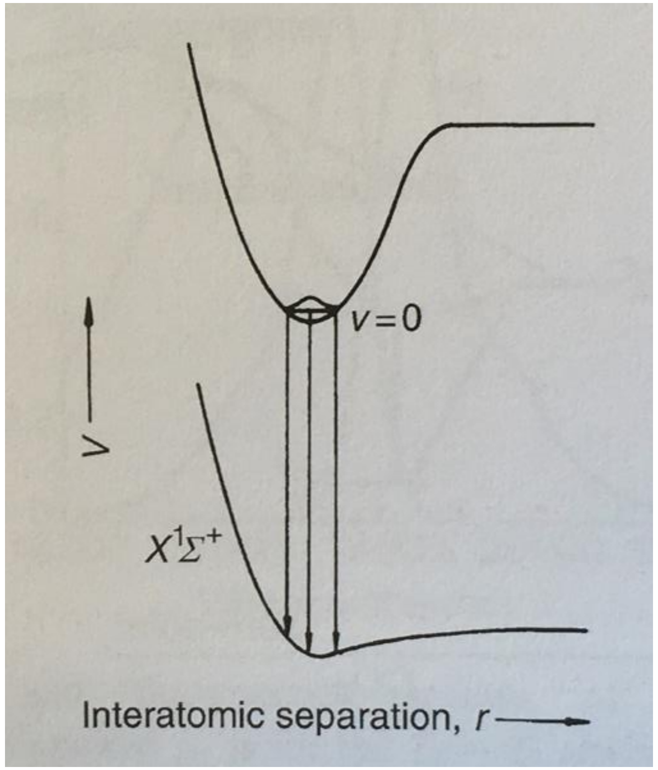
Selected laser examples: Molecular gas laser

- Example: CO_2 laser
- Output in the mid-IR region
- High-power cw laser
- Machining and medical applications



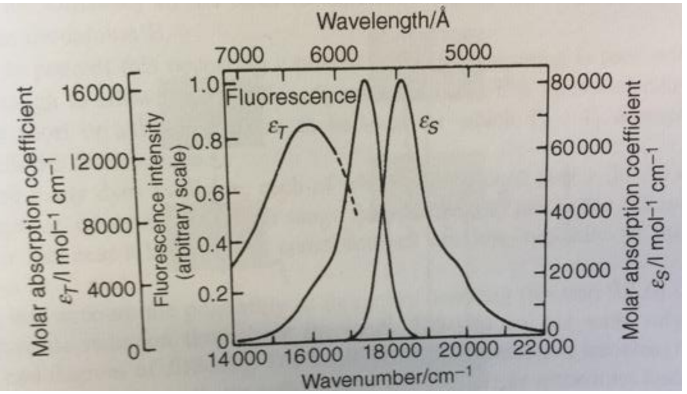
Selected laser examples: Excimer laser

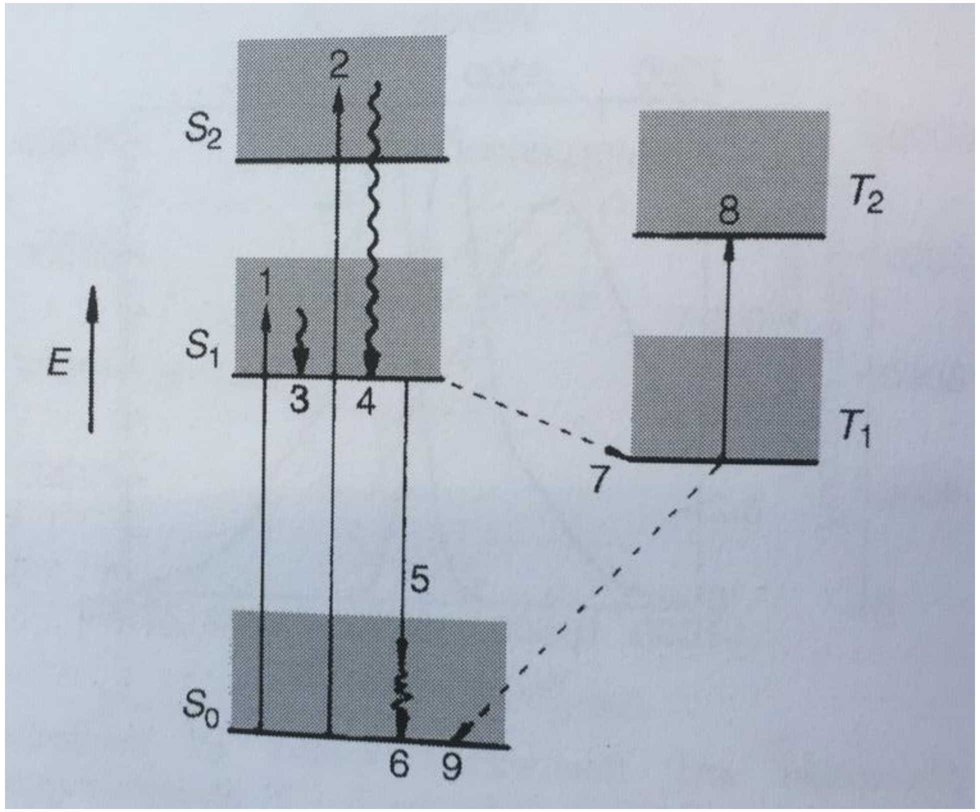
- Excimer – ”excited dimer”
- Important for output in UV spectral region
- UV processing, medical applications
- Pulsed, high output



Selected laser examples: Dye laser

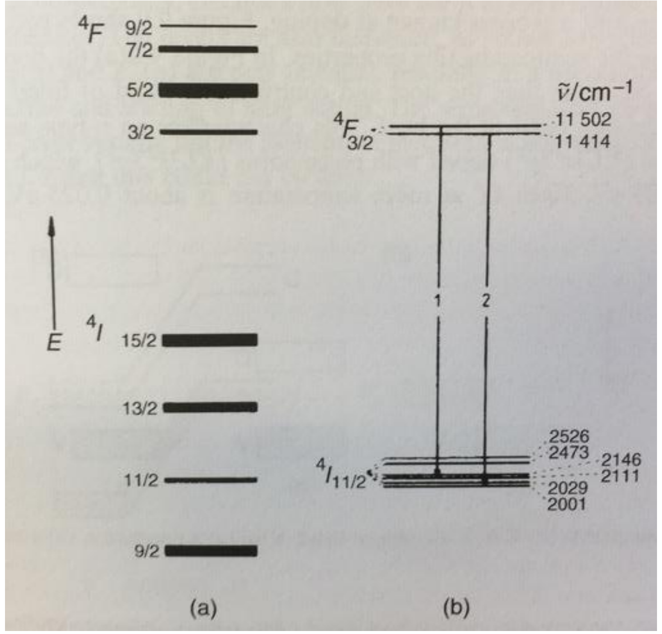
- Tunable over large wavelength regime
- Organic dyes in solution
- High maintenance, mostly replaced by solid state lasers





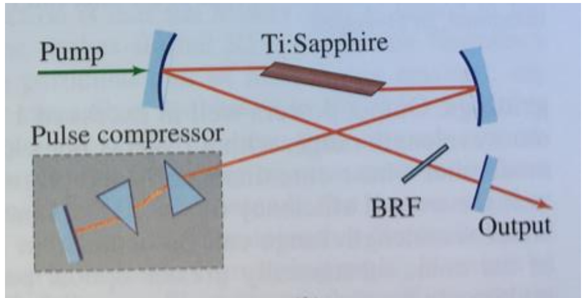
Selected laser examples: Nd:YAG

- Neodym doped Yttrium-Aluminium-Granate
- Nd3+ ions in glass matrix
- Solid state laser
- Main line 1064 nm
- Work horse laser in many laboratories

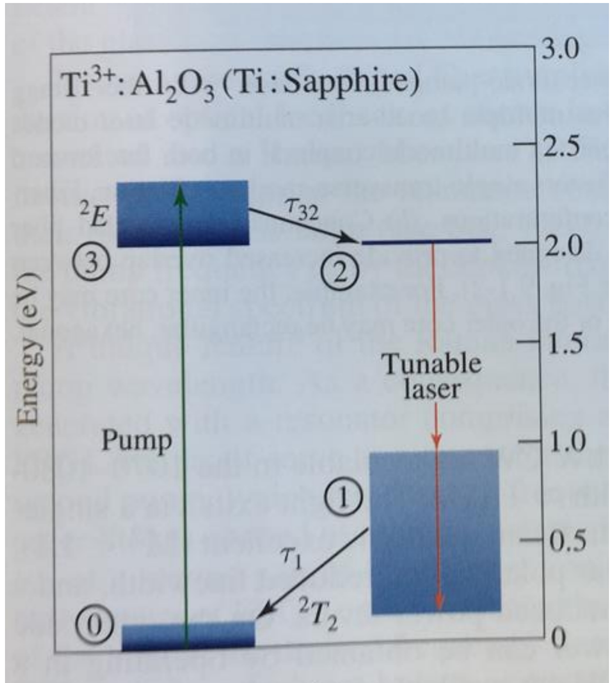


Selected laser examples: TiSa

- Ti^{3+} ions in Al_2O_3 (Saphire)
- Tunable, broad bandwidth
- Can provide ultrashort pulses
- Workhorse laser for ultrafast sciences

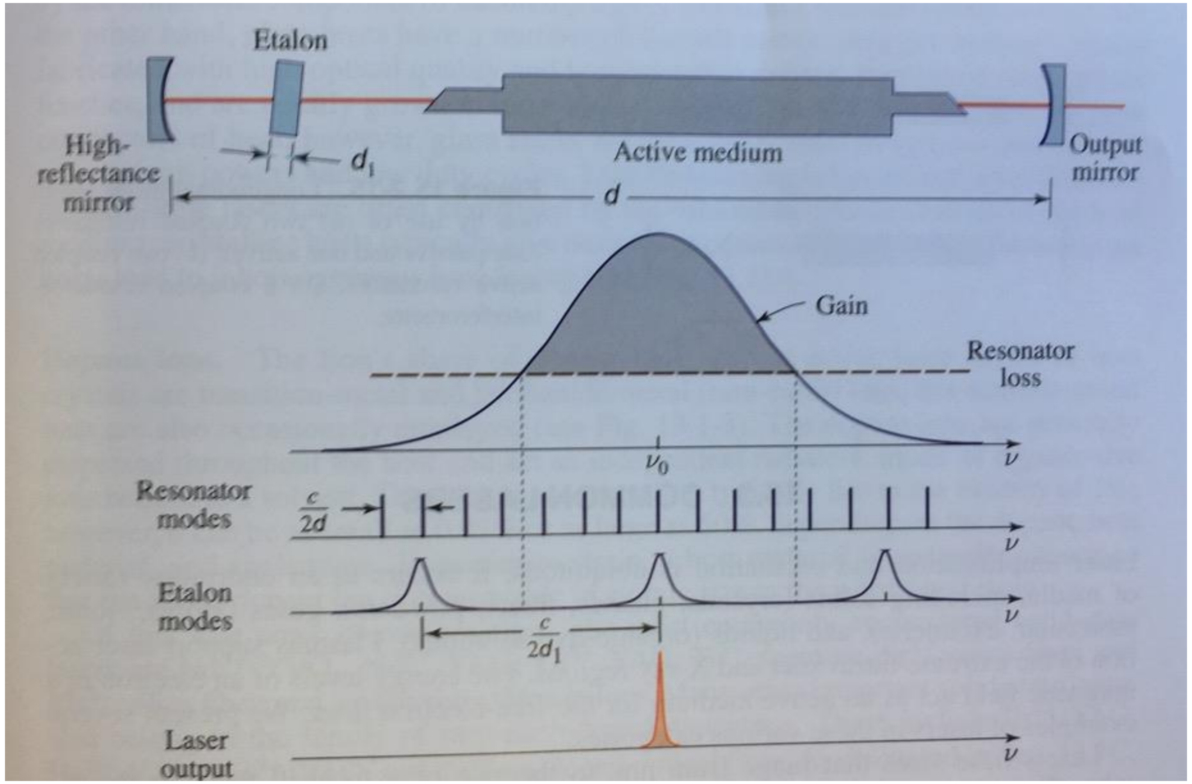


(b)



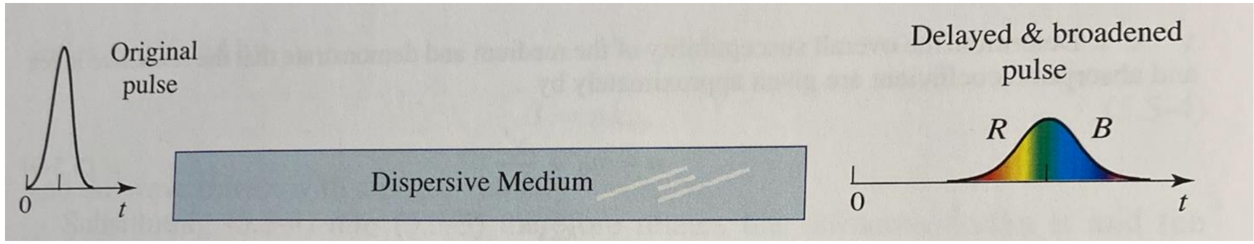
(a)

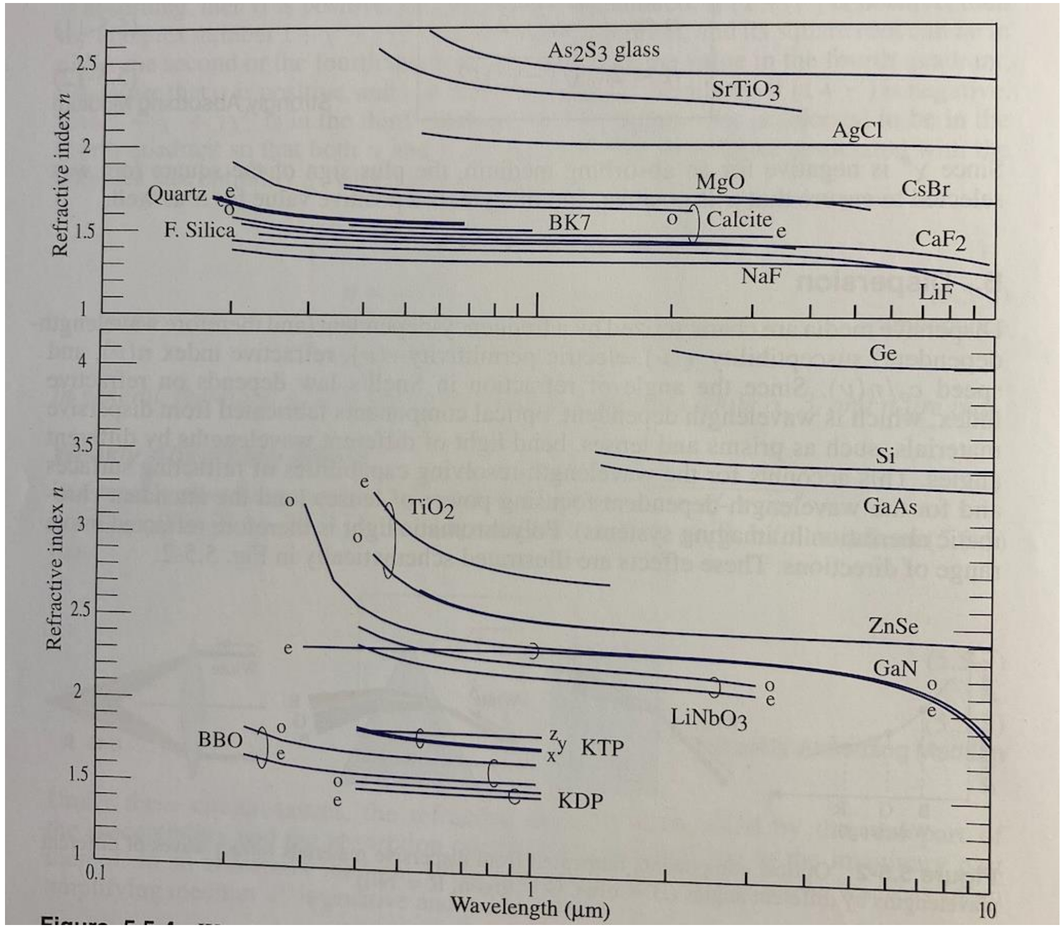
Better approach: Mode selection witn intracavity etalon



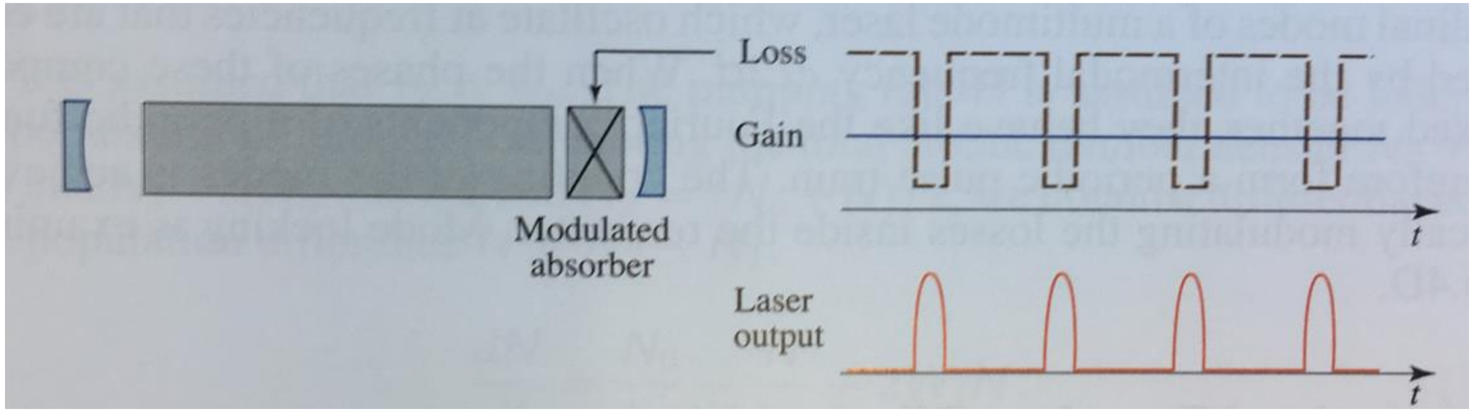
Pulsed and Ultrafast Lasers

A short pulse in a dispersive medium

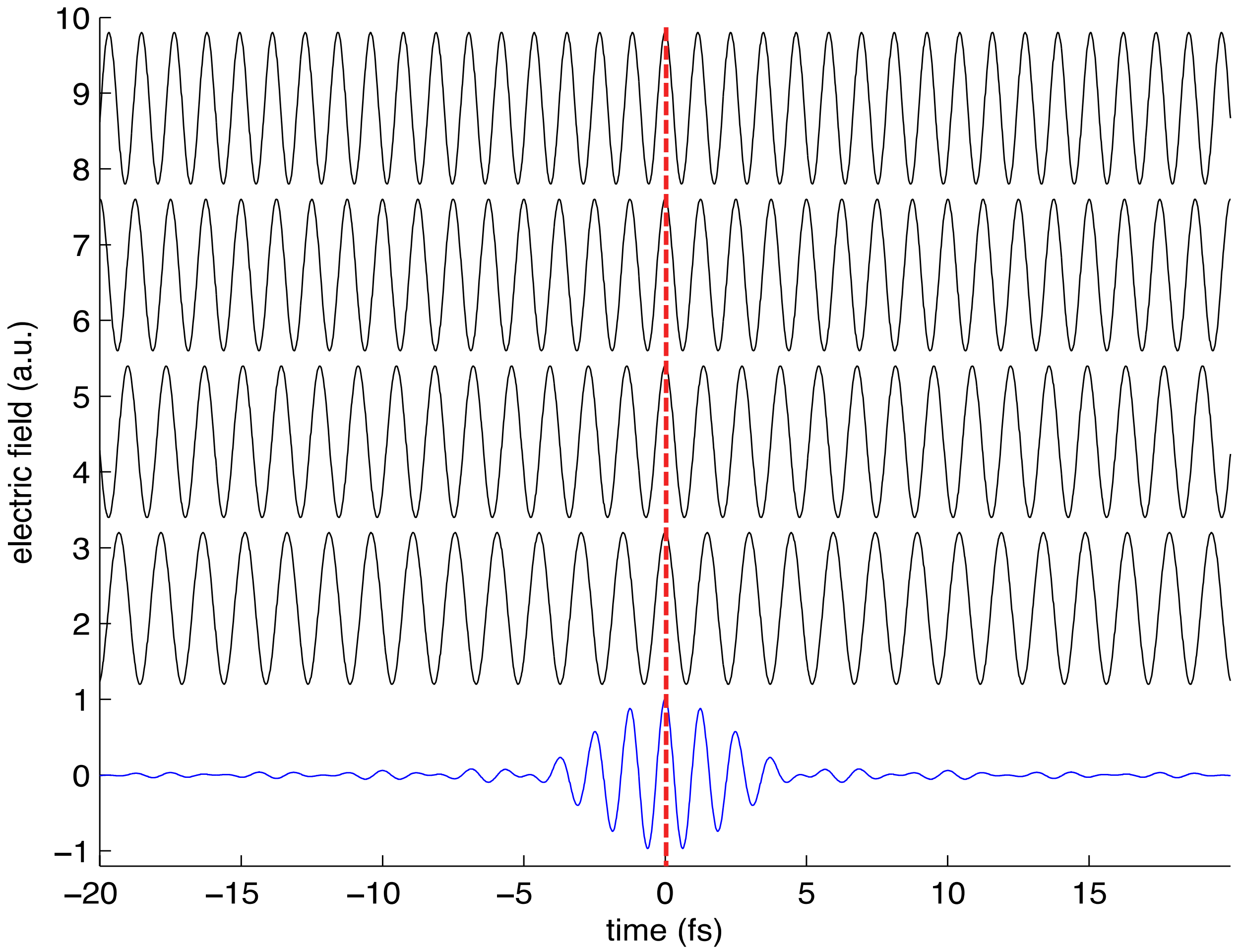




Pulsed lasers: Q-switching



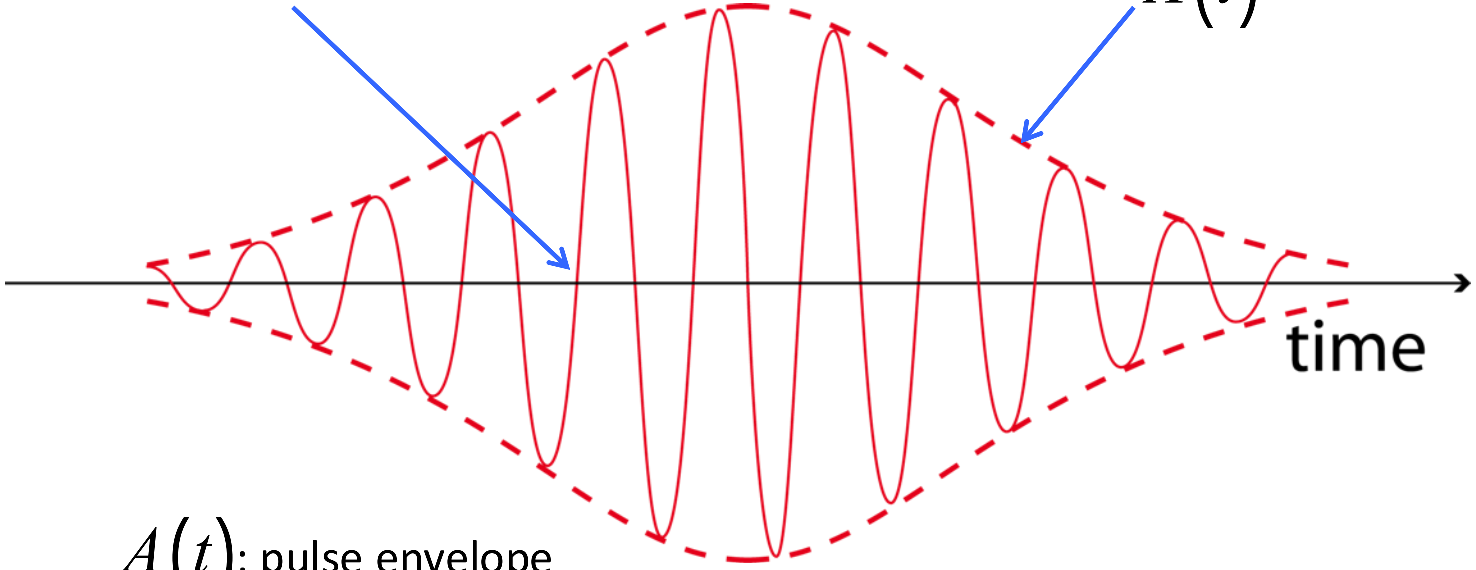
Short pulse needs many frequencies: Shortest pulse is Fourier transform limited pulse (aka bandwidth limited pulse)



Note: Mathematical description of optical pulse

$$E(t) = A(t)e^{ij(t)}e^{ij_0}$$

$A(t)$



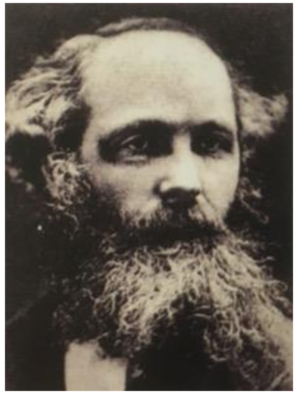
$A(t)$; pulse envelope

$j(t)$; time dependent phase of electric field

$w(t) = -\dfrac{dj(t)}{dt}$; instantaneous frequency

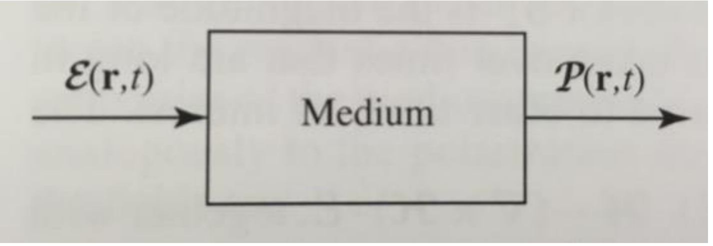
j_0 ; absolute phase (typically neglected for multi-cycle pulses)

Back to formal description of light as EM wave



James Maxwell
1831 - 1879

$$\nabla \times \mathcal{H} = \epsilon_o \frac{\partial \mathcal{E}}{\partial t}$$
$$\nabla \times \mathcal{E} = -\mu_o \frac{\partial \mathcal{H}}{\partial t}$$
$$\nabla \cdot \mathcal{E} = 0$$
$$\nabla \cdot \mathcal{H} = 0,$$



But stick with linear, nondispersive, homogenous, and isotropic media right now:

$$\mathcal{P} = \epsilon_o \chi \mathcal{E},$$

$$\nabla \times \mathcal{H} = \epsilon \frac{\partial \mathcal{E}}{\partial t}$$
$$\nabla \times \mathcal{E} = -\mu \frac{\partial \mathcal{H}}{\partial t}$$
$$\nabla \cdot \mathcal{E} = 0$$
$$\nabla \cdot \mathcal{H} = 0.$$

Generalization of susceptibility $\mathbf{X}$ (still linear)

- Inhomogenous media
- Anisotrope media
- Dispersive media

General:

Interpretation: Dynamic relationship between E an P

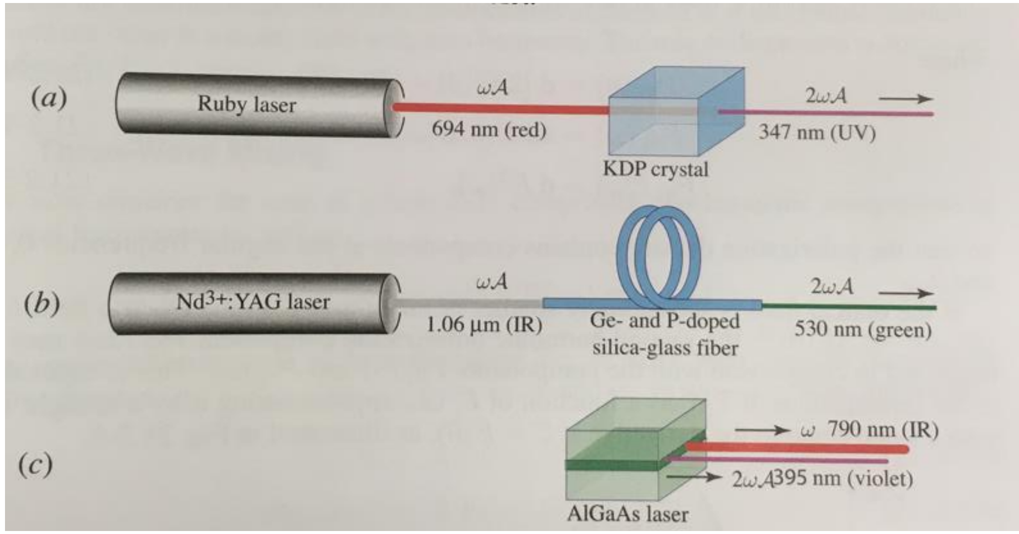
- E induces bound electrons in material to oscillate
- Time-dependent Polarization density P(t)
- Time-delay between E(t) and P(t)

Non-linear optical media

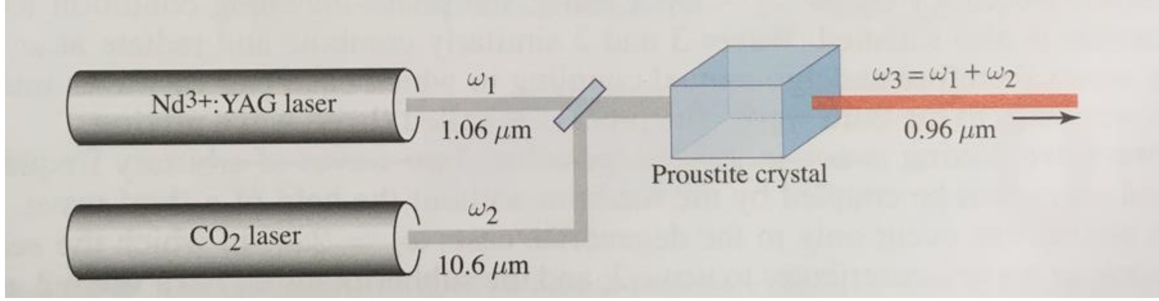
Handwaving:

- Linear: restoring force of light induced fields linear ("Hookes law applies")
- Non-linear: Light induced fields comparable to inter-atomic fields in crystal ("no more linear forces")
- (Note: fields still weak compared to intra-atomic fields – that is a later topic)

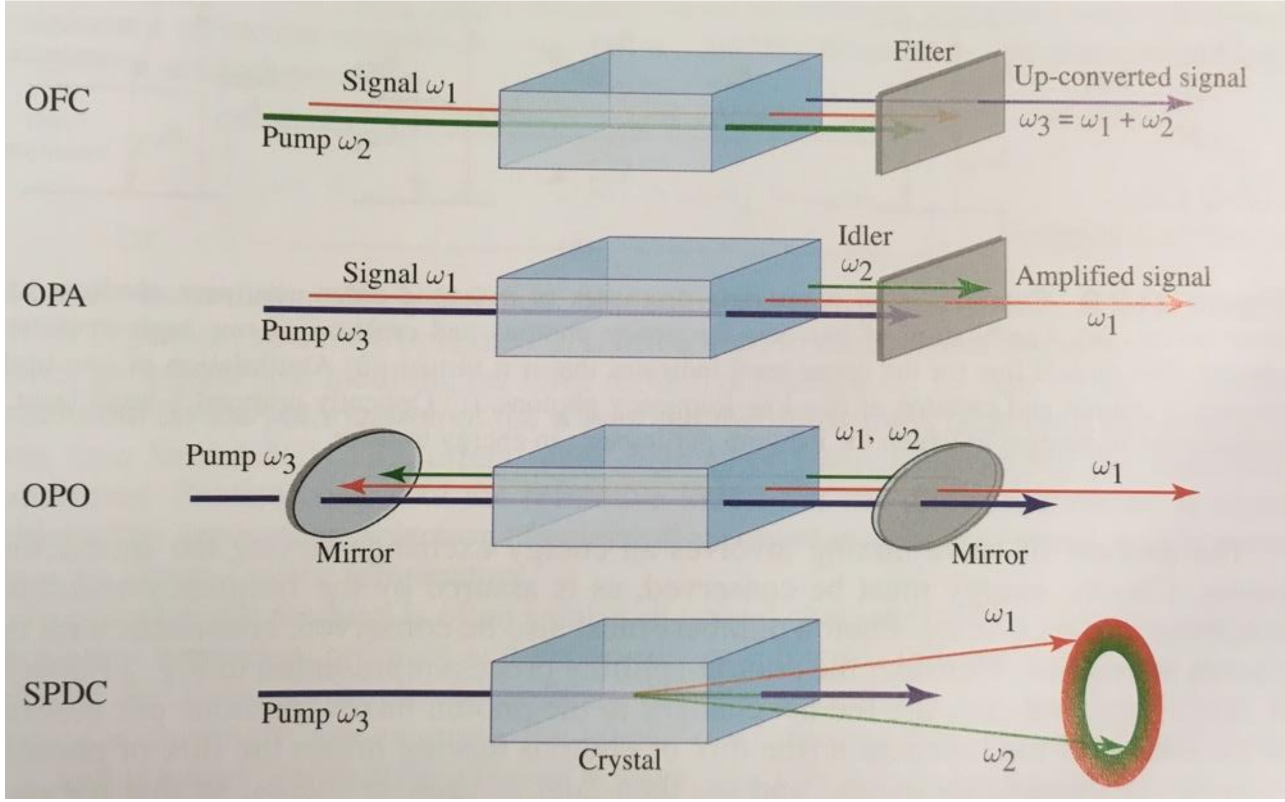
Second order non-linear optics example: Second harmonic generation



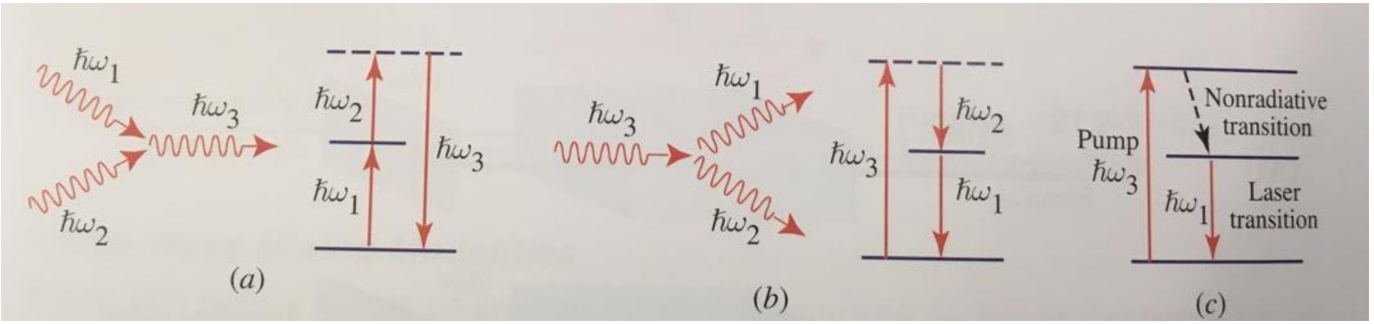
Second order non-linear optics example: Sum frequency generation



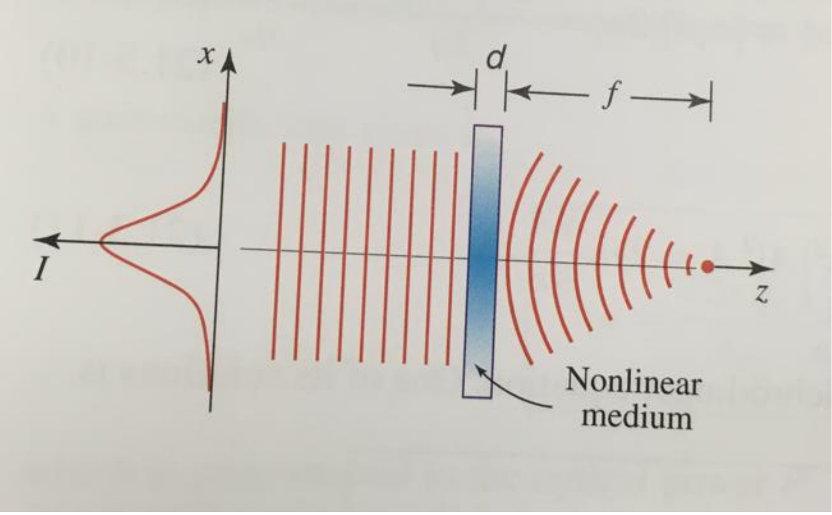
Second order non-linear optics example: Optical parametric devices



Second order non-linear optics example: Description as photon interaction process

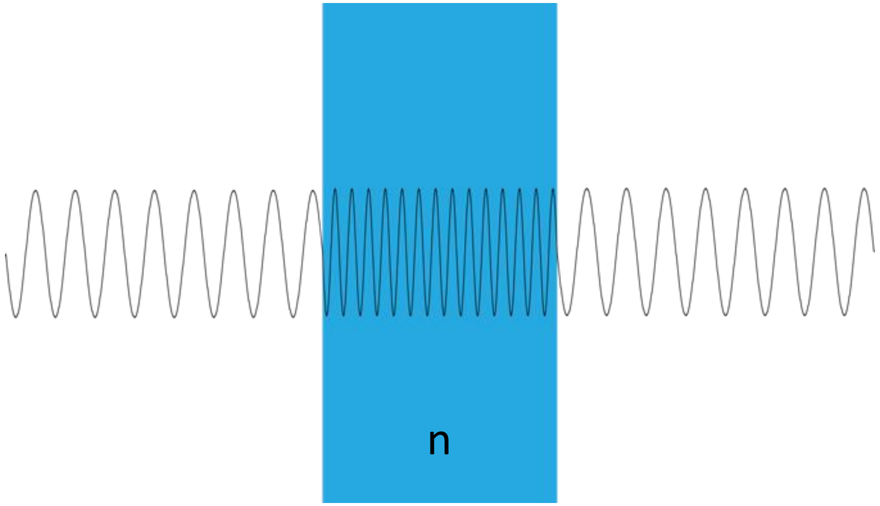


Third order non-linear optics example: Optical Kerr Effect and Self-Focusing

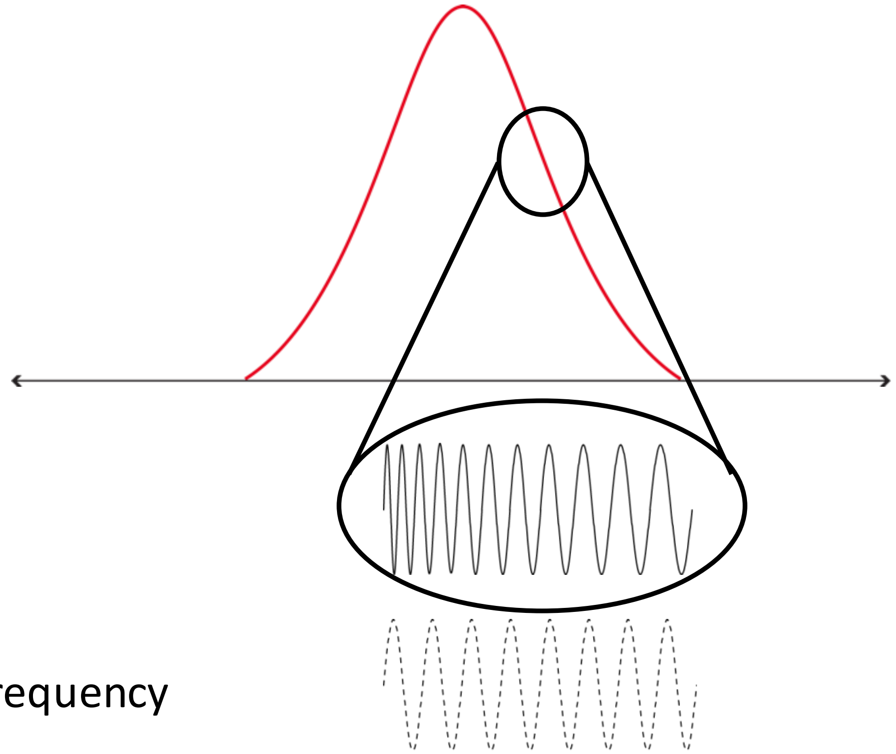


Third order non-linear optics example: Self-phase modulation

normal refractive index



time-dependent refractive index

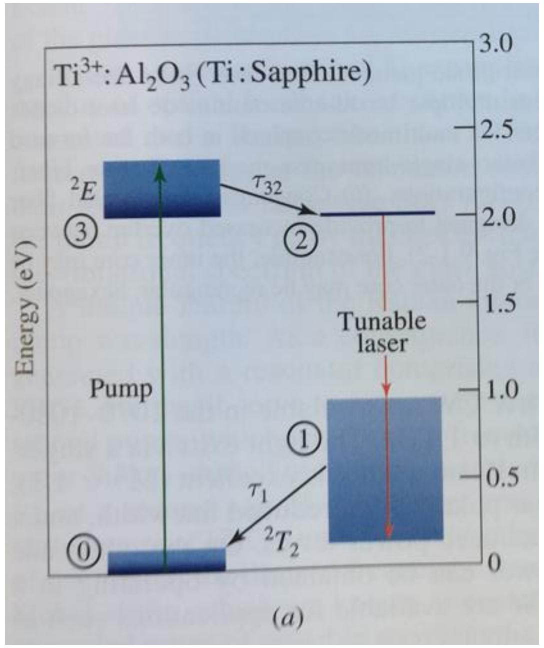


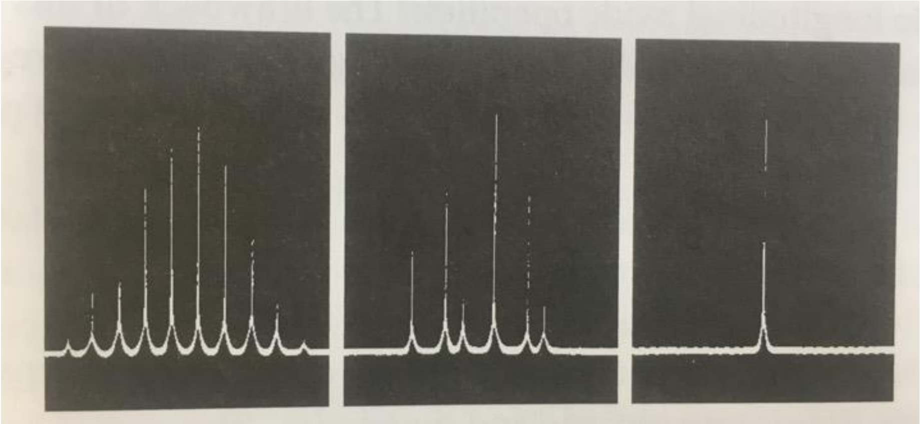
$$\omega(t) = -\frac{d\varphi(t)}{dt}$$; instantaneous frequency

- Conceptually – consider a plane monochromatic wave
- Time-dependent index leads to time-dependent frequency
- New frequency components are generated

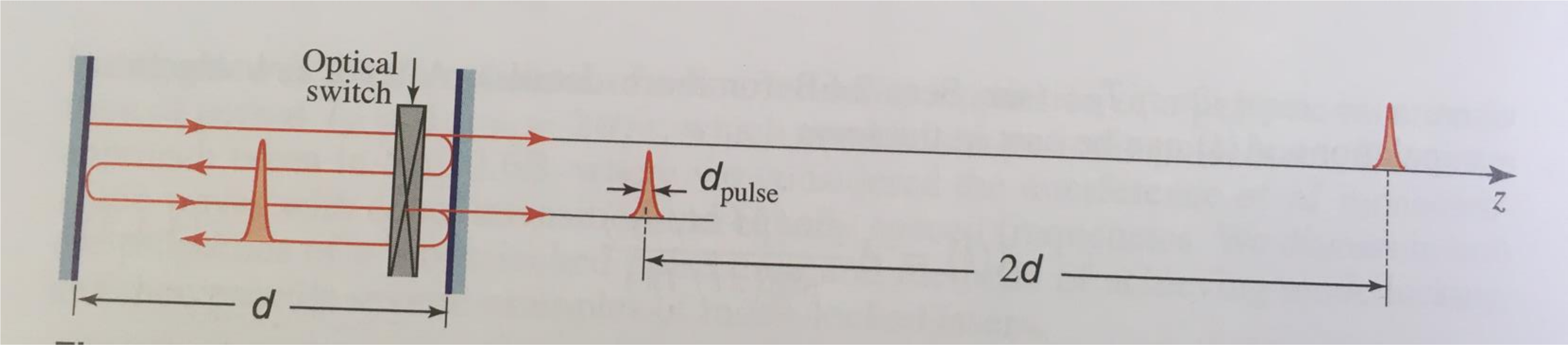
Back to lasers. Remember the problem?

Short pulses and cavities – how do they go together?



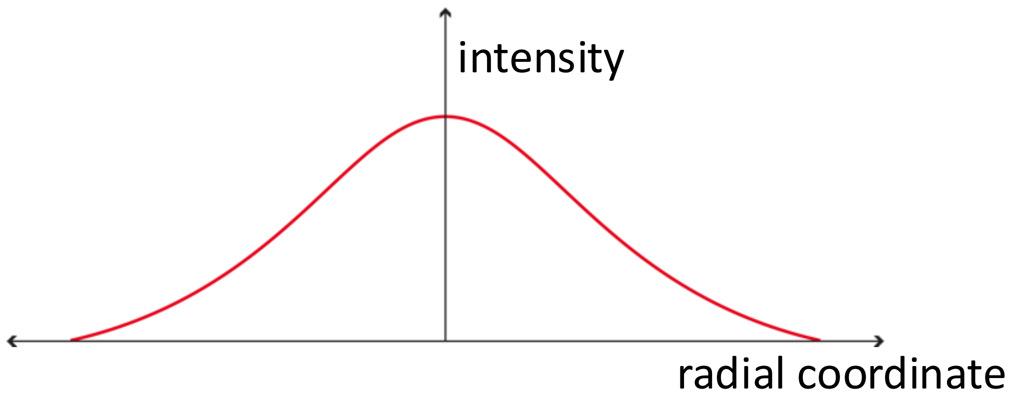


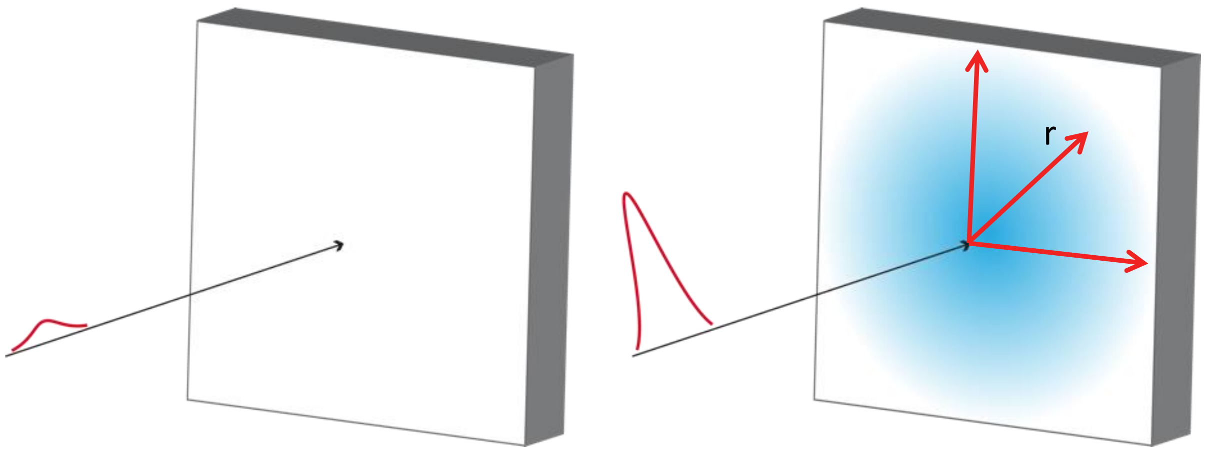
Mode locking



Kerr lens from non-linear refractive index

spatial profile:

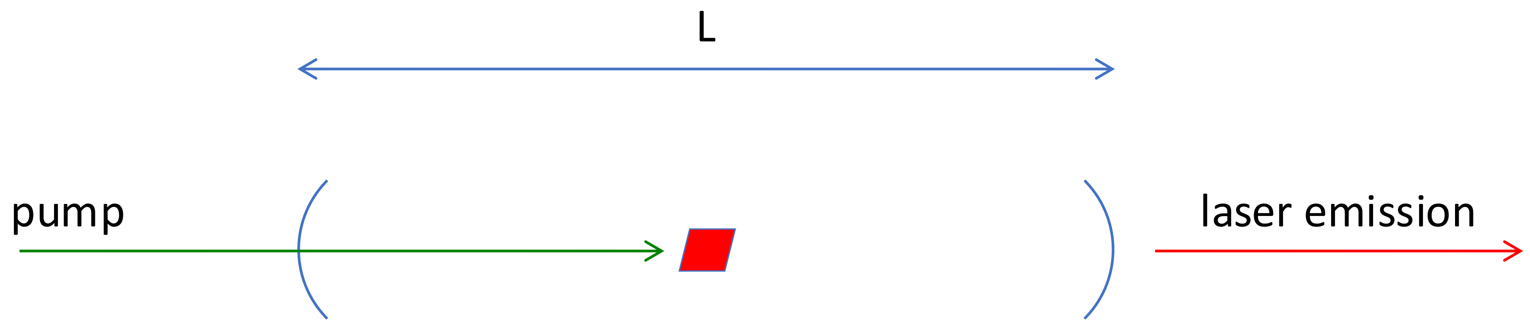




material behaves transparent

material behaves as a lens

Resonant laser cavity

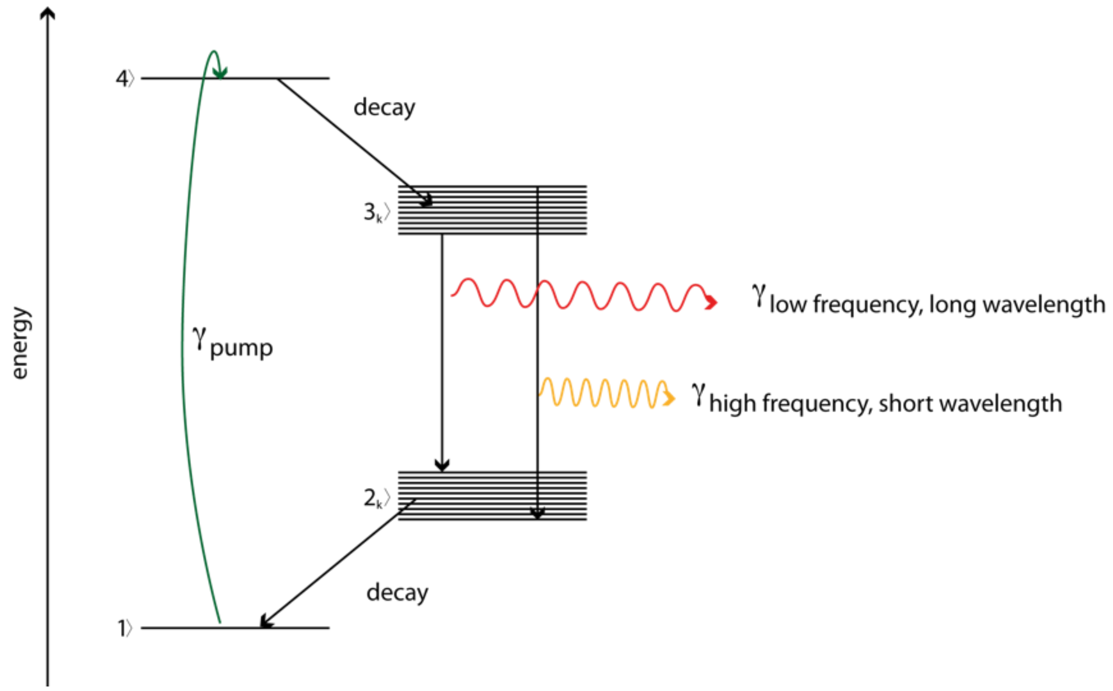


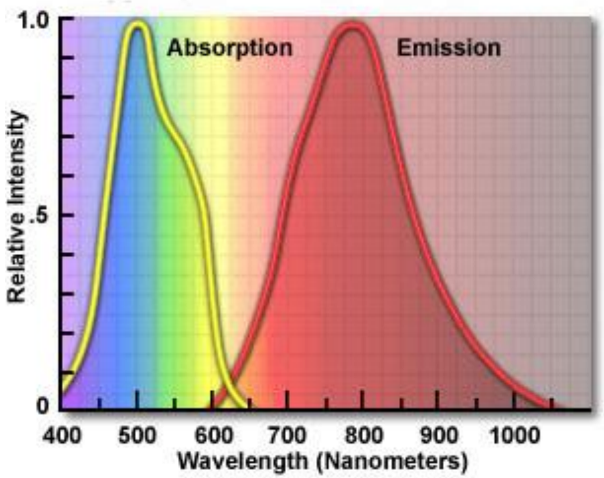
Resonant modes have nodes at cavity end mirrors

Resonant wavelengths and possible frequency modes given by:

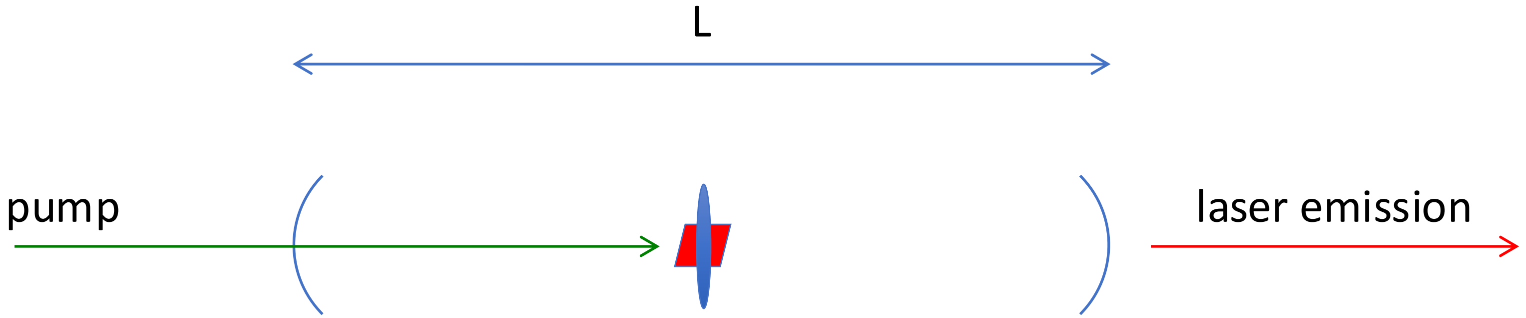
$$\lambda_n = \frac{2L}{n} \qquad \nu_n = n\left(\frac{c}{2L}\right)$$

TiSaphire gain medium





Self mode locking

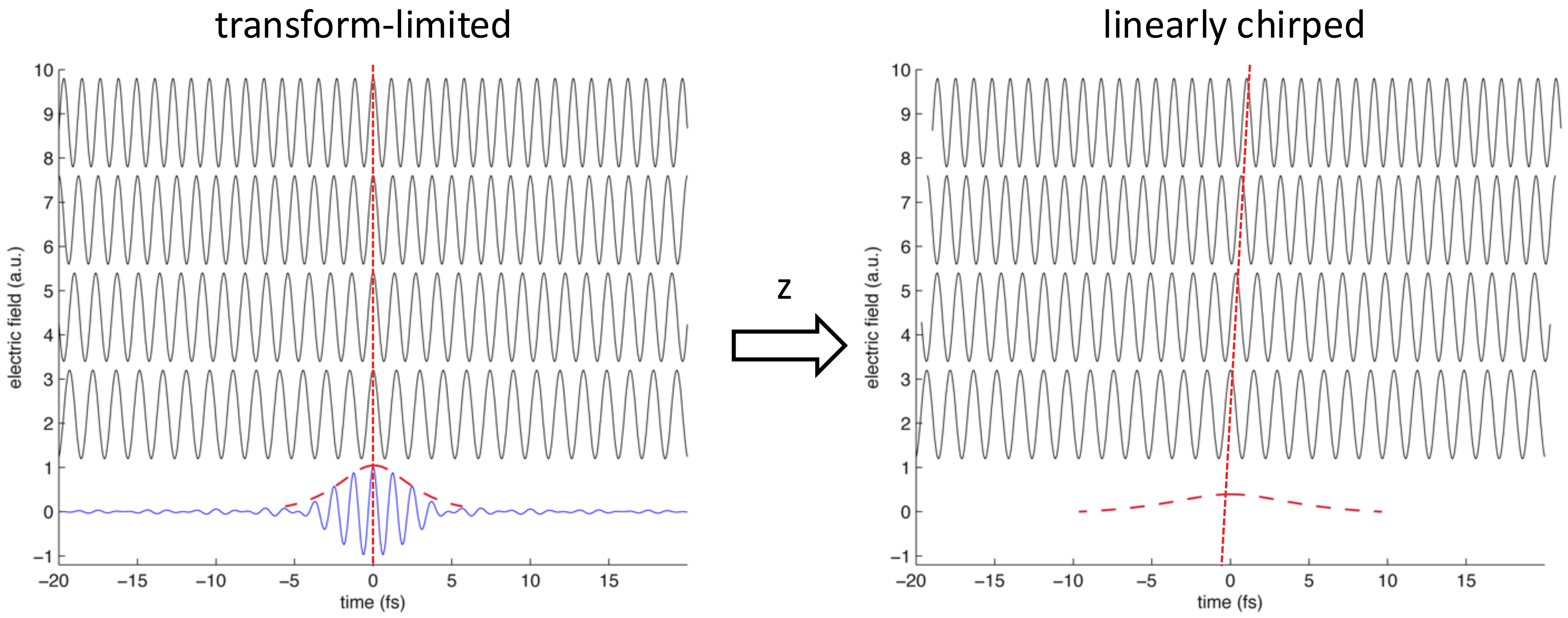


- Kerr Lens Effect, due to nonlinear index of refraction
- At high intensities, the gain crystal acts like a lens
- Cavity tuned so that is most efficient with the crystal behaving as a lens
- Many modes lase and automatically arrange phases for pulsed high-intensity operation
- Intra-cavity dispersion tuned to support pulsed operation
- nJ pulse energies as short as 4 fs FWHM
- Output ~100MHz repetition rate pulse train

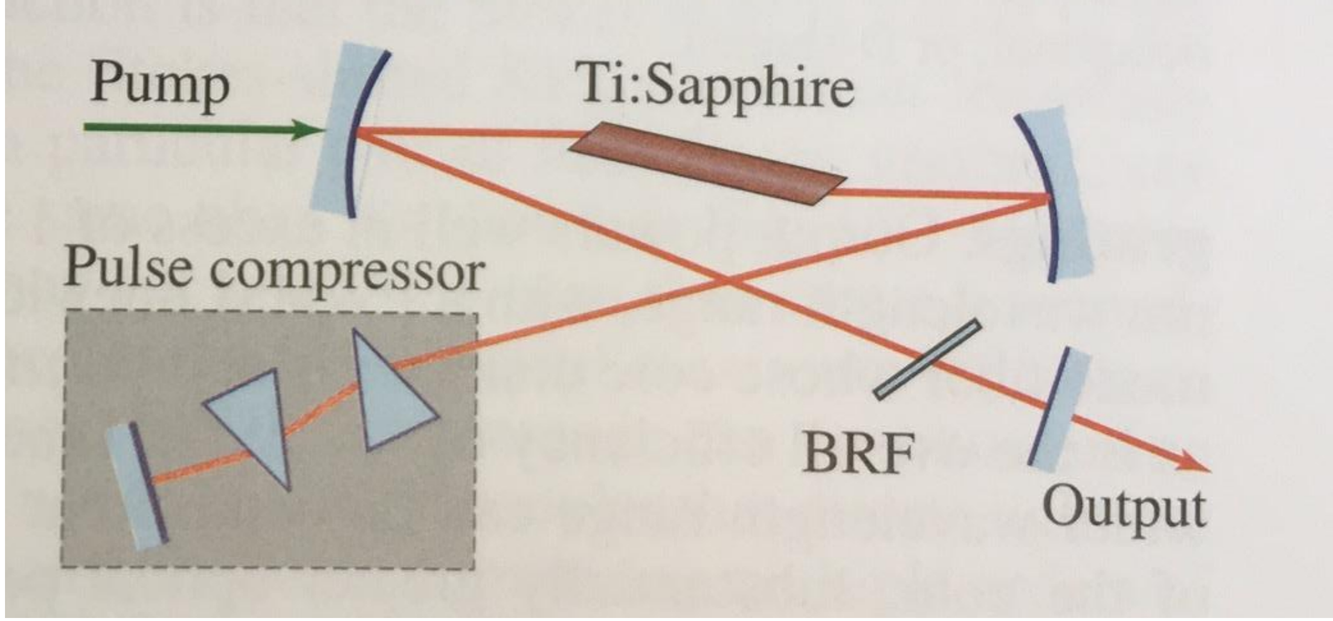
$$\nu_{rep-rate} = \left(\frac{c}{2L}\right)$$

A note on “chirp”

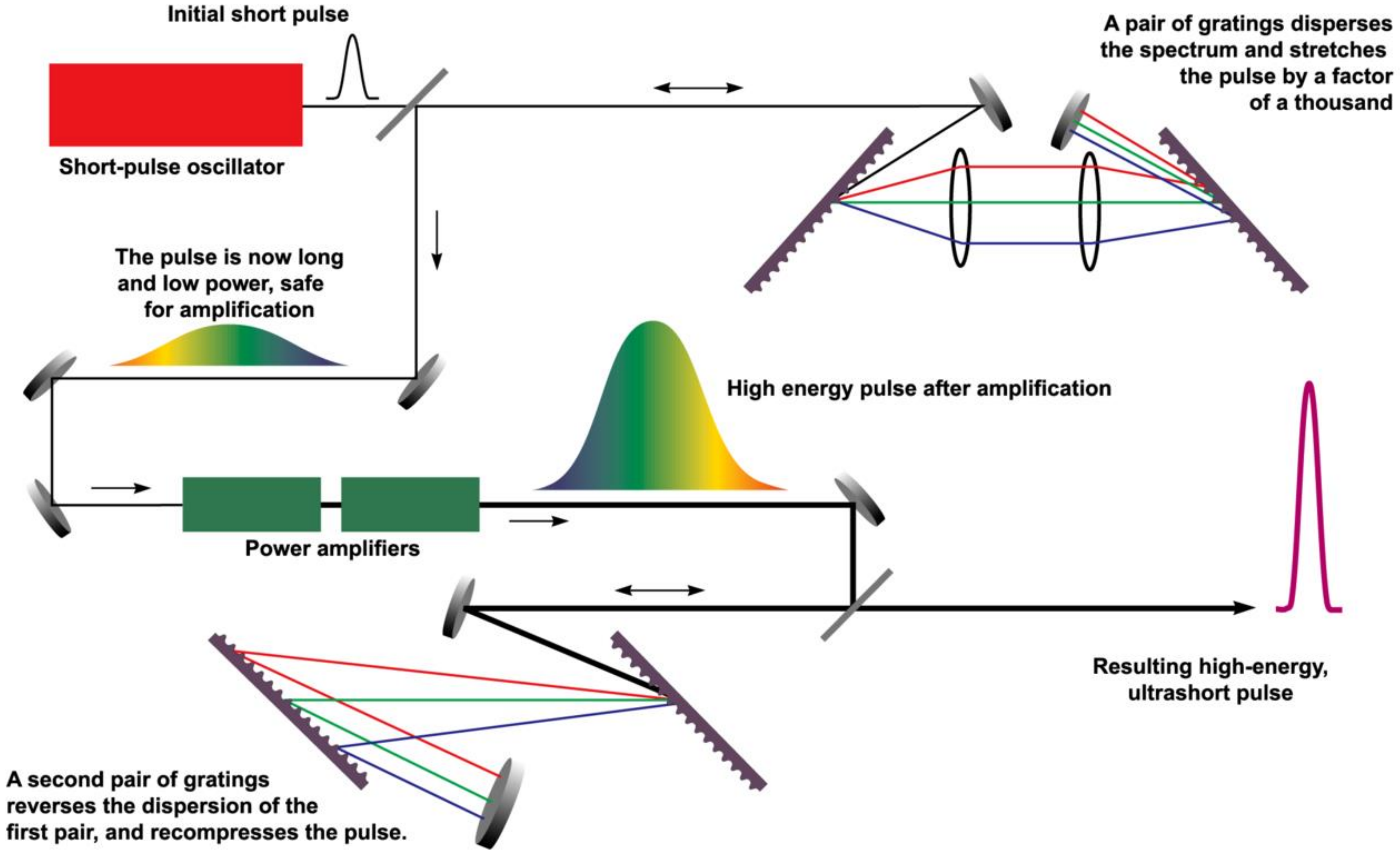
Initially transform limited pulse becomes chirped upon propagation, ($k_2 \neq 0$, $\gamma = 0$)



TiSaphire oscillator setup



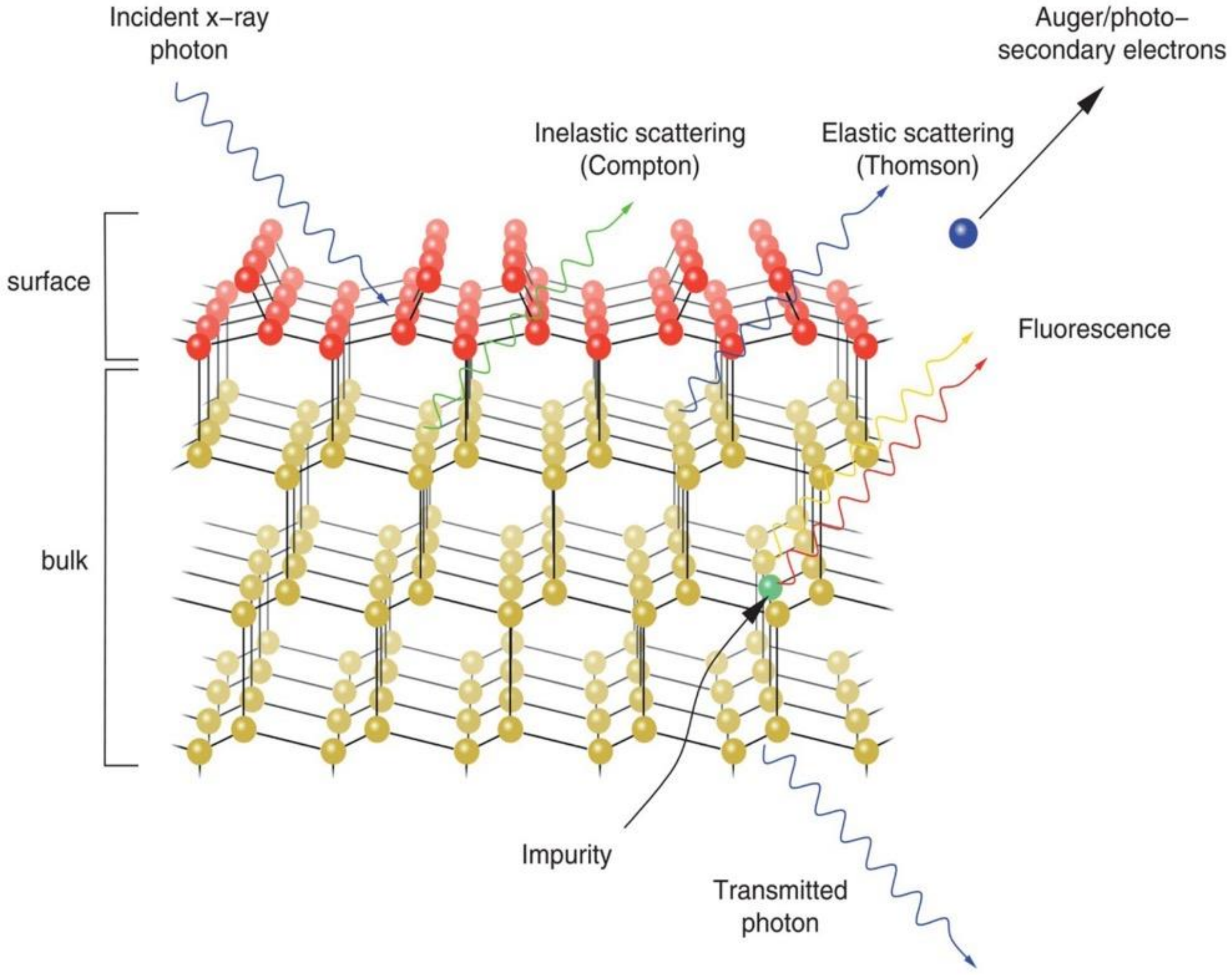
Chirped pulse amplification



X-rays

X-ray interactions with matter

X-ray interactions with matter



X-ray cross sections

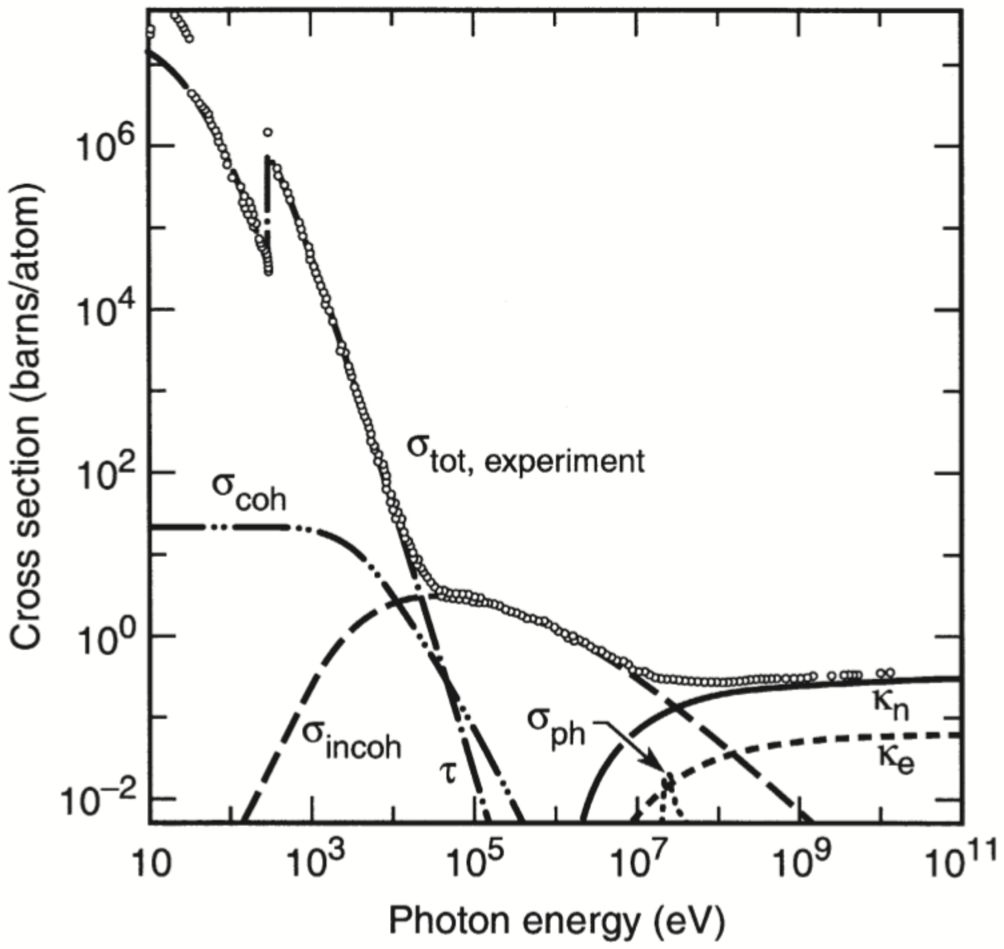
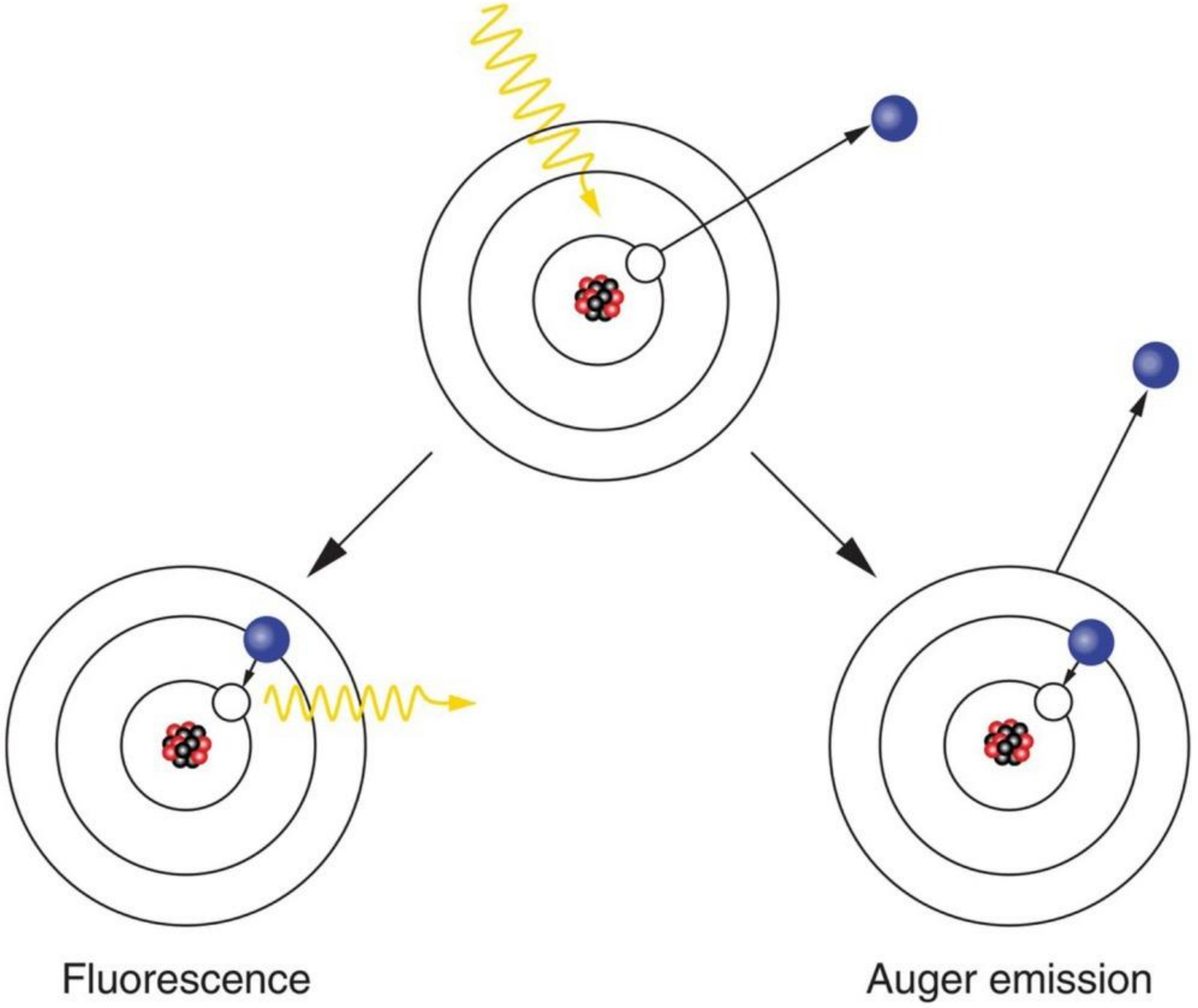


Fig. 3-1. *Total photon cross section σ_{tot} in carbon, as a*

Photoionization / absorption



Ionization energies of elements

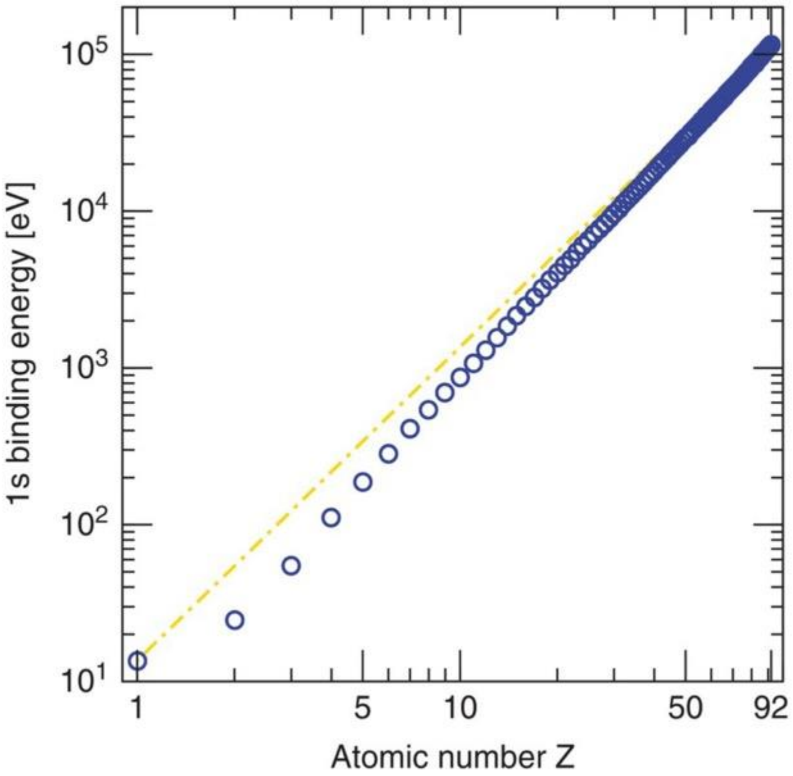
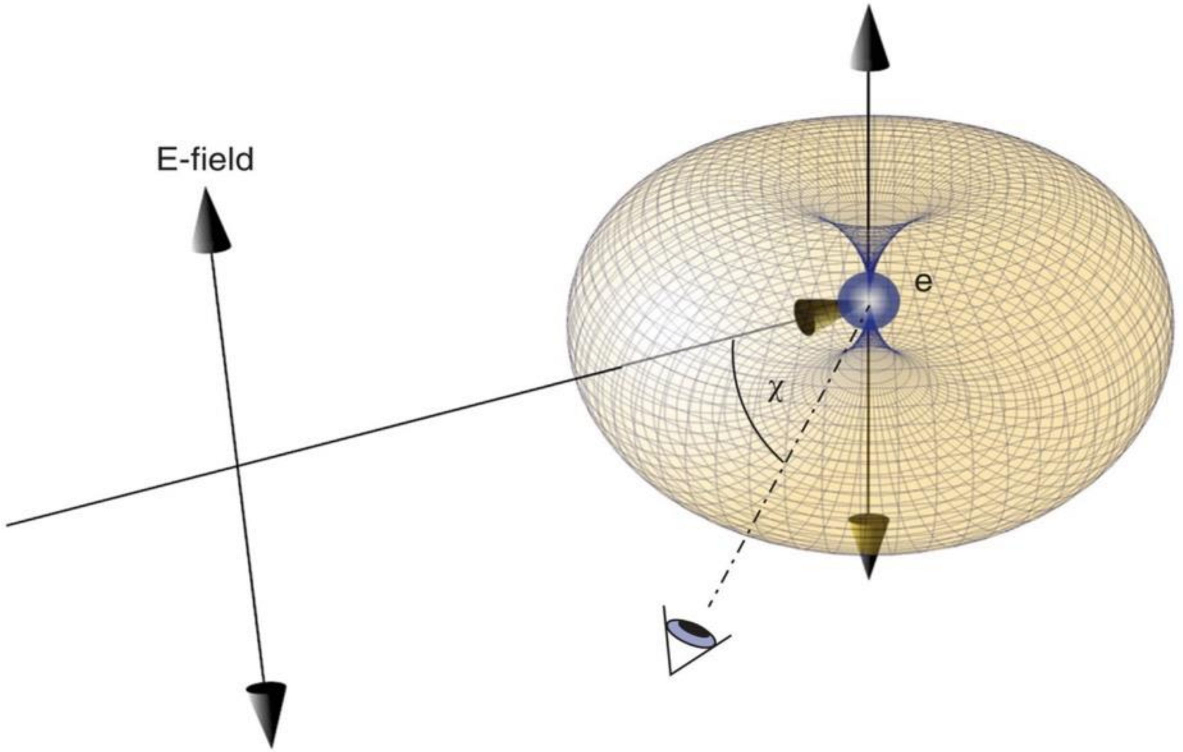


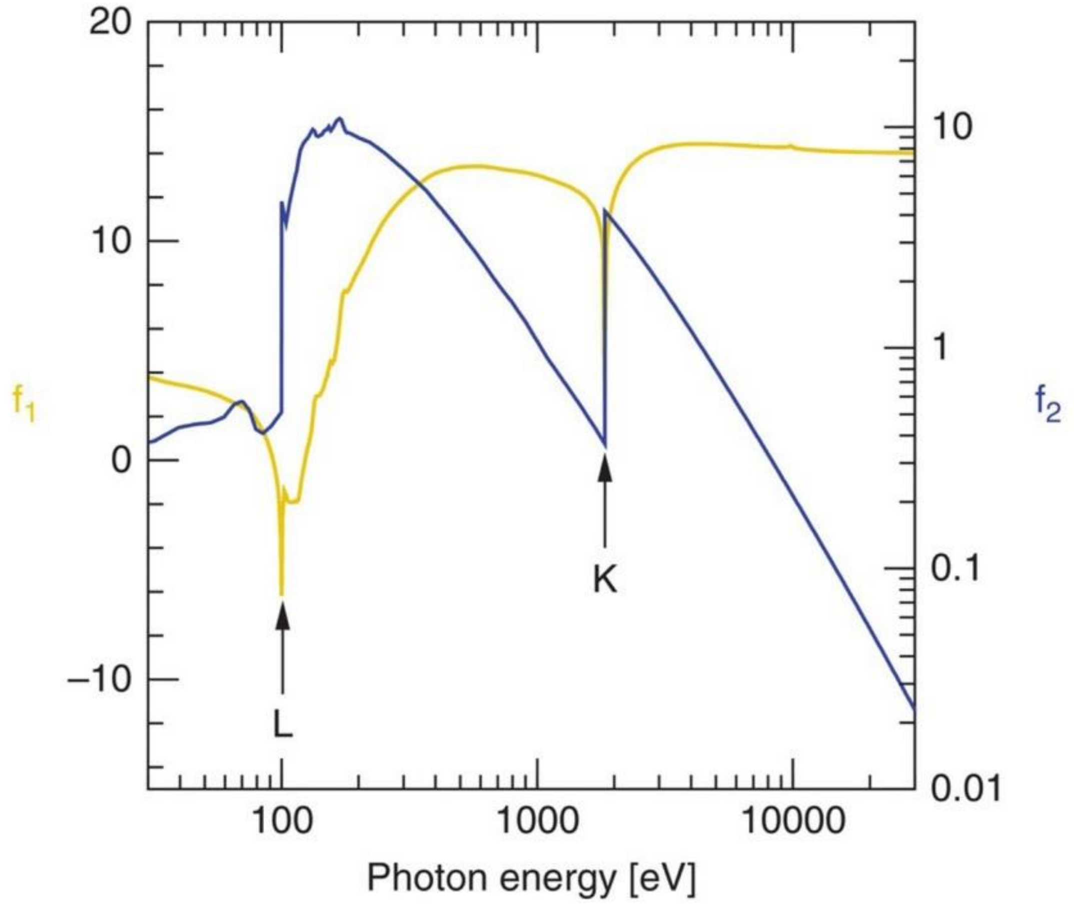
Table 1-1. Electron binding energies, in electron volts, for the elements in their natural forms.

Element	K 1s	L_1 2s	L_2 $2p_{1/2}$	L_3 $2p_{3/2}$	M_1 3s	M_2 $3p_{1/2}$	M_3 $3p_{3/2}$	M_4 $3d_{3/2}$	M_5 $3d_{5/2}$	N_1 4s	N_2 $4p_{1/2}$
1 H	13.6										
2 He	24.6*										
3 Li	54.7*										
4 Be	111.5*										
5 B	188*										
6 C	284.2*										
7 N	409.9*	37.3*									
8 O	543.1*	41.6*									
9 F	696.7*										
10 Ne	870.2*	48.5*	21.7*	21.6*							
11 Na	1070.8†	63.5†	30.65	30.81							
12 Mg	1303.0†	88.7	49.78	49.50							
13 Al	1559.6	117.8	72.95	72.55							
14 Si	1839	149.7*b	99.82	99.42							
15 P	2145.5	189*	136*	135*							
16 S	2472	230.9	163.6*	162.5*							
17 Cl	2822.4	270*	202*	200*							
18 Ar	3205.9*	326.3*	250.6†	248.4*	29.3*	15.9*	15.7*				
19 K	3608.4*	378.6*	297.3*	294.6*	34.8*	18.3*	18.3*				
20 Ca	4038.5*	438.4†	349.7†	346.2†	44.3 †	25.4†	25.4†				
21 Sc	4492	498.0*	403.6*	398.7*	51.1*	28.3*	28.3*				
22 Ti	4966	560.9†	460.2†	453.8†	58.7†	32.6†	32.6†				

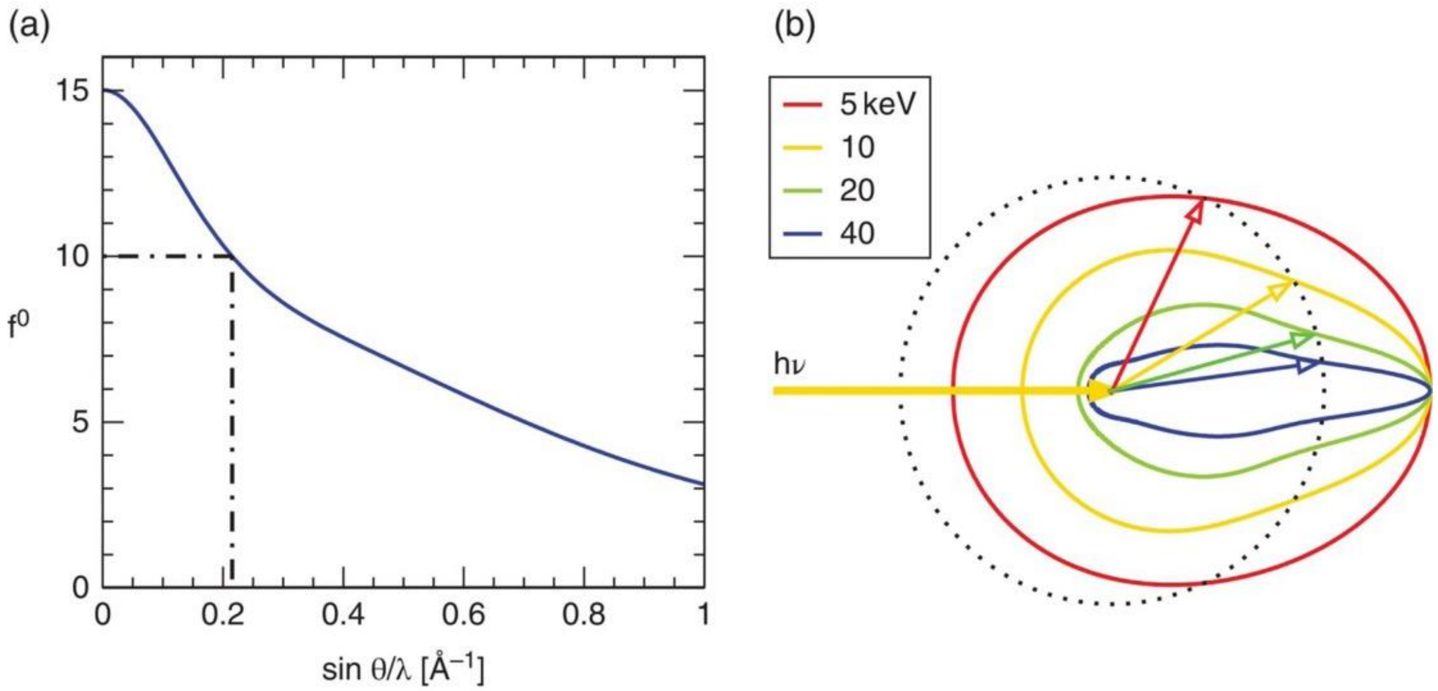
Thomson scattering



Atomic scattering factors and refractive index

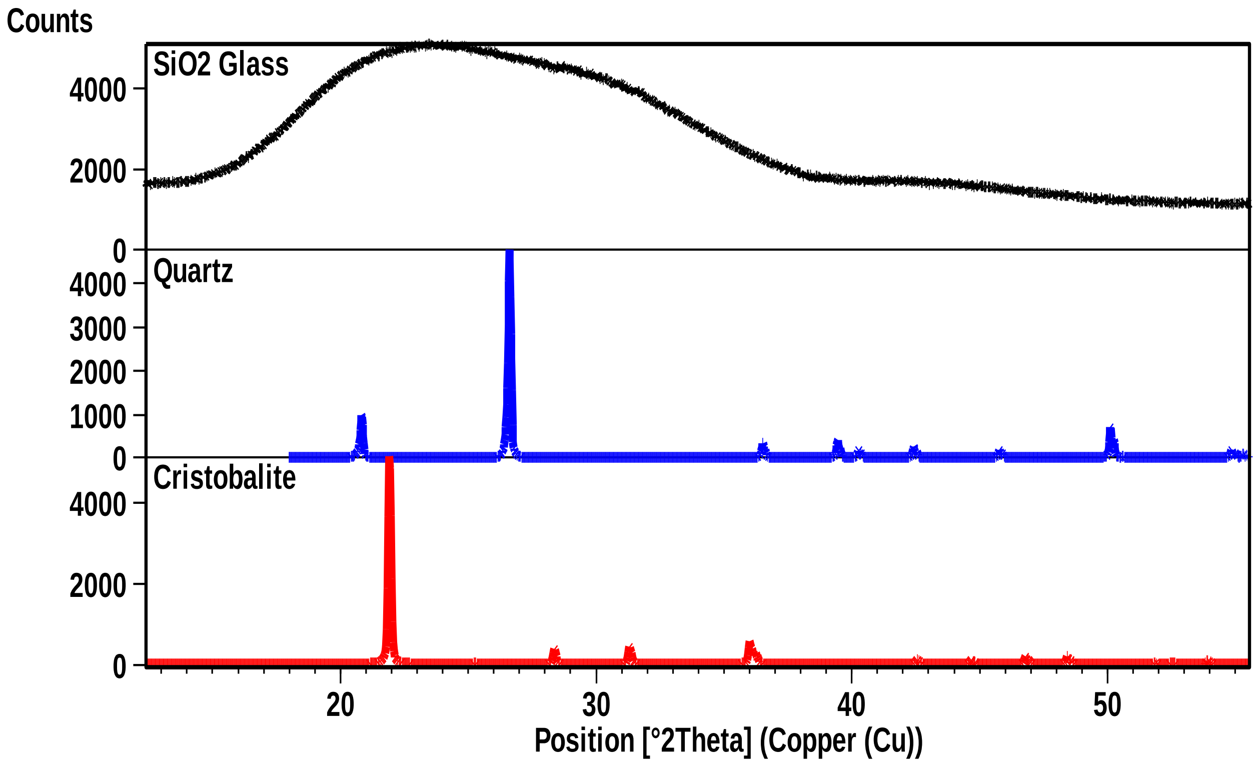


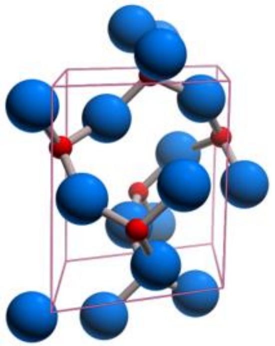
Now full cross section / atomic scattering factors

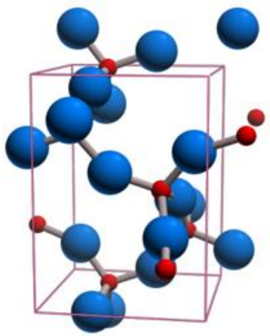


Diffraction by a crystal

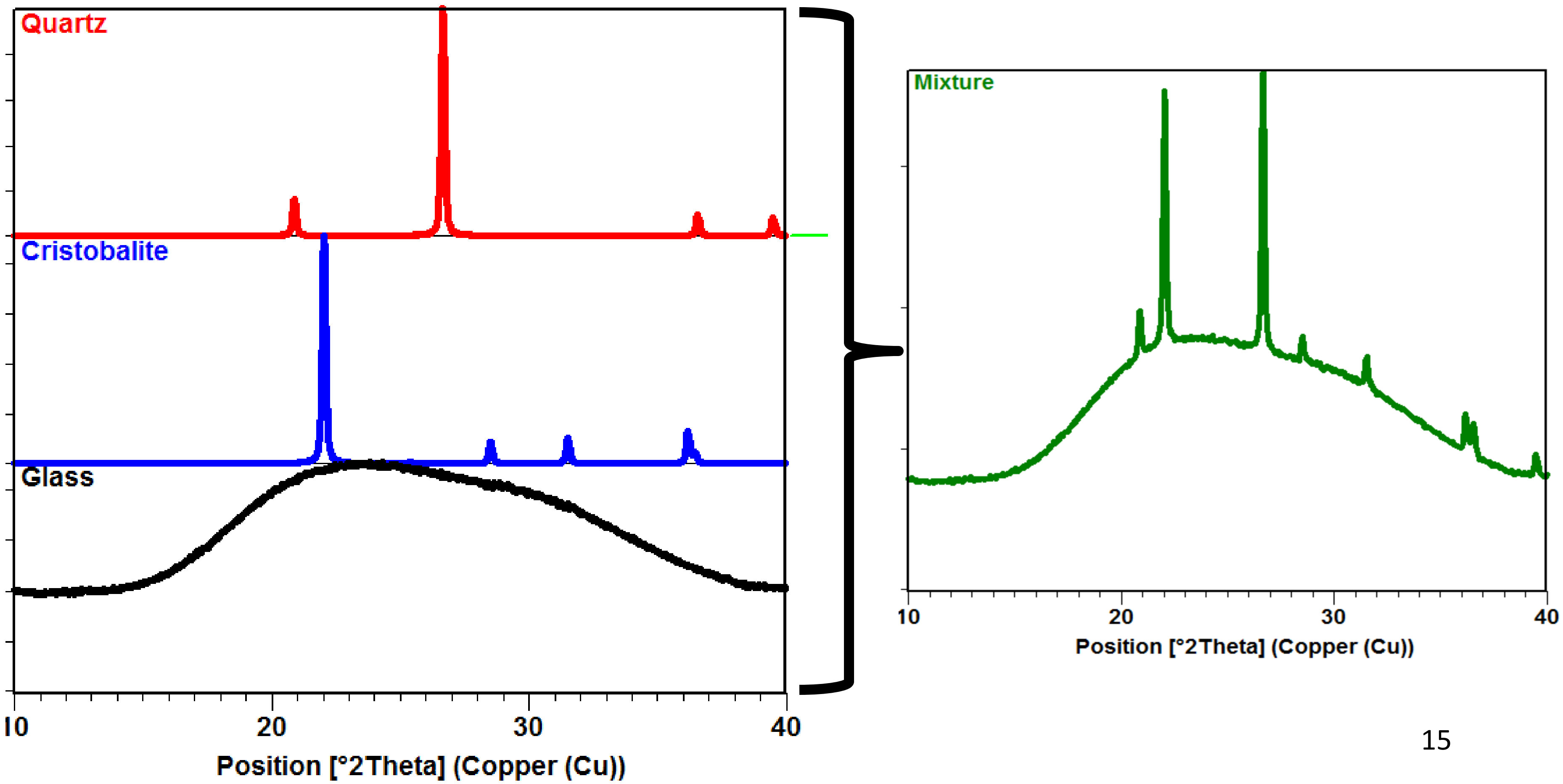
Characteristic signals from different – chemically identical – samples



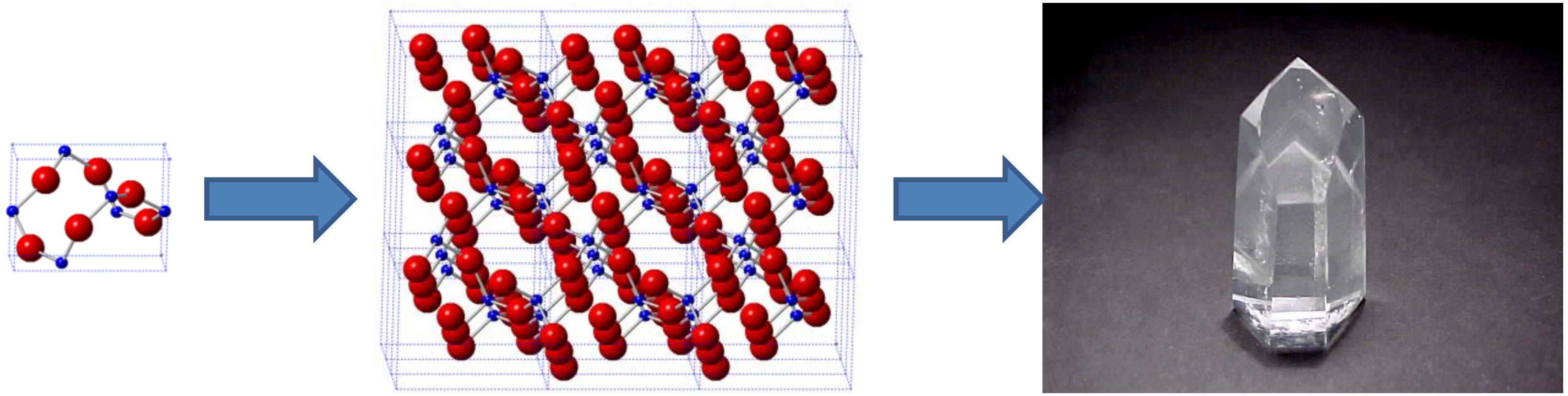


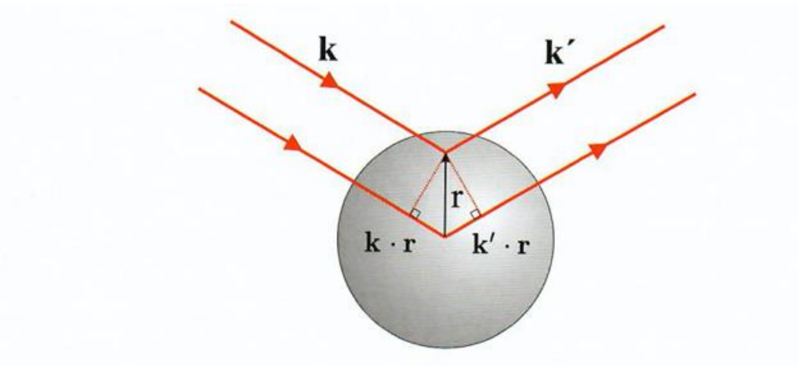


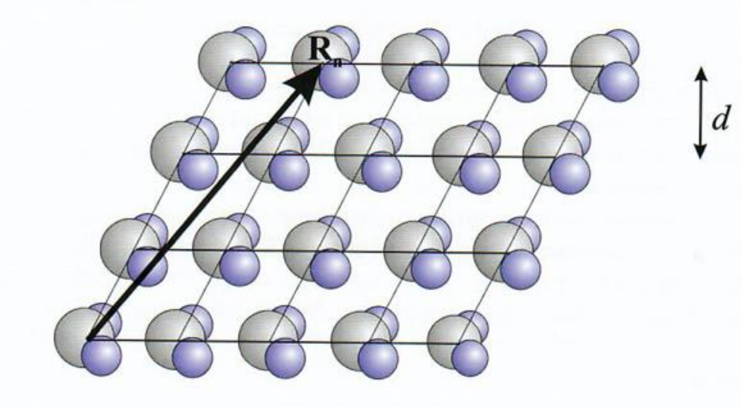
The diffraction pattern of a mixture is a simple sum from each component phase



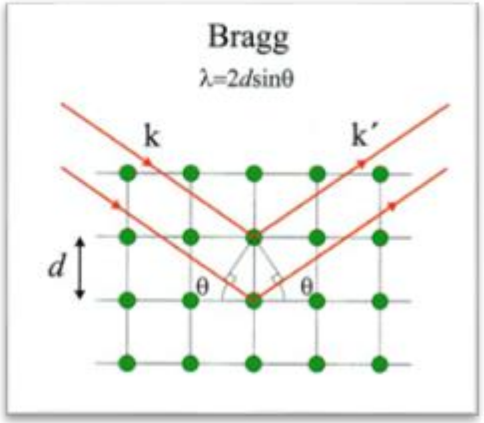
Crystaline materials are characterized by the long-range order

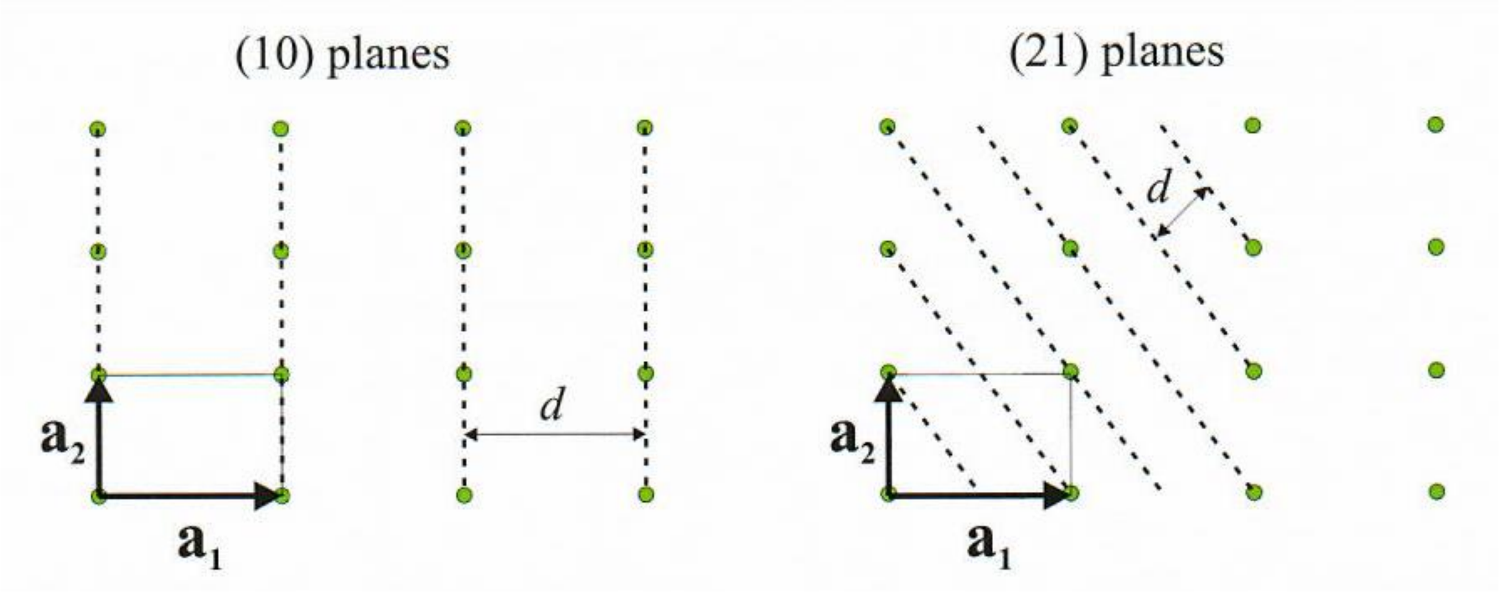




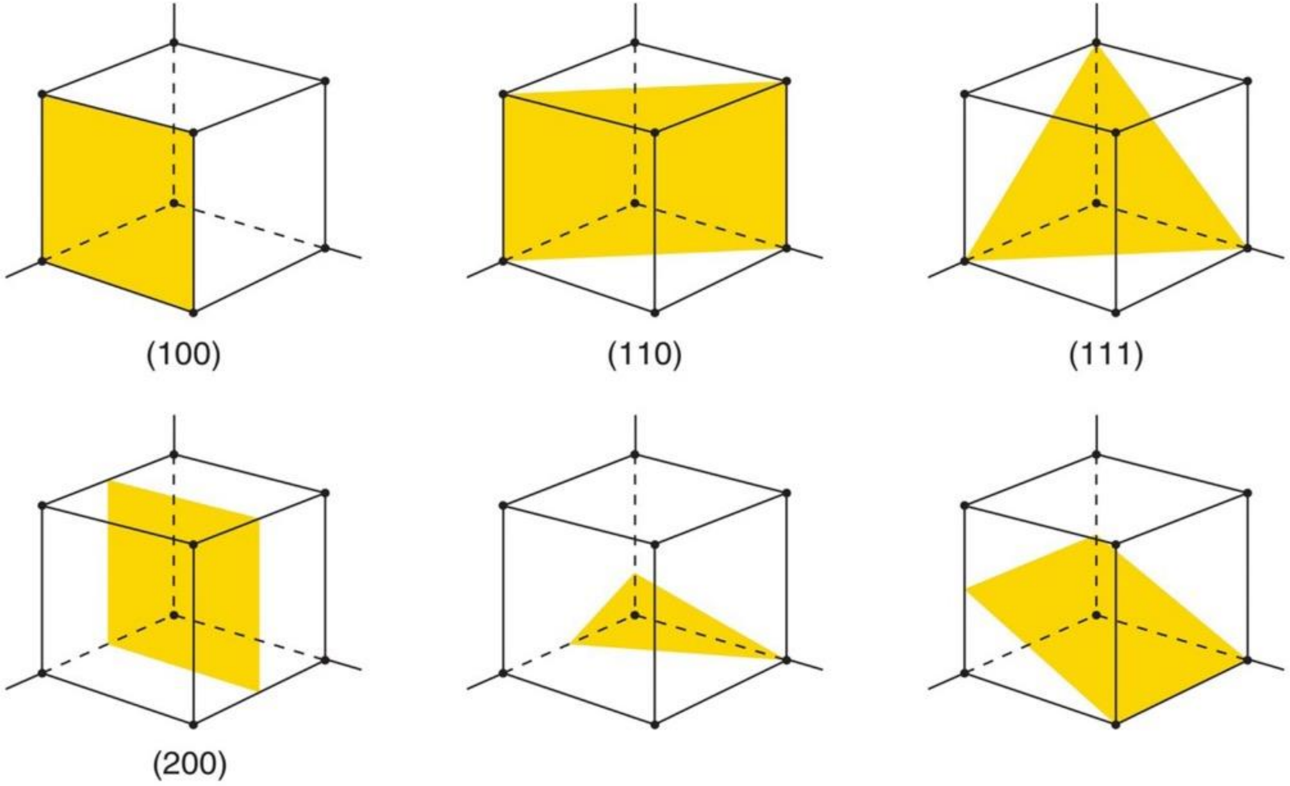


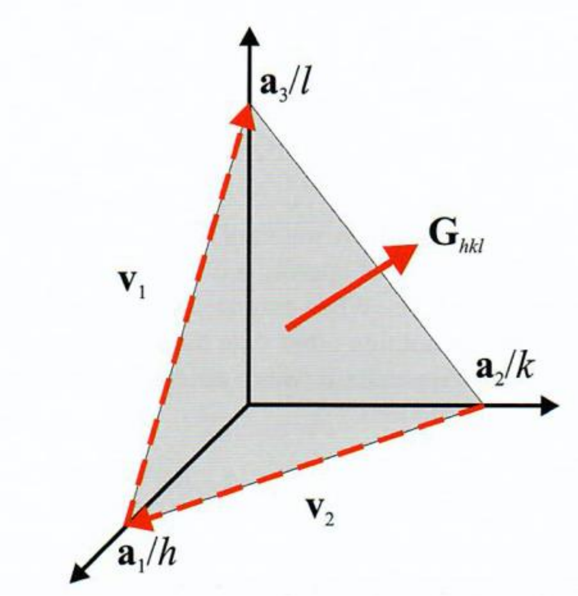
Lattice planes





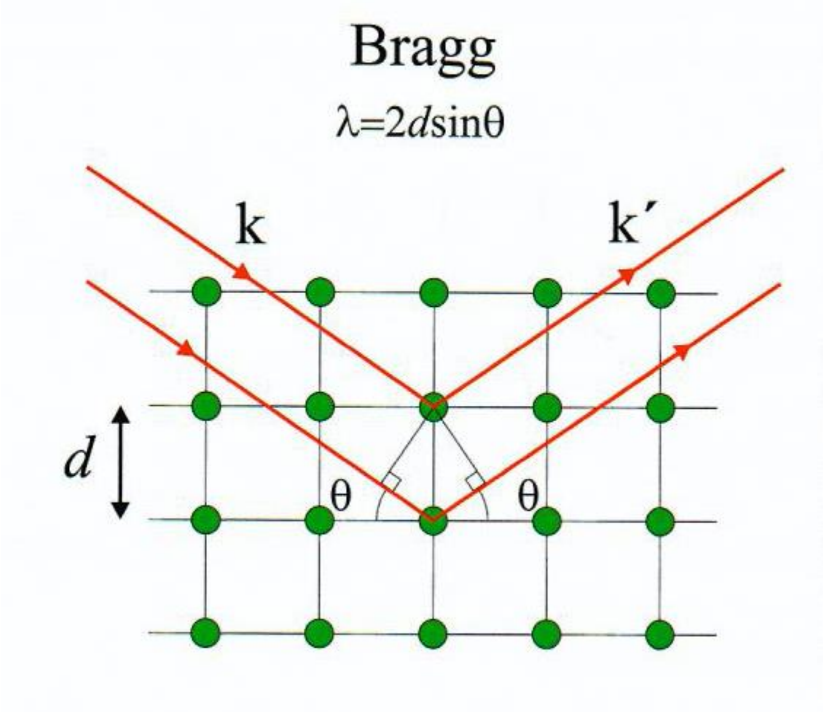
Miller indices

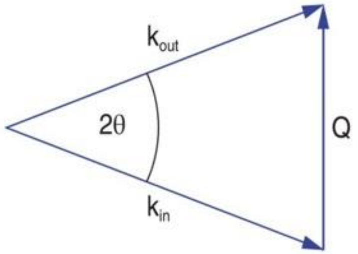




The Nobel Prize in Physics 1915

Bragg scattering





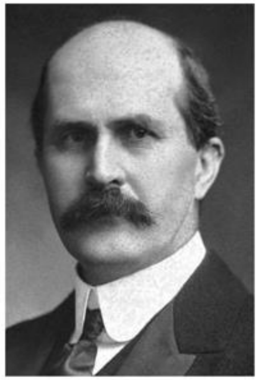


Photo from the Nobel Foundation archive.

Sir William Henry Bragg

Prize share: 1/2

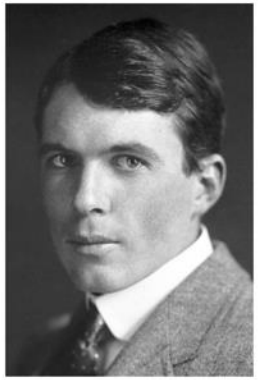
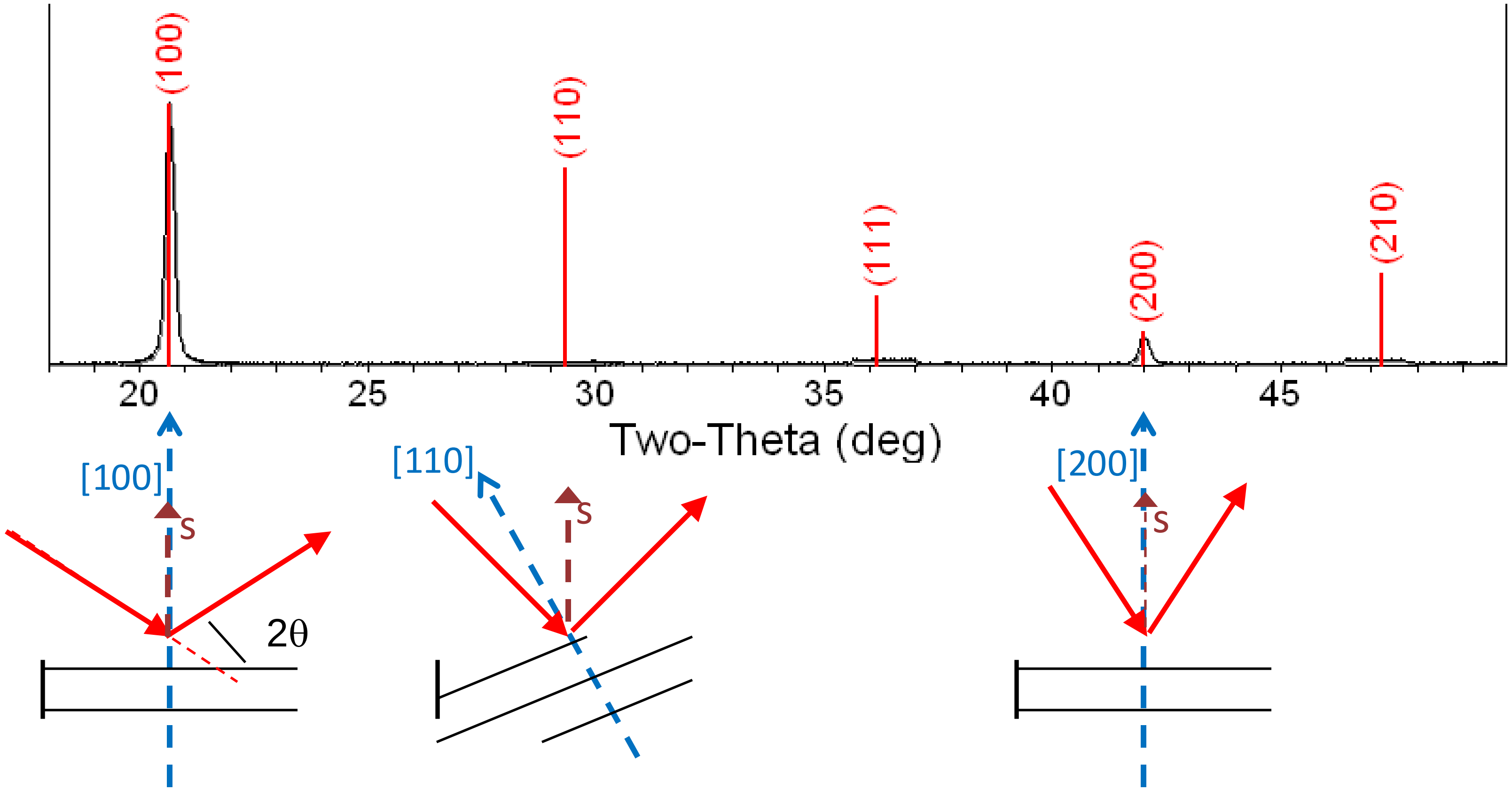


Photo from the Nobel Foundation archive.

William Lawrence Bragg

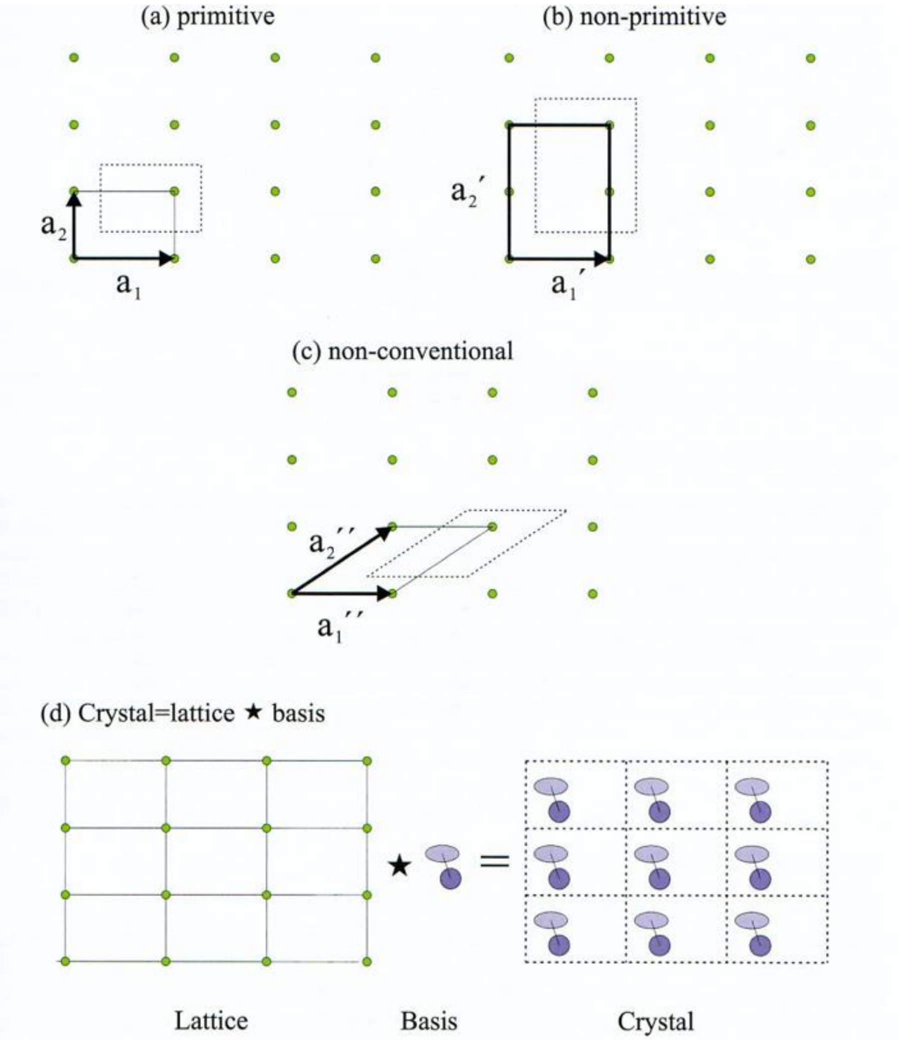
Prize share: 1/2

A single crystal (typically) produces one family of Bragg peaks for fixed geometry and λ



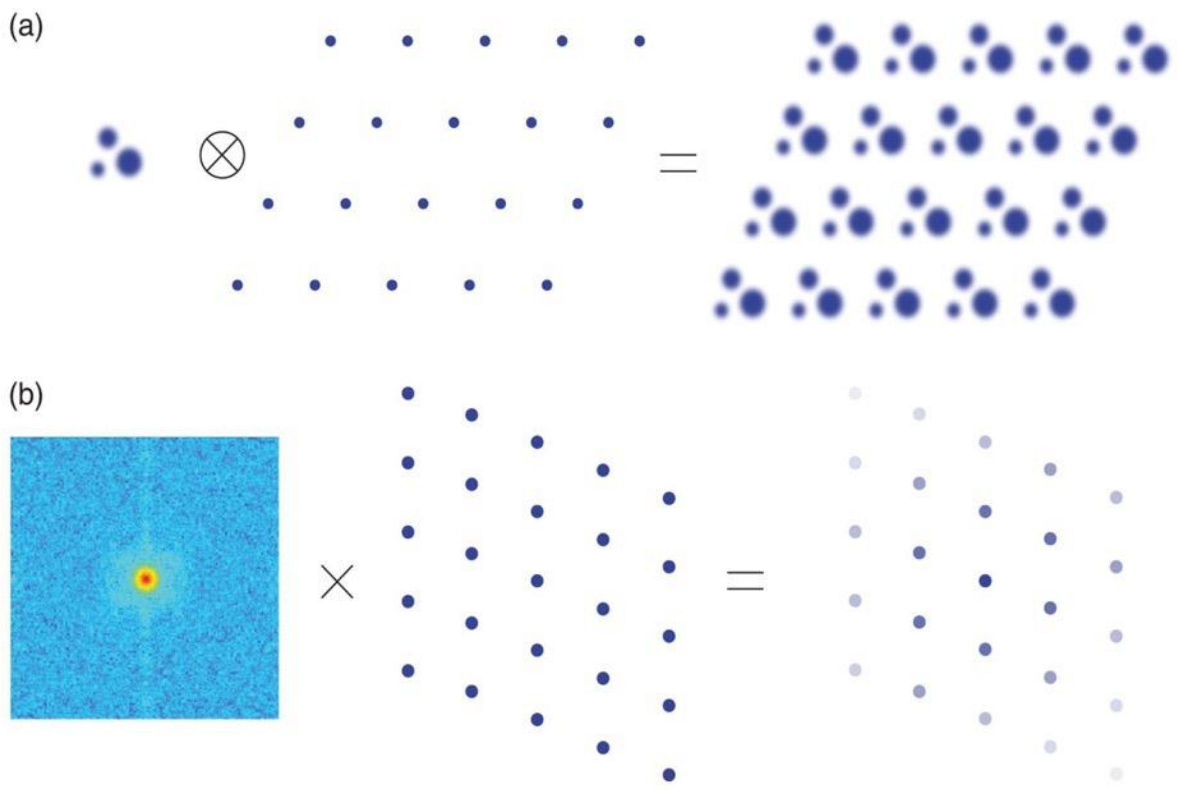
Why care about x-ray diffraction of crystals?

A crystal is defined by ist lattice and basis

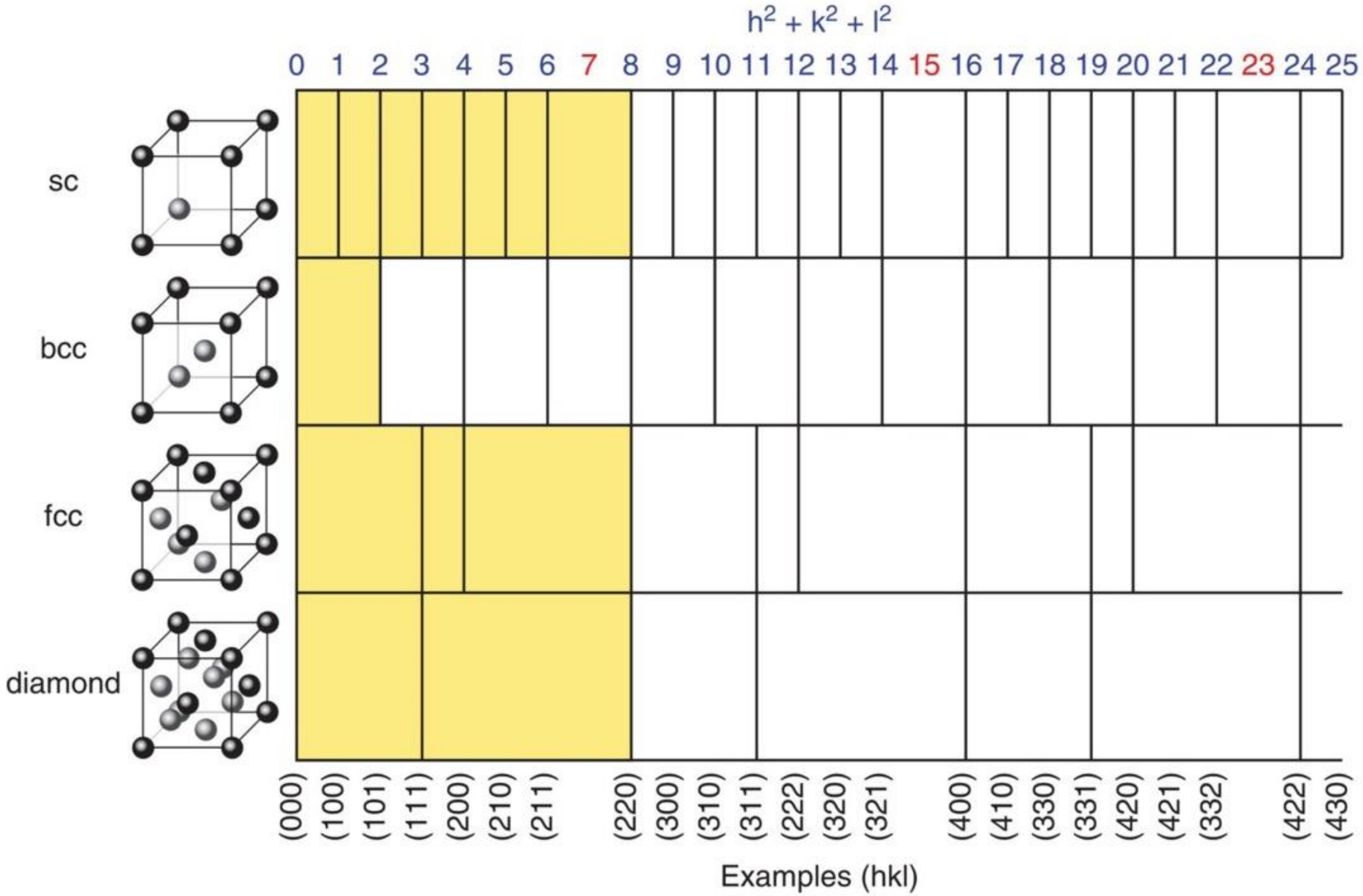


Why and how does it work?

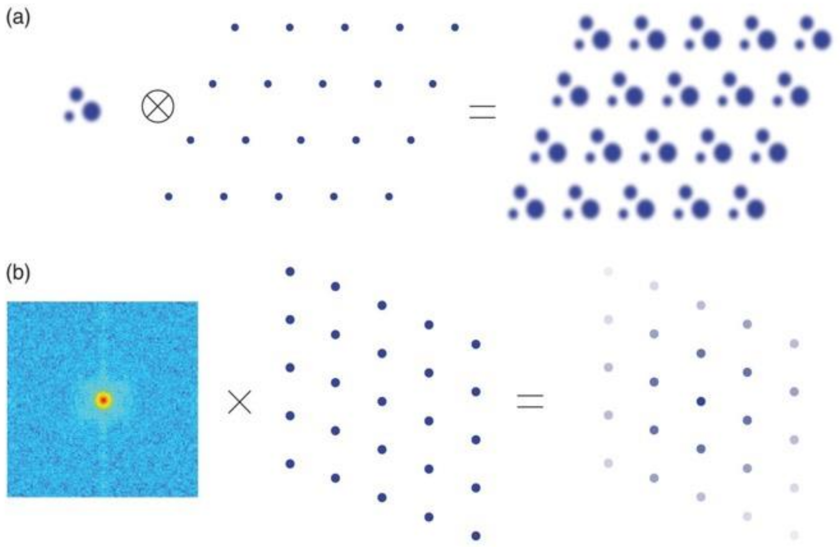
Remember last week:

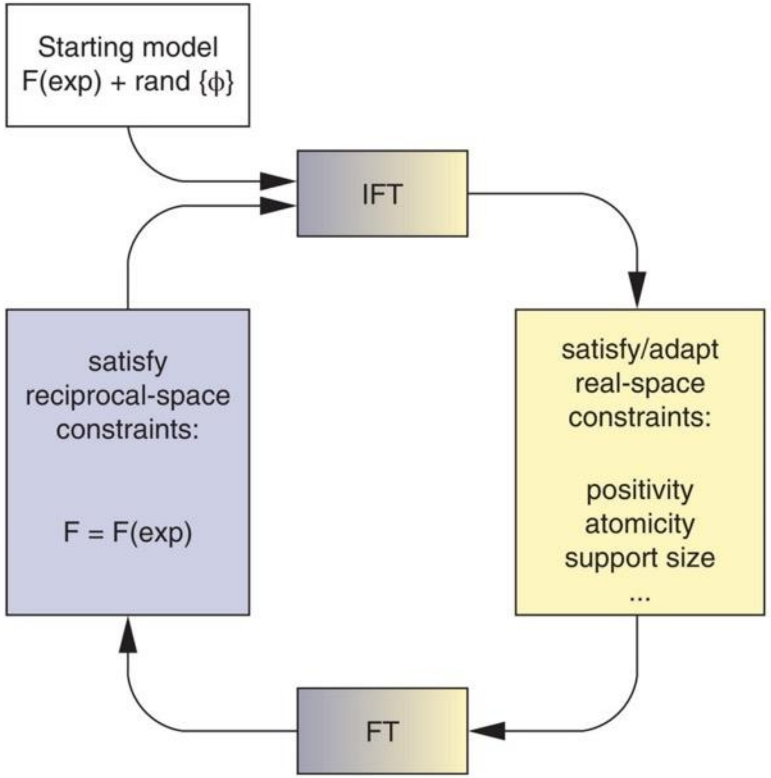


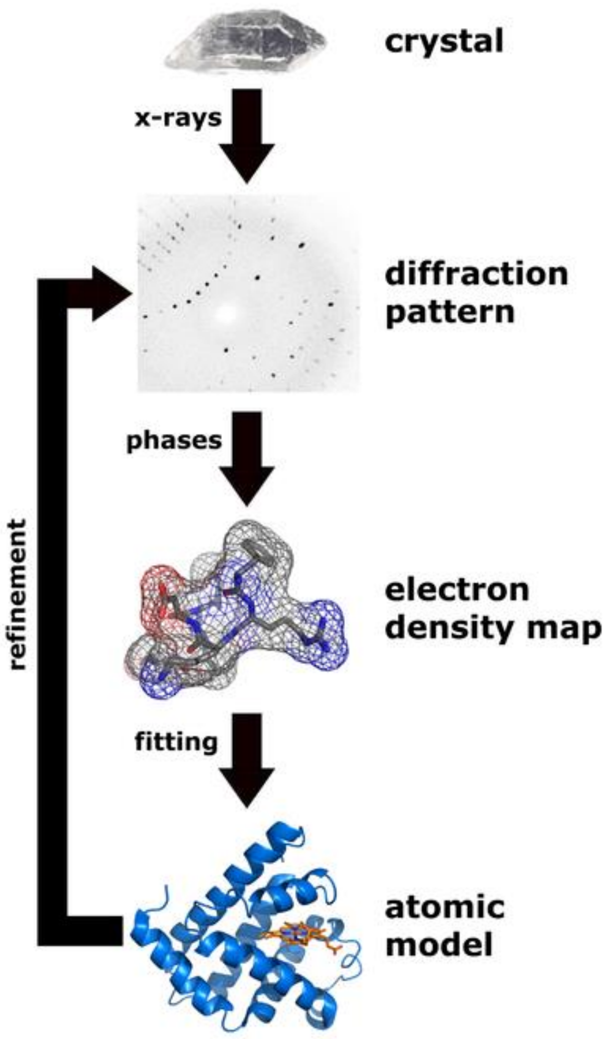
Allowed and forbidden reflections



Solving a crystal structure

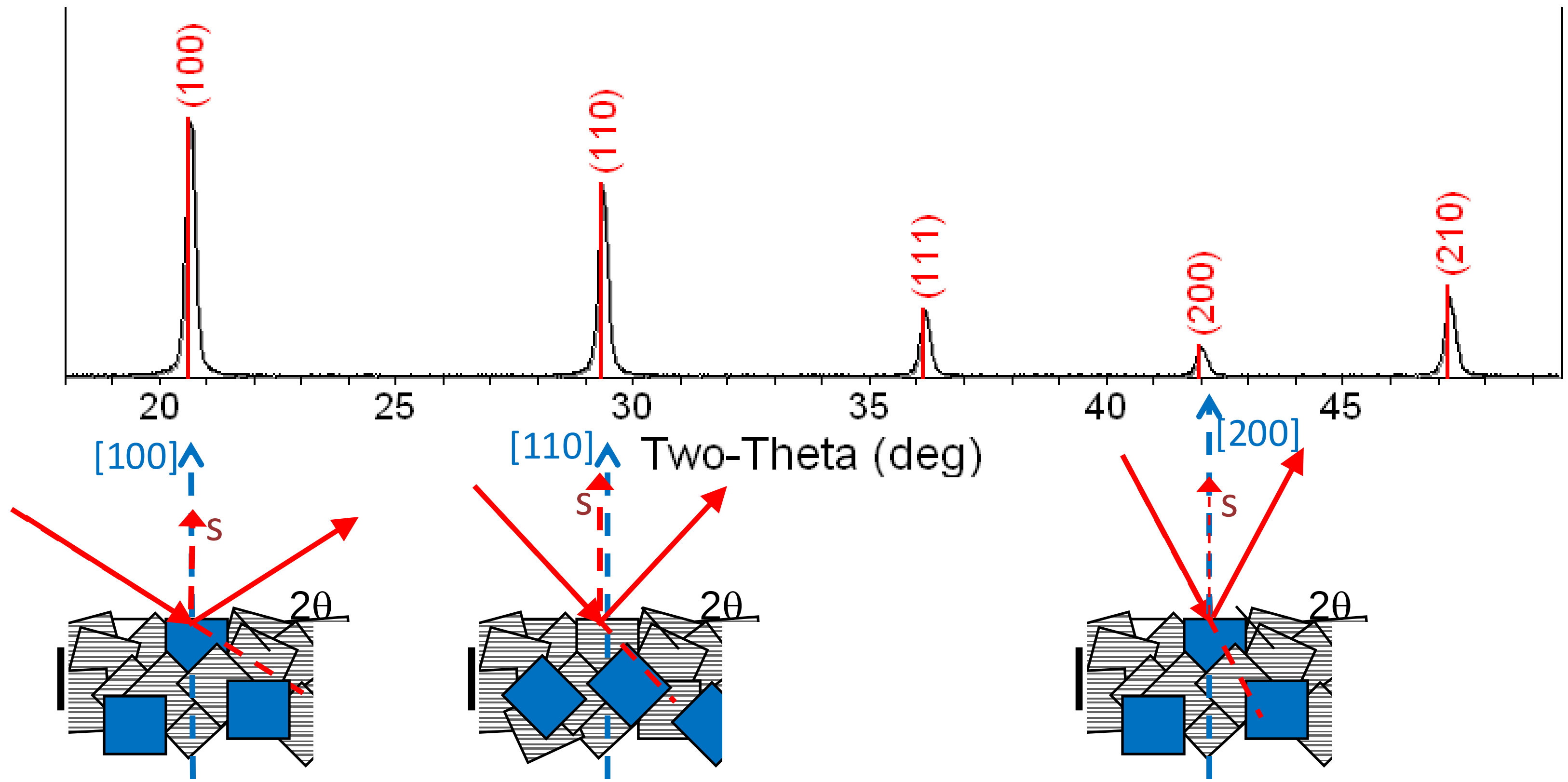




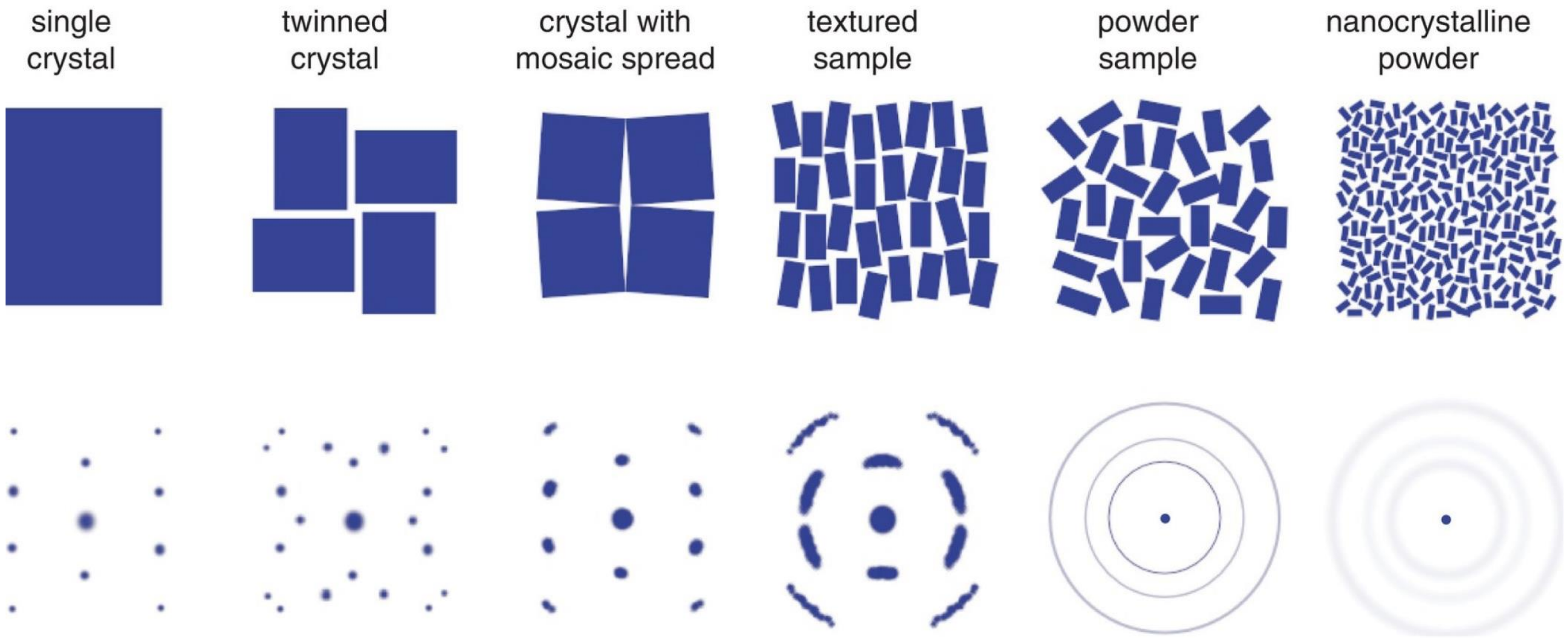


Powder diffraction

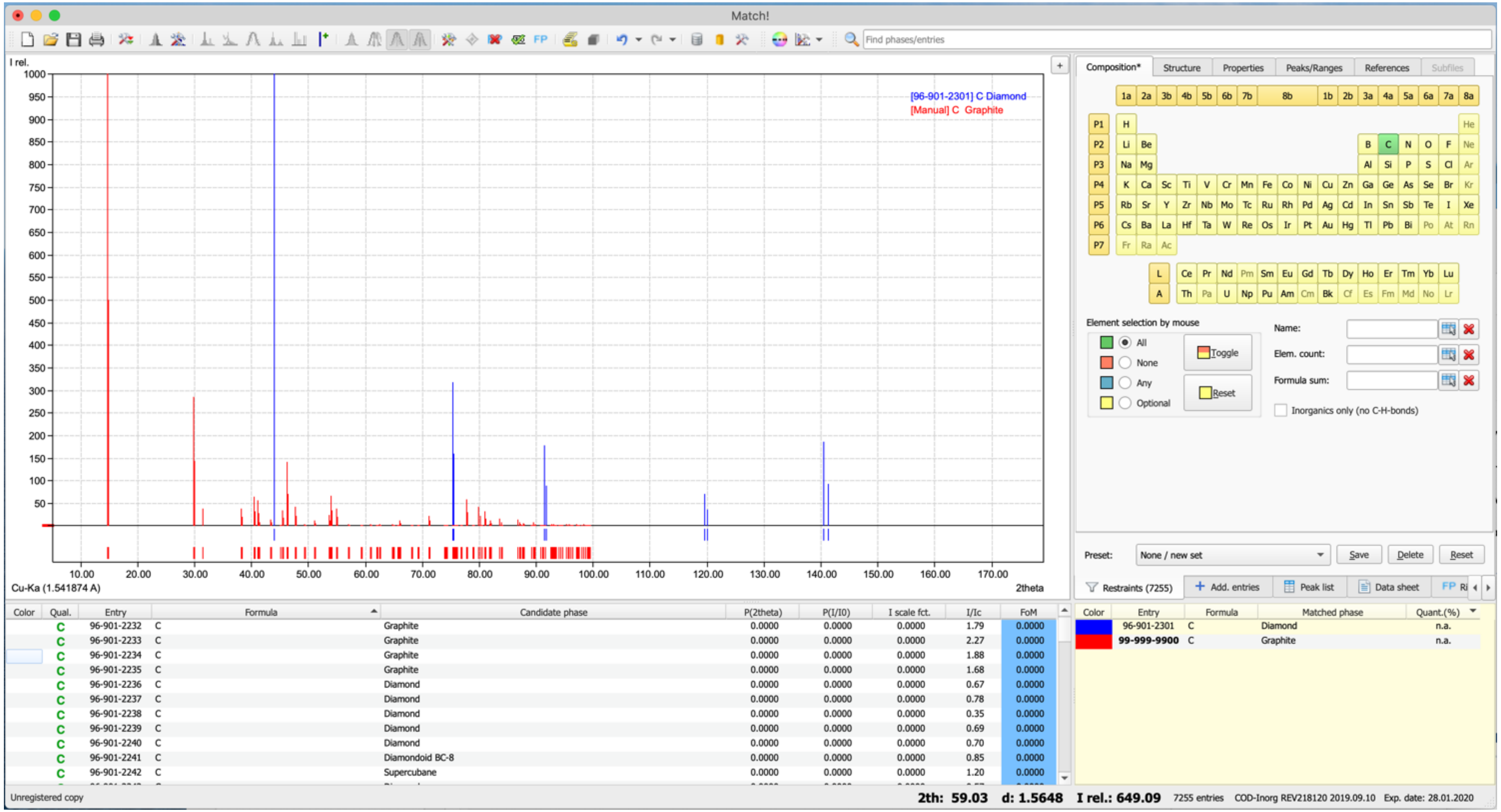
Diffraction of a polycrystalline sample



Diffraction signal of different sample types

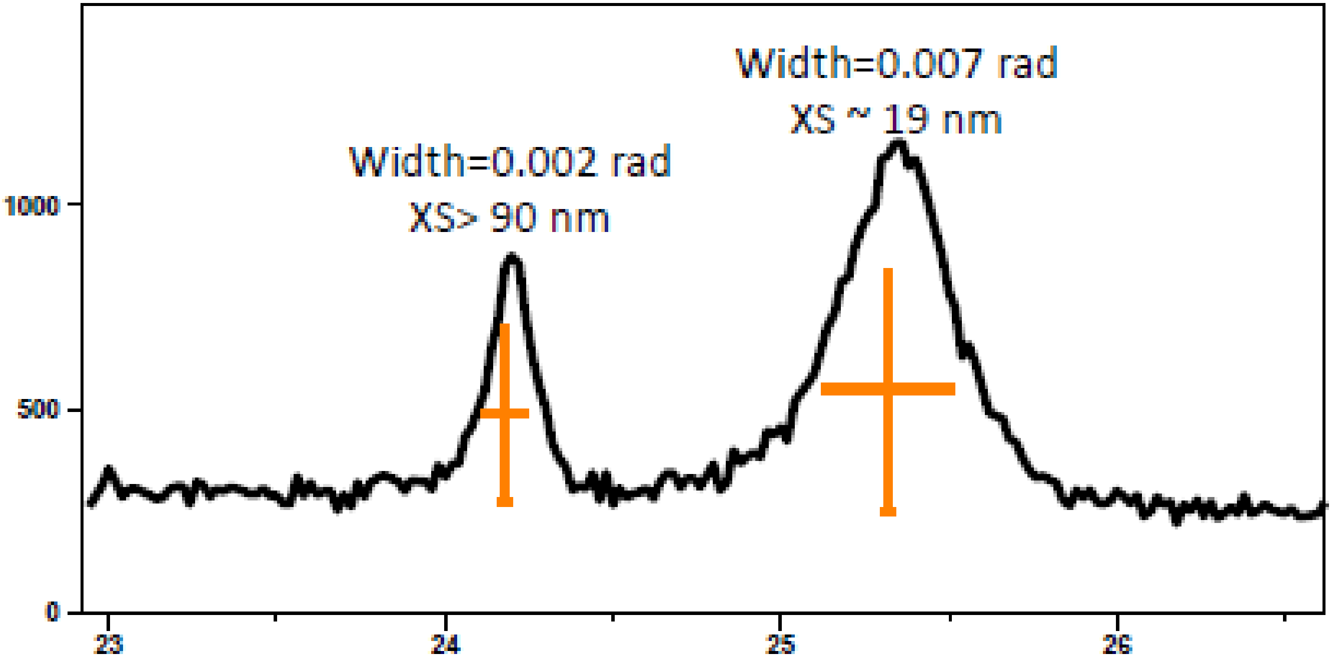


Powder diffraction data bases for elemental analysis

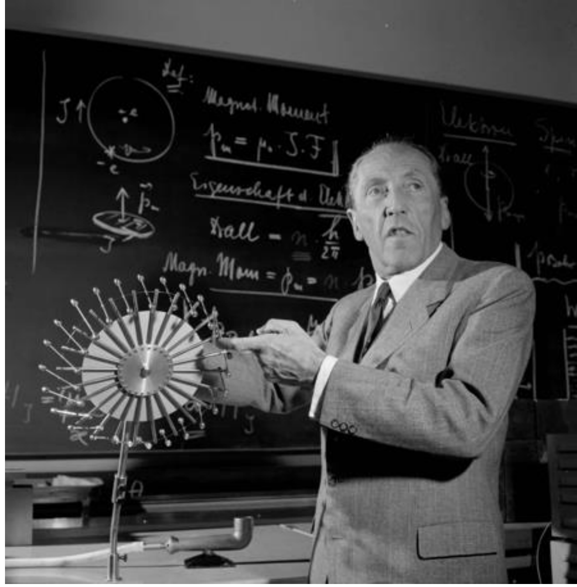


Debye-Scherrer Formula

The diffraction peak width may contain microstructural information



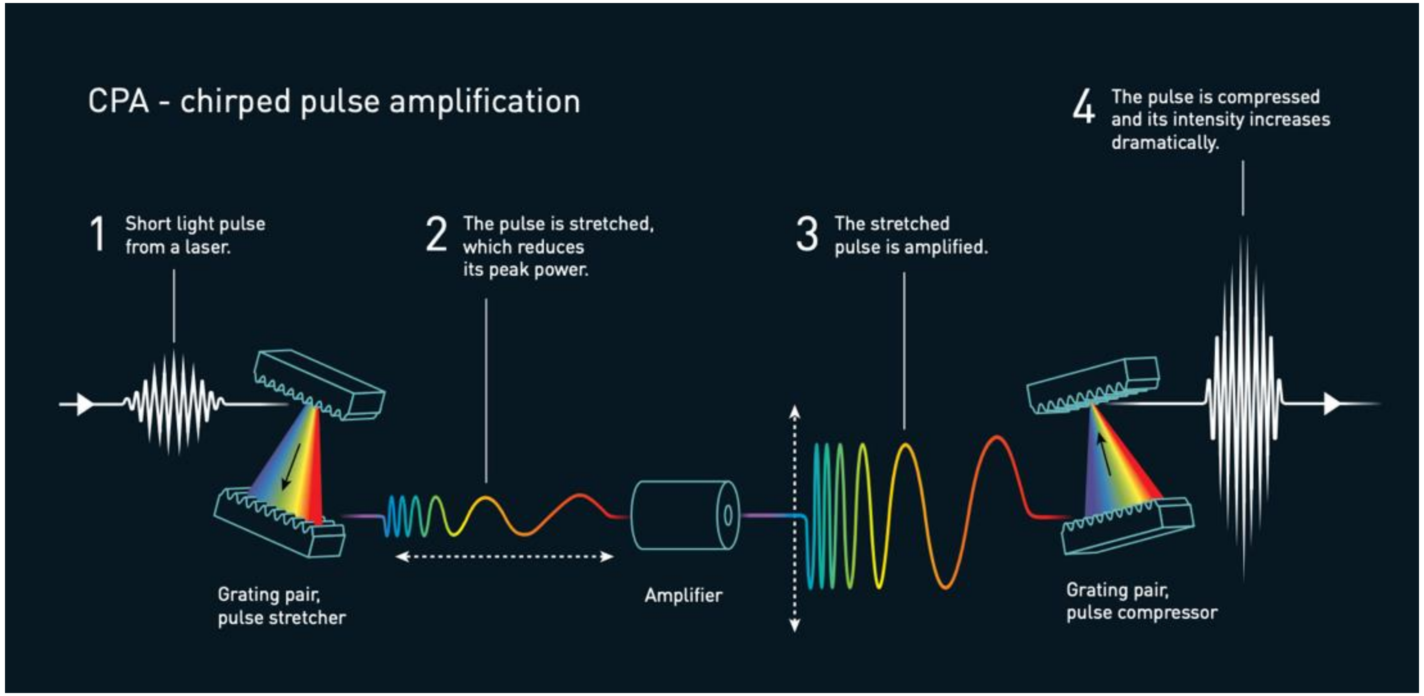
$$Size = \frac{K\lambda}{Width * \cos\theta}$$

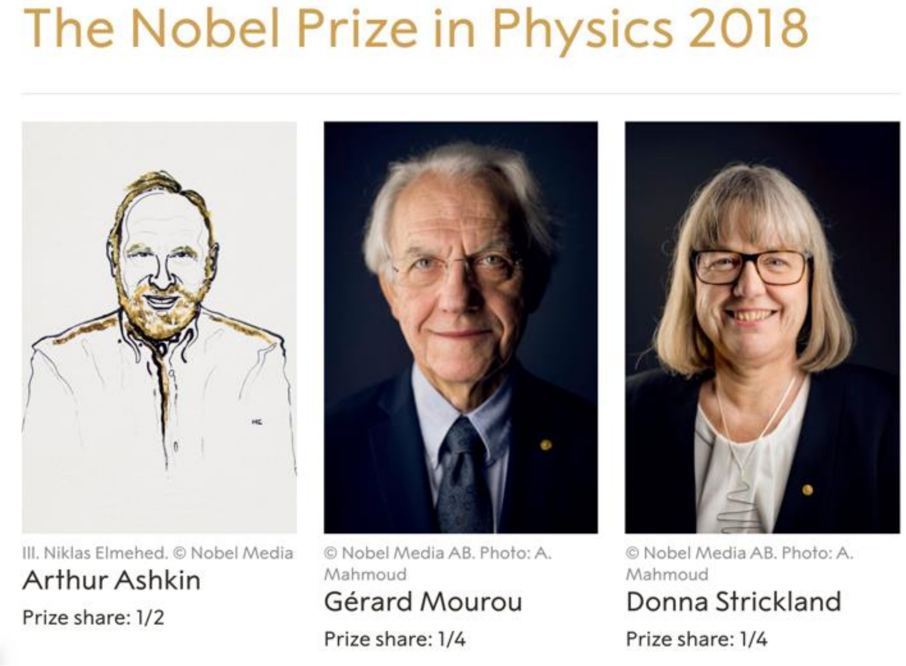


Paul Scherrer
Swiss Physicist (1890-1969)

Things you may want to remember

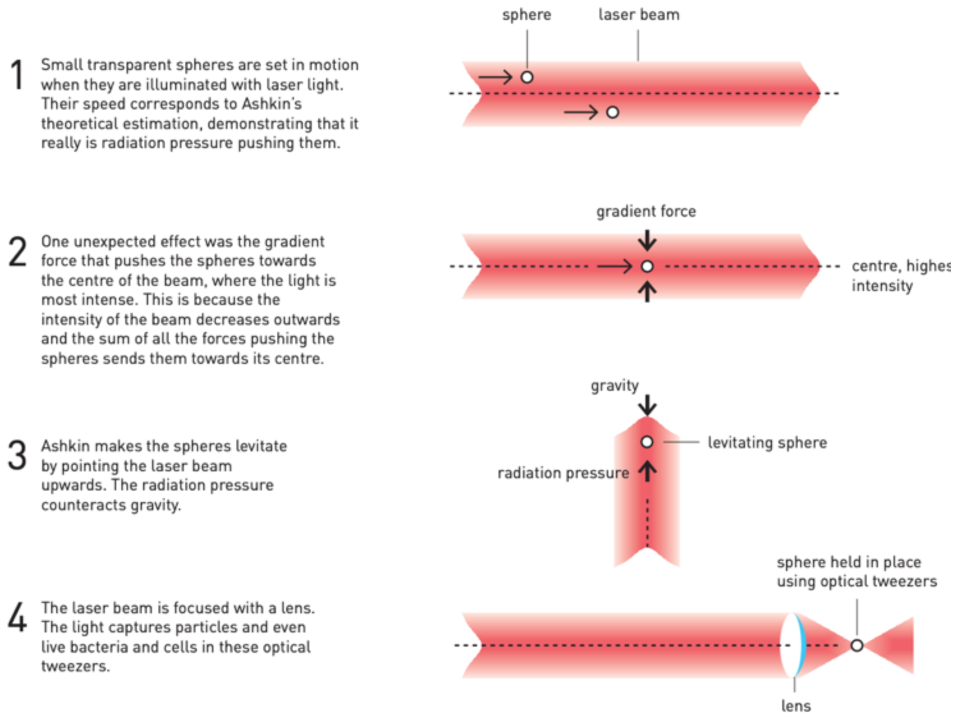
Back to start

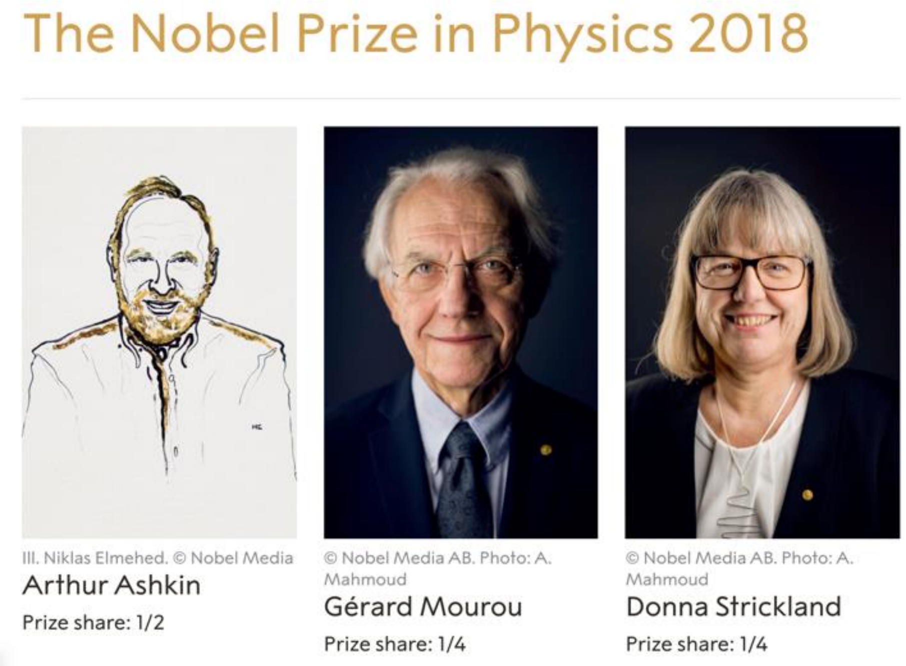




The inventions being honoured this year have revolutionised laser physics. Extremely small objects and incredibly fast processes now appear in a new light. Not only physics, but also chemistry, biology and medicine have gained precision instruments for use in basic research and practical applications. Arthur Ashkin invented optical tweezers that grab particles, atoms and molecules with their laser beam fingers. Viruses, bacteria and other living cells can be held too, and examined and manipulated without being damaged. Ashkin's optical tweezers have created entirely new opportunities for observing and controlling the machinery of life. Gérard Mourou and Donna Strickland paved the way towards the shortest and most intense laser pulses created by mankind. The technique they developed has opened up new areas of research and led to broad industrial and medical applications; for example, millions of eye operations are performed every year with the sharpest of laser beams.

Also in physics

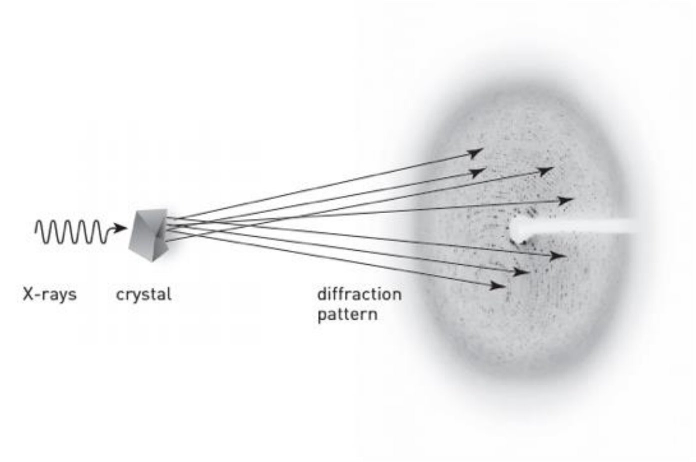




Optical tweezers:
https://www.youtube.com/watch?v=ju6wENPtXu8

The inventions being honoured this year have revolutionised laser physics. Extremely small objects and incredibly fast processes now appear in a new light. Not only physics, but also chemistry, biology and medicine have gained precision instruments for use in basic research and practical applications. Arthur Ashkin invented optical tweezers that grab particles, atoms and molecules with their laser beam fingers. Viruses, bacteria and other living cells can be held too, and examined and manipulated without being damaged. Ashkin's optical tweezers have created entirely new opportunities for observing and controlling the machinery of life. Gérard Mourou and Donna Strickland paved the way towards the shortest and most intense laser pulses created by mankind. The technique they developed has opened up new areas of research and led to broad industrial and medical applications; for example, millions of eye operations are performed every year with the sharpest of laser beams.

Recent examples of applications of light to chemistry



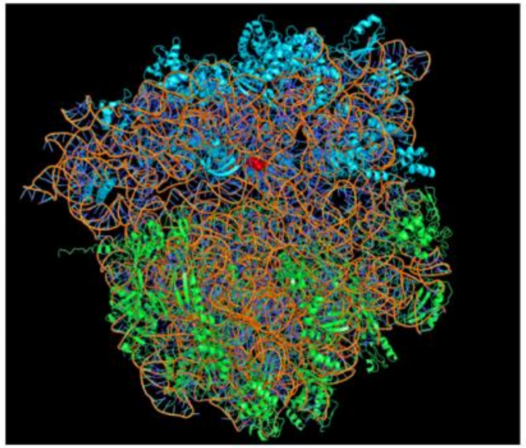


Figure 4. X-ray crystallography. The researchers create X-rays using synchrotrons, circular tunnels where electrons are acceler-ated to nearly the speed of light. When the rays hit the ribosome crystal they scatter, making millions of dots on a CCD detector. By analyzing this pattern, researchers can determine the position of each atom in the ribosome. Special software is used to visualize the ribosome (picture to the right).

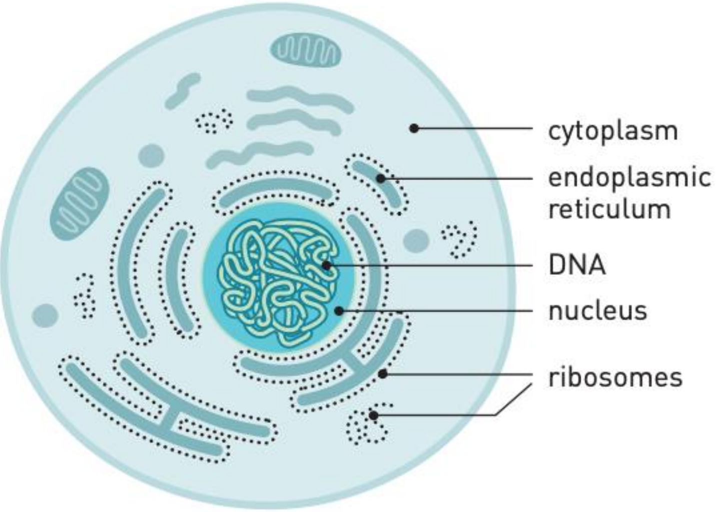
At the beginning of the twentieth century, the chemical foundations for life were a mystery. Today we know how many of the most important processes function, all the way down to the atomic level. The 2009 Nobel Prize in Chemistry is awarded for the detailed mapping of the ribosome – the cell's own protein factory. The ribosome translates the passive DNA information into form and function.

The Nobel Prize in Chemistry 2009

Venkatraman Ramakrishnan
Prize share: 1/3

Thomas A. Steitz
Prize share: 1/3

Ada E. Yonath
Prize share: 1/3



The Nobel Prize in Chemistry 1999

Recent examples of applications of light to chemistry

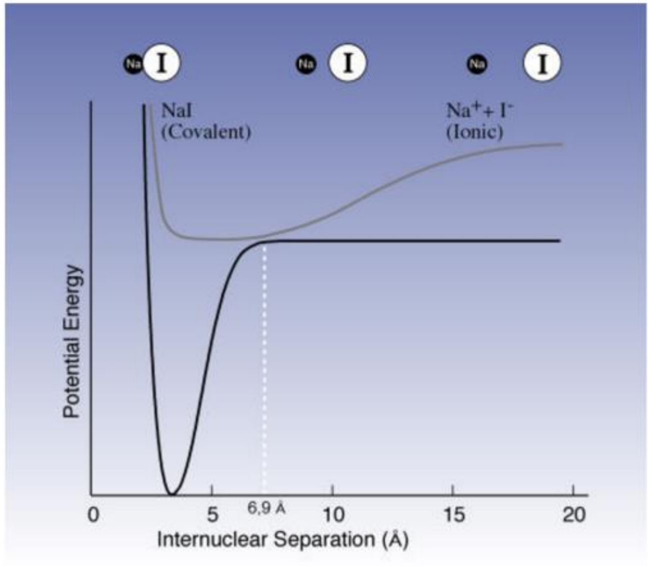


Fig. 1a) Potential energy curves showing the energies of ground state (bottom curve with deep minimum) and excited state (top curve) for NaI as function of the distance between the nuclei.

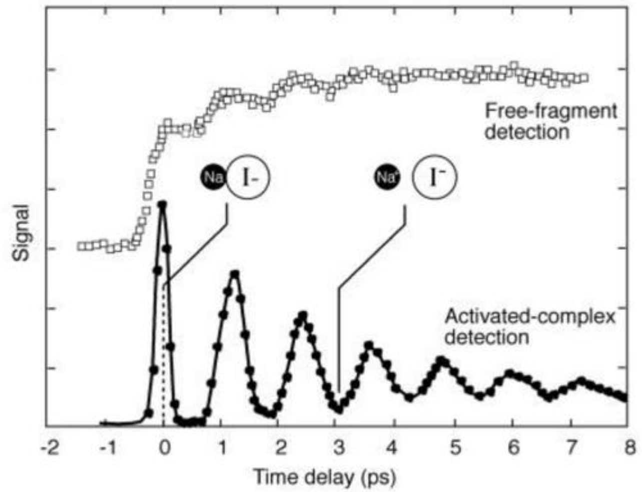


Fig. 1b) Experimental observations of coherent vibrations (so-called wave-packet motion) in femtosecond-excited NaI, on one hand manifested in terms of amount of activated complex [Na-I] at covalent (short) distance, on the other*

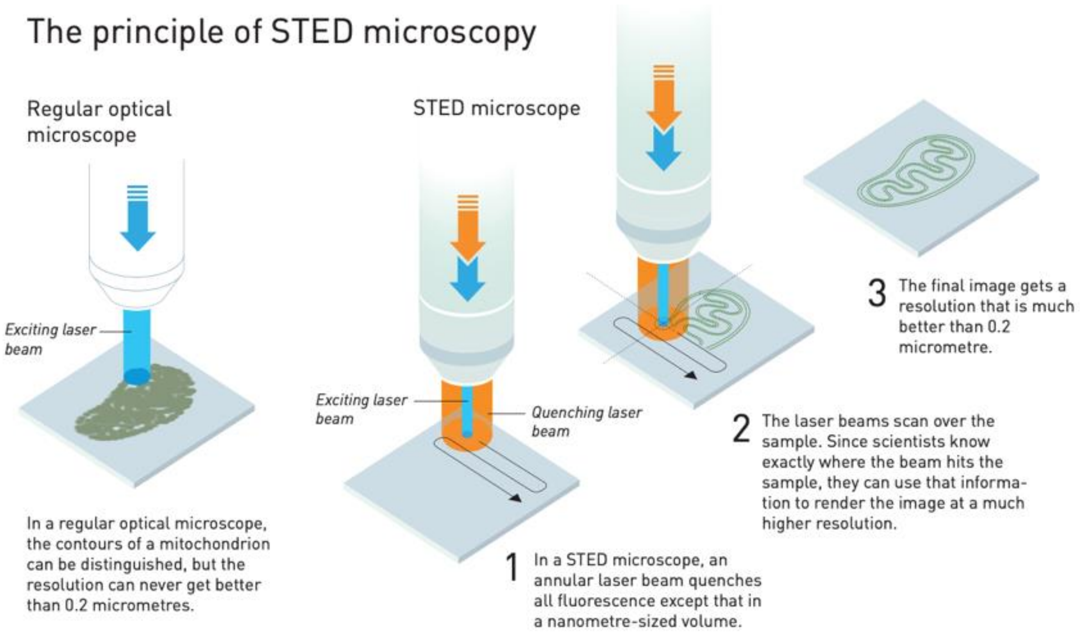
Photo from the Nobel Foundation archive.

Ahmed H. Zewail

Prize share: 1/1

This year's Nobel Laureate, Professor Ahmed Zewail, is rewarded for his pioneering investigations of chemical reactions on the time-scale they really occur. This is the same timescale on which the atoms in the molecules vibrate, namely femtoseconds (1 fs = 10-15 seconds). Only recently have developments in laser technology enabled us to study such rapid processes, using ultra-short laser flashes. Professor Zewail's contributions have brought about a revolution in chemistry, with consequences for many other fields of science, since this type of investigation allows us to understand and predict important processes.

Last comment: Remember session 1?
Recent examples of applications of light to chemistry



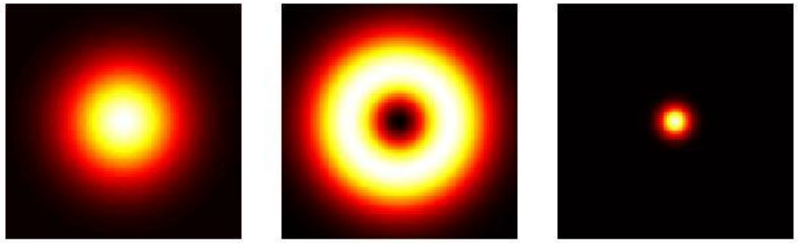
Eric Betzig, Stefan W. Hell *and* ***William E. Moerner*** *are awarded the Nobel Prize in Chemistry 2014 for having bypassed a presumed scientific limitation stipulating that an optical microscope can never yield a resolution better than 0.2 micrometres. Using the fluorescence of molecules, scientists can now monitor the interplay between individual molecules inside cells; they can observe disease-related proteins aggregate and they can track cell division at the nanolevel.*

Stefan Hell: Stimulated Emission Depletion Microscope (STED)

- Based on Fluorescence Microscope
- Based on Laser Scanning Microscope

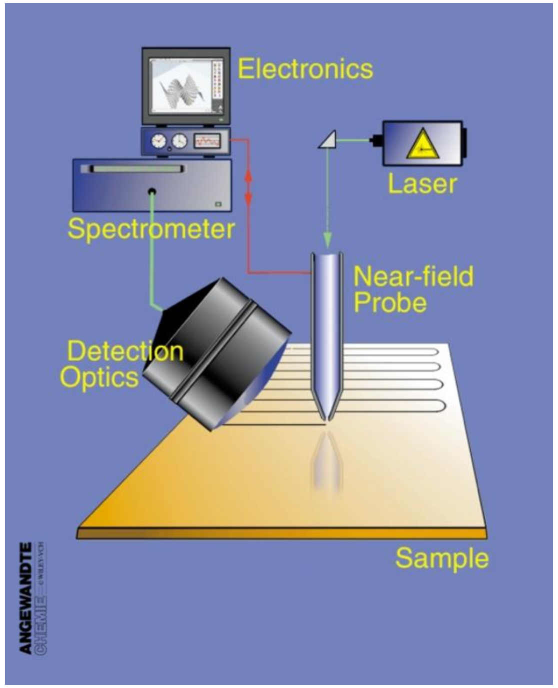
But with Important additional concepts:

Remember Gaussian, Bessel beams, focal spots

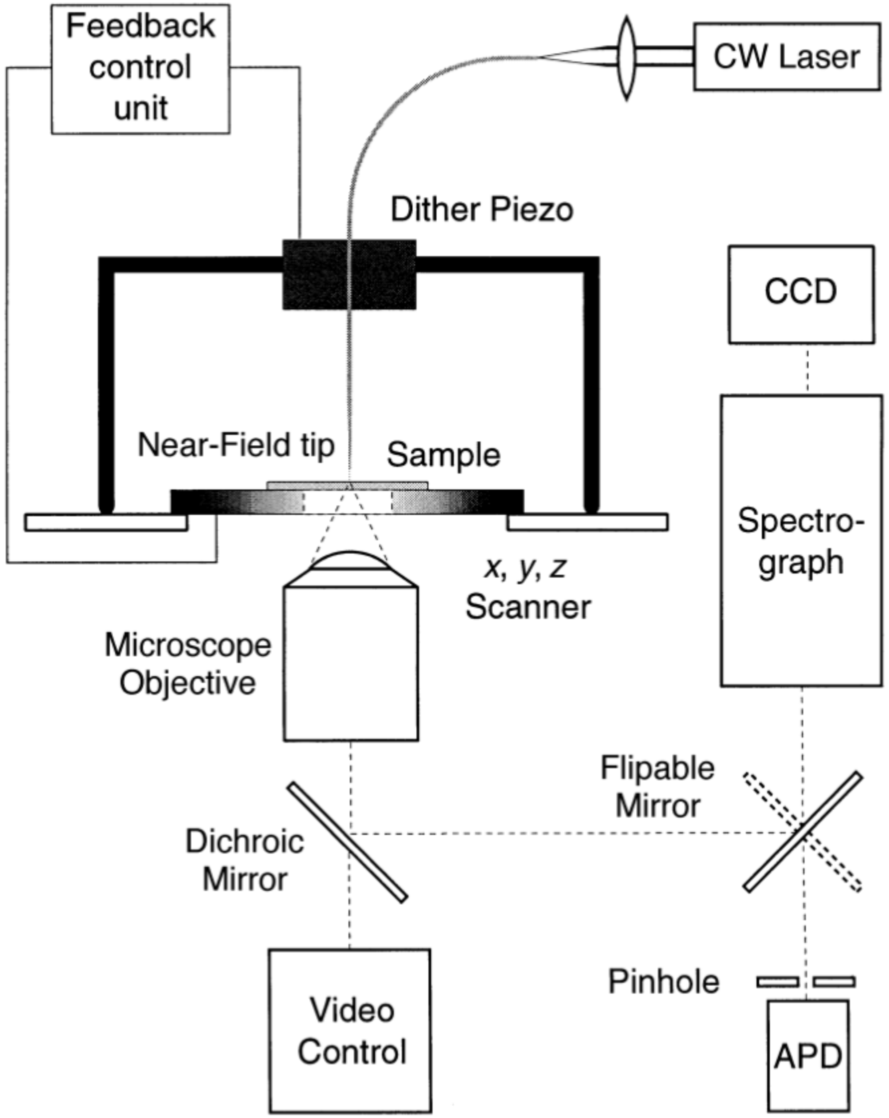


Enjoy video: https://www.youtube.com/watch?time_continue=428&v=0NCNy6pVIZE

SNOM – Scanning Near Field Optical Microscope



Zenobi and Deckert, Angew. Chemie Review, 2000



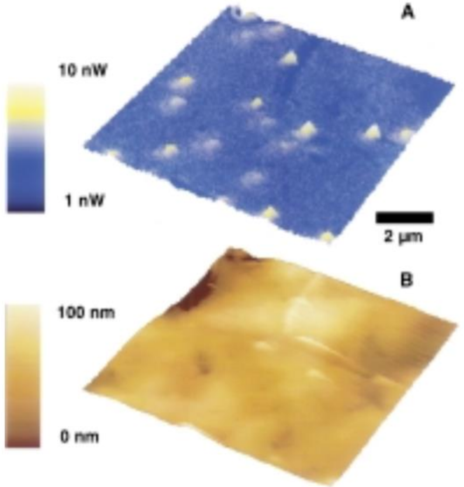


Figure 4. A) SNOM/fluorescence image and B) topographic image of a 10 × 10 µm area of a PVB film containing fluorescent microspheres. The spheres had a diameter of 288 nm. The fluorescence was excited with the 488 nm line of an Ar-ion laser.