Foundations of Medical Physics

1. Could be considered as the first part of **Medical Biophysics** course in the second semester. The two courses form one unit.
2. **Summary** and **overlook** of the physical bases with new “medical” aspects.
3. **It is not a premedical course of elementary physics.** If you do not know the basic physical quantities and laws, you have to learn it from textbooks or internet (e.g. HyperPhysics in Google)!

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Why do we learn it?

Reasons:

1. The structure and function of human body,
2. the methods, techniques, equipments of medical diagnosis and therapy have bases of natural science.

φυσιζ = nature
physics = natural science

It is interesting that the meaning of
„physic” = „art of healing, medical science”

3. Medical mentality
logical, analyzing, systematic,
an important peculiarity is the continual skepticism.

Purposes:

I. To get knowledge
II. Solving problems, methods
III. Approach, attitude of mind

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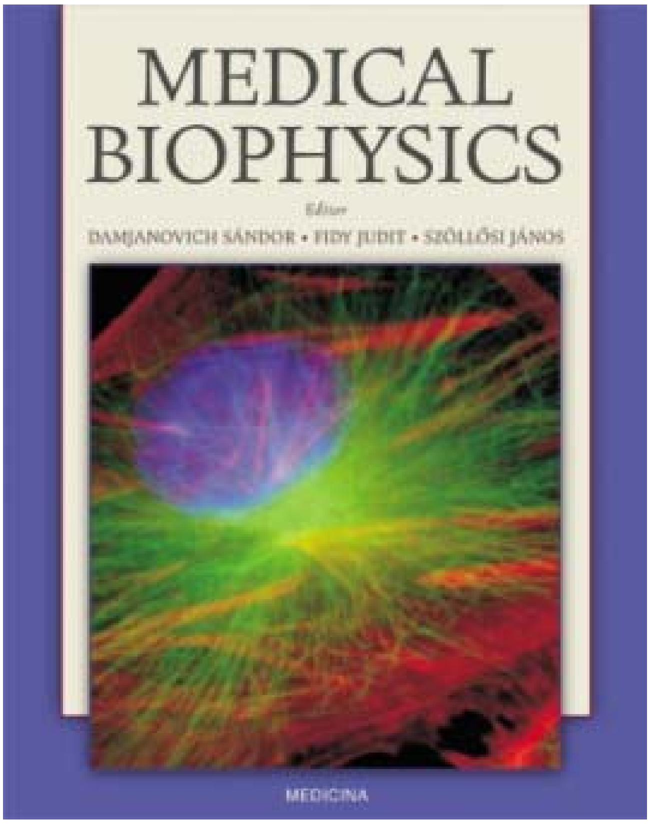
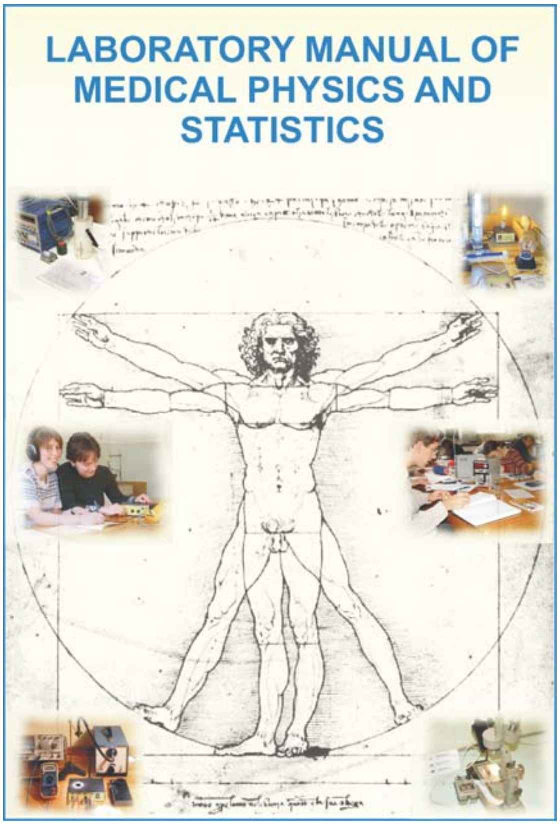
Suggested textbook and manual:
(they are usable for second semester as well)

Medical Biophysics
Editors: Damjanovich Sándor, Fidy Judit, Szöllősi János
Medicina

LABORATORY MANUAL OF MEDICAL PHYSICS AND STATISTICS
Authors: staff of the Institute of Biophysics and Radiation Biology





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Mathematical bases

Need not too much, but…

e.g. $\log(ab) = ?$, $\log a^b = ?$

Simple functions and their graphical representations

e.g. $f(x) = ax + b$ or $f(x) = a \sin(x - b)$

Usage of calculators, calculation with exponents

EE or EXP or $\times 10^x$ and not $\mathbf{y^x}$

How much is the circumference and area of a circle,
or the surface area and volume of a sphere?

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Physical quantities, units, prefixes, orders of magnitude

We need accurate definitions.

e.g.. „radiation" is not a physical quantity, thus we can not speak about its decrease and increase.

Sometimes definition is a simple formula, but it could be a measuring instruction with several conditions (see in 2nd semester e.g. dosimetry).

Notations:

p could be momentum, but pressure or permeability as well.

A numerical data without unit tells nothing.

If the units are known they could help.

e.g. What is the simple connection among
the speed of light (c [m/s]),
its wavelength (λ [m]) and
its frequency (f [1/s])?

$\cancel{c = \lambda/f}$, or $\cancel{c = f/\lambda}$, either $\boldsymbol{c = \lambda f}$?

Prefixes: (**you should know**)

10^{-18}	atto	a
10^{-15}	femto	f
10^{-12}	pico	p
10^{-9}	nano	n
10^{-6}	micro	μ
10^{-3}	milli	m
10^{-2}	centi	c
10^{-1}	deci	d
10^{0}		
10^{1}	deka	da
10^{2}	hecto	h
10^{3}	kilo	k
10^{6}	mega	M
10^{9}	giga	G
10^{12}	tera	T
10^{15}	peta	P
10^{18}	exa	E

Order of magnitudes:

e.g.	aJ	~ atomic energy
	fm	~ size of a nucleus
	pm	~ wavelength of x-ray
	GW	~ power of the nuclear power plant in Paks

Remark: have to know the greek letters and their conventional meanings

e.g. $\Delta x = x_2 - x_1$

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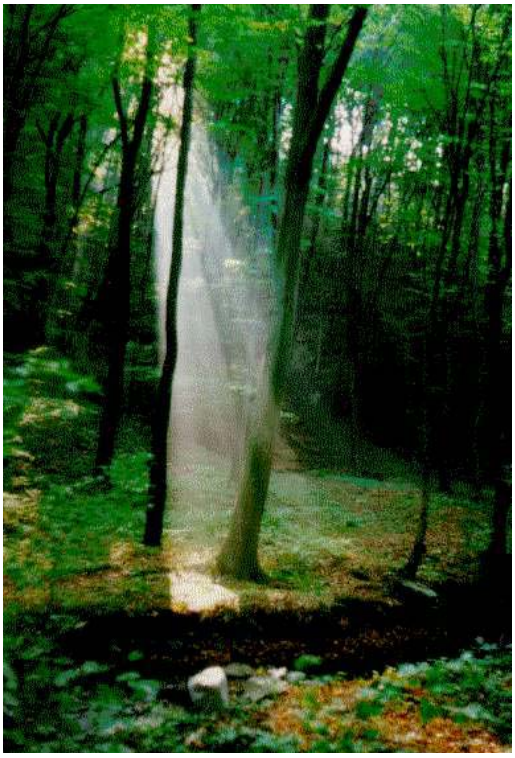
Geometrical and wave optics

What is light? Visible electromagnetic radiation



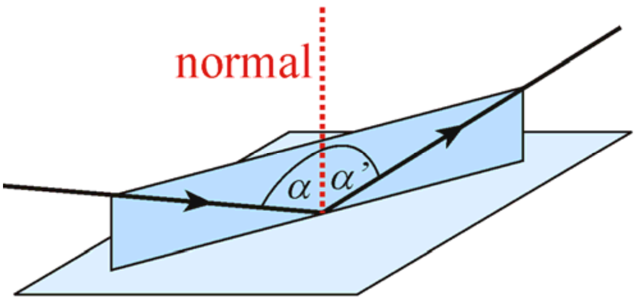
Geometrical optics (model)

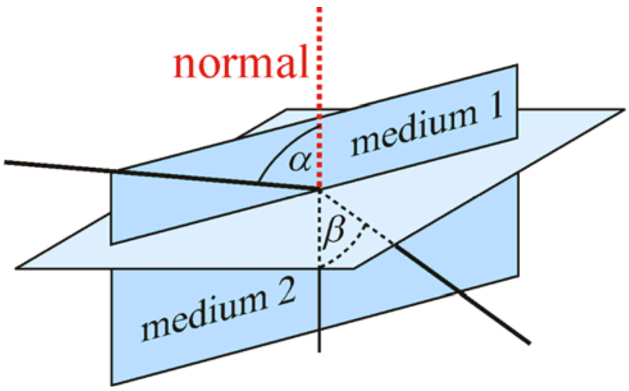
Light-ray: extremely thin parallel light beam

Using this model, the explanation of several optical phenomena can be given as the solution of simple **geometric problems**.

1. law of rectilinear propagation
2. law of reflection
3. law of refraction

2a, 3a) The incident ray, the normal and the reflected ray, or refracted ray lie in the same plane.





2b) $\alpha = \alpha'$

3b) $$\frac{\sin\alpha}{\sin\beta} = \frac{c_1}{c_2} = n_{21} = \frac{n_2}{n_1}$$

($c_1 > c_2$ thus $n_1 < n_2$)

All the angles are measured from the normal!

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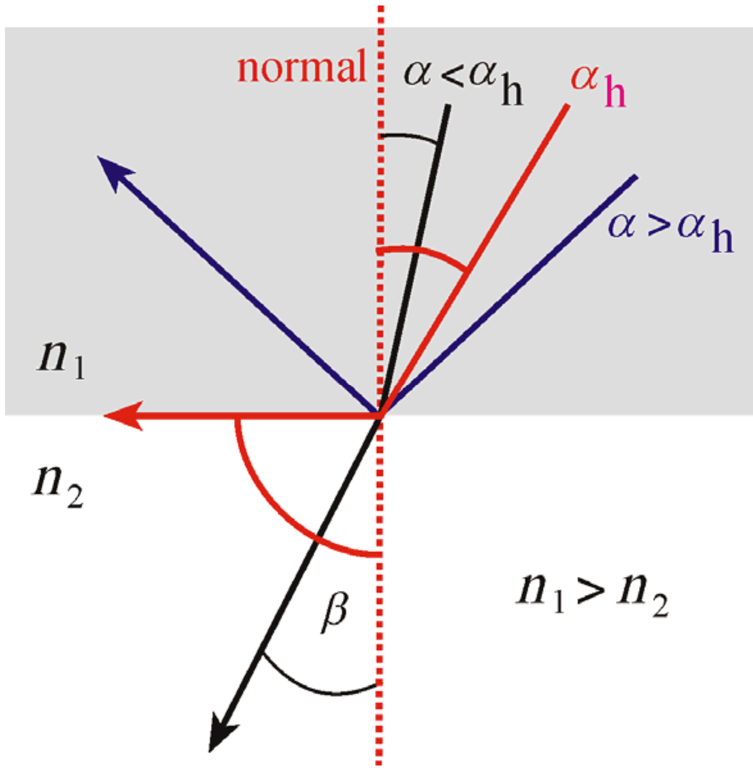
All these laws can be deduced from a single common principle!

Fermat-priciple

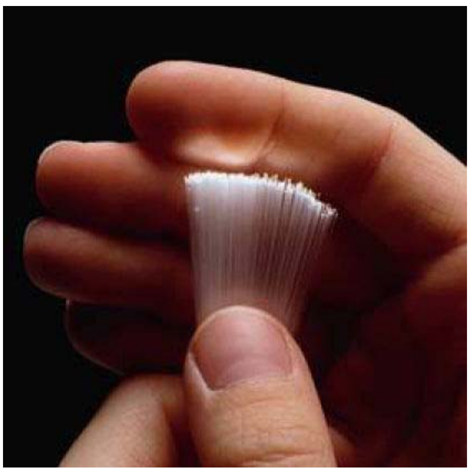
The **'principle of shortest time'**: out of the geometrically possible paths, light will travel along the one that requires the shortest time to pass.

Total reflection
(If $n_1 > n_2$)

$$\frac{\sin \alpha_h}{\sin \frac{\pi}{2}} = \sin \alpha_h = \frac{n_2}{n_1}$$



Application e.g.: Optical fiber (endoscopy)



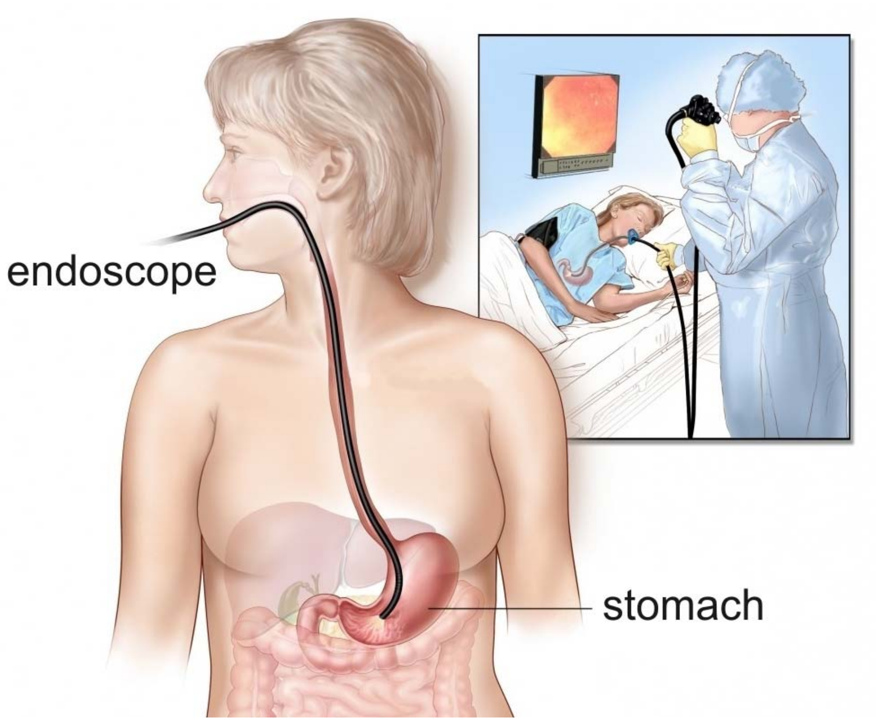


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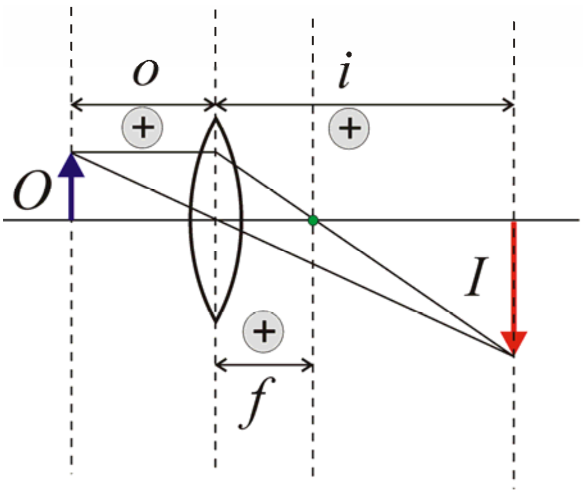
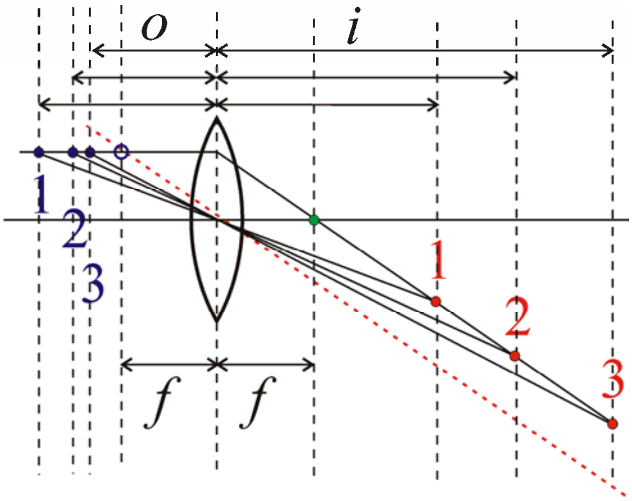
Image formation by lenses (thin lens approximation)





Lens equation and **lens-makers' equation**:

$$\frac{1}{o}+\frac{1}{i}=\frac{1}{f}=(n-1)\left(\frac{1}{r_1}+\frac{1}{r_2}\right)$$

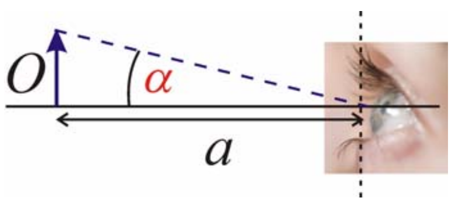
r_1, r_2: radii of curvature of the lens surface,

n: refractive index of the medium of the lens.

Simple magnifier

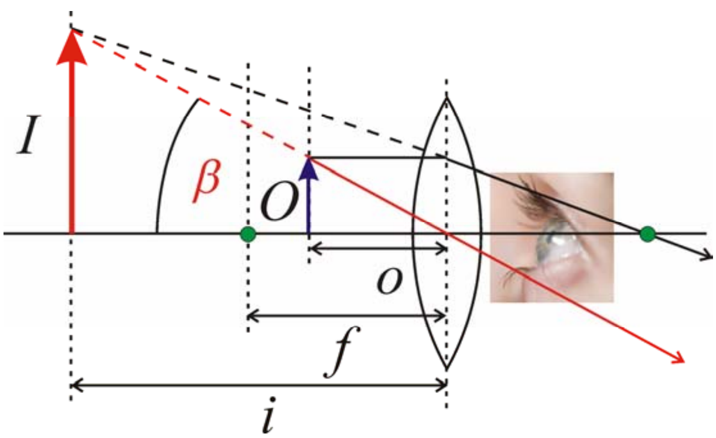
We have to compare two cases: eye looks at the O object

1. without lens from the conventional near point ($a \approx 25$ cm), under the angle of α



2. with lens from the distance o, under the angle of β

I virtual image



Angular magnification (definition):

$$N = \frac{tg\beta}{tg\alpha} \qquad \text{and we use} \qquad \frac{1}{o} = \frac{1}{f} - \frac{1}{i}$$

In our case (simple magnifier):

$$N = \frac{tg\beta}{tg\alpha} = \frac{\dfrac{I}{i}}{\dfrac{O}{a}} = \frac{\dfrac{O}{o}}{\dfrac{O}{a}} = \frac{a}{o} = a\left(\frac{1}{f} - \frac{1}{i}\right).$$

Two possible answers:

I. if $i = -a$ than $N = \dfrac{a}{f} + 1,$

II. if $i = -\infty$ than $N = \dfrac{a}{f}$

In the I. case eye looks at the virtual image with accommodation, in the II. case without accommodation, eye is focused at infinity, thus $o = f$.

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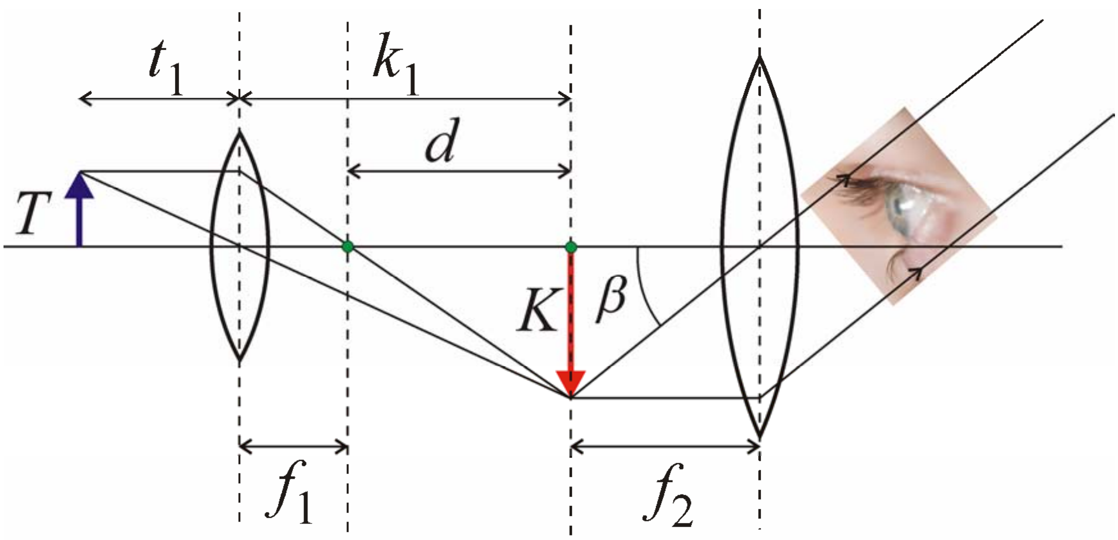
Lens systems (1) microscope



Without accommodation, eye is focused at infinity.

Angular magnification of microscope:

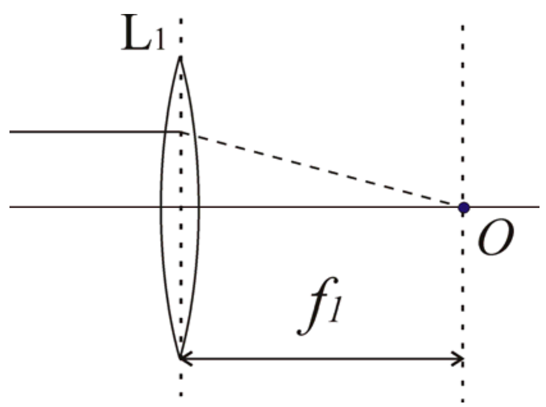
$$N=\frac{tg\beta}{tg\alpha}=\frac{\dfrac{I}{f_2}}{\dfrac{O}{a}}=\frac{I}{f_2}\frac{a}{O}=\frac{I}{O}\frac{a}{f_2}=\frac{i_1}{o_1}\frac{a}{f_2};$$

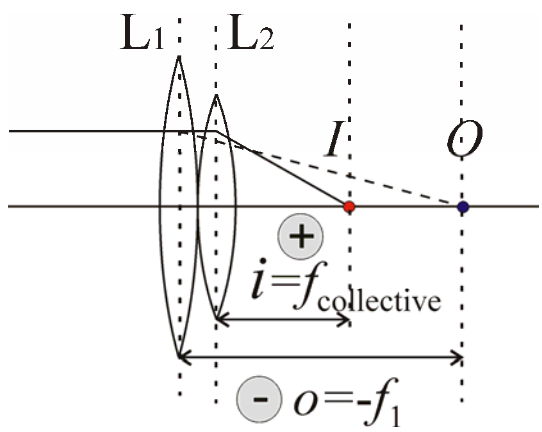
$$\frac{1}{o_1}=\frac{1}{f_1}-\frac{1}{i_1}=\frac{i_1-f_1}{f_1 i_1}=\frac{d}{f_1 i_1}$$

$$N=\frac{d}{f_1 i_1}\frac{i_1 a}{f_2}=\frac{da}{f_1 f_2}$$

Lens systems (2) **power** (refractive strength)

How high the collective focal length of two close juxtaposed lenses is $\{L_1(f_1), L_2(f_2)\}$?





Let's apply the lens equation for *O* as a virtual object.

$$-\frac{1}{f_1}+\frac{1}{f_{\text{collective}}}=\frac{1}{f_2} \qquad \frac{1}{f_{\text{coll.}}}=\frac{1}{f_1}+\frac{1}{f_2}=D_{\text{coll.}}=D_1+D_2$$

In such cases powers are added. Units [1/m], dioptre, [dpt].
Application e.g.: glasses, contact lenses.

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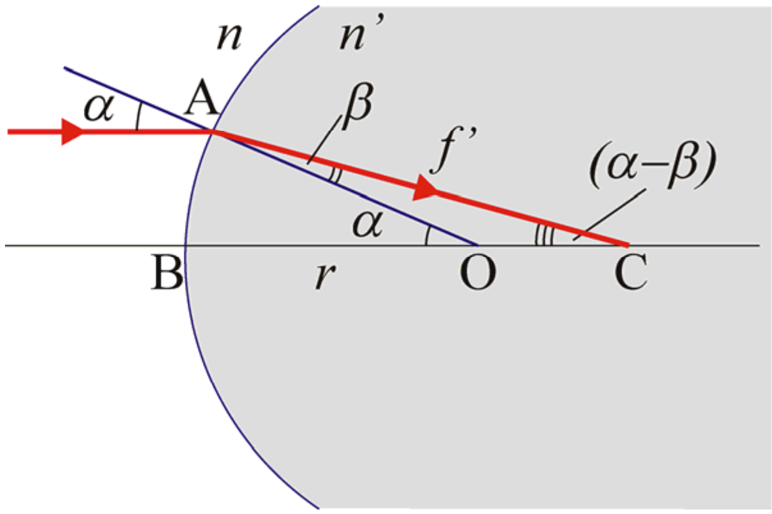
Image formation by simple curved surface (sphere with radius r):



For small angles:

1. $$\frac{\sin\beta}{\sin\alpha} = \frac{n}{n'} \approx \frac{\beta}{\alpha}$$

For the arc AB:

2. $$f'(\alpha - \beta) \approx r\,\alpha$$

$$\frac{\alpha-\beta}{\alpha} = \frac{r}{f'} \qquad\qquad 1 - \frac{\beta}{\alpha} = \frac{r}{f'}$$

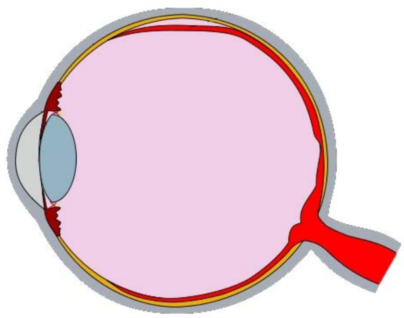
Substitution according to equation 1.:

$$1 - \frac{n}{n'} = \frac{r}{f'}, \qquad \frac{n'-n}{n'} = \frac{r}{f'}$$

The power in this case:

$$D = \frac{n'}{f'} = \frac{n'-n}{r}$$

Application: for the human eye
e.g. the power of cornea



medium	***r*** [mm]	***n***	***n'-n***	***D*** [dpt]
air		1		
			0,37	48
cornea	7,7	1,37		

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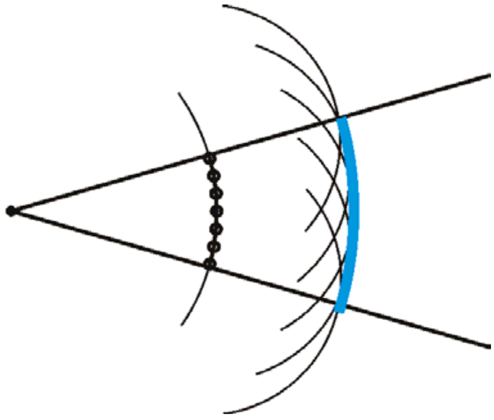
There are phenomena that cannot be explained by this model.

Physical or wave optics
(other model)



Its bases: **Huygens–Fresnel-principle**

According to the Huygens principle, elementary waves originate from every point of a wavefront, and the new wavefront is the common envelope of these elementary waves.

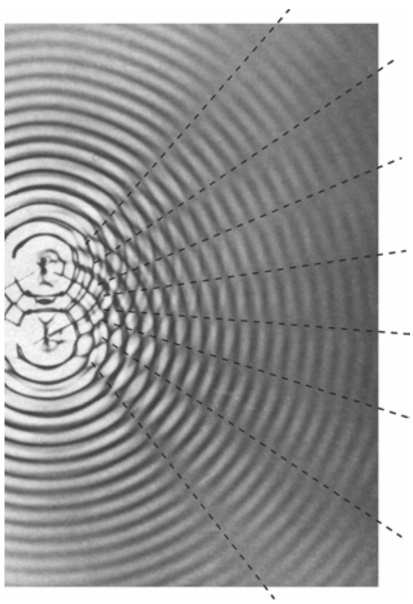
The laws of rectilinear propagation, the reflection and refraction can be described by this model as well.

Fresnel supplemented this by observing that the **superposition** principle is also in effect during the formation of the new wave front, which is nothing else than the quantitative formulation of the empirical fact that waves will propagate through each other without disturbance. Interference.

Waves (we learned about them earlier; dynamics, „repetition")

E.g. „water wave": it can be observed directly.
Because it changes slowly enough (low frequency, f) and the typical (wave) size is large enough (long wavelength, λ).

„Light waves" are different.



At certain conditions patterns can be formed, which don't or slowly change in time, and their size is much larger than the wavelength, λ.

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Interference (two or more waves meet)

the most important phenomenon in connection with waves

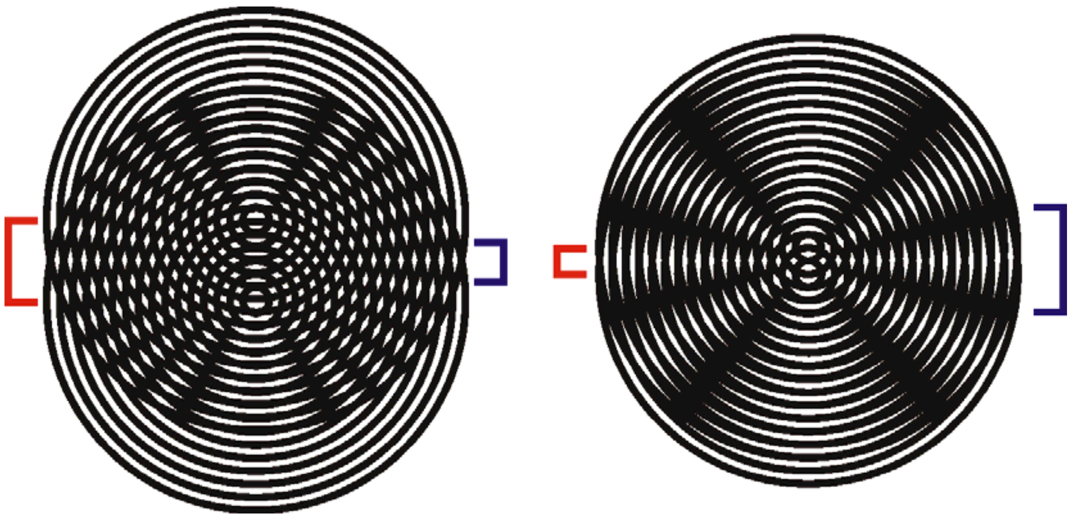
Incoherent and coherent waves

Rise of coherent waves is controlled in space and time, they are synchronized somehow.

Light interference

Nothing but the produced patterns can be observed.
Conditions for existent of observable patterns in the case of point like sources:

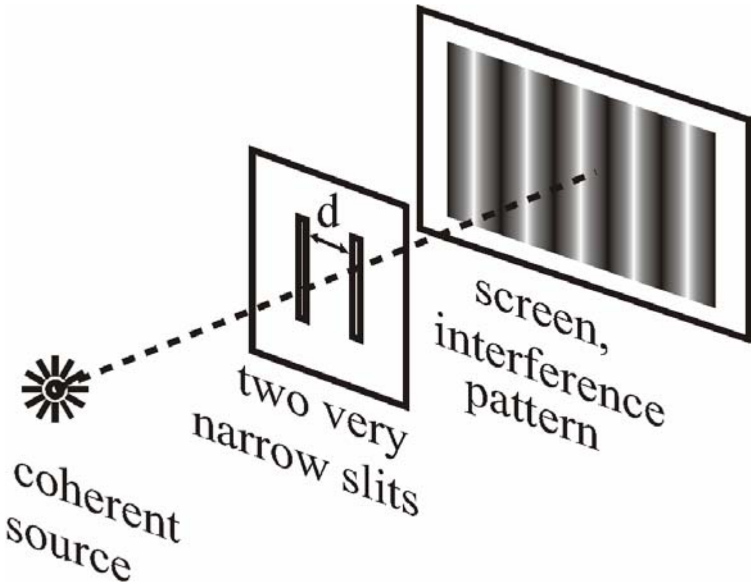
1. coherent waves (e.g. difference of phases ($\Delta\varphi$) is constant)
2. distance of sources is commensurable with the wavelength (λ).



The smaller the distance of sources (red mark),
the bigger the typical size of the pattern (blue mark).

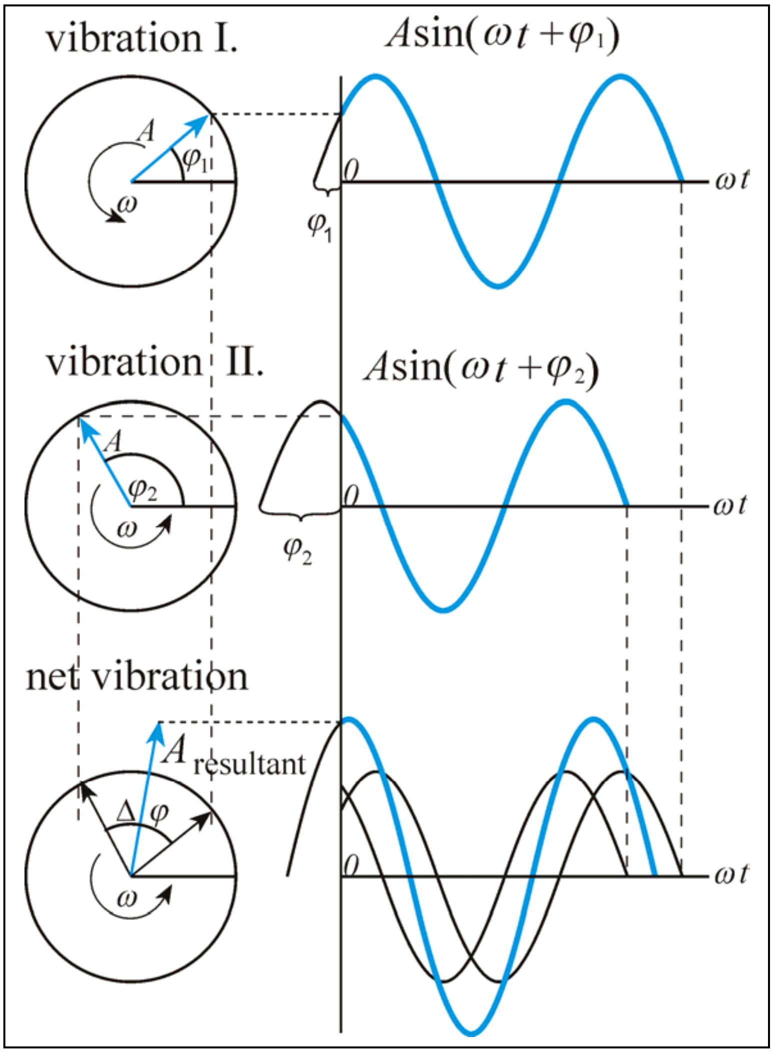
Typical experiment and pattern of light interference

Young's
double slit experiment
(diffraction)



The places of constructive and destructive interference are determined by the difference in phase ($\Delta\varphi$).

At a certain place the vibrational states are demonstrated by rotating vectors:

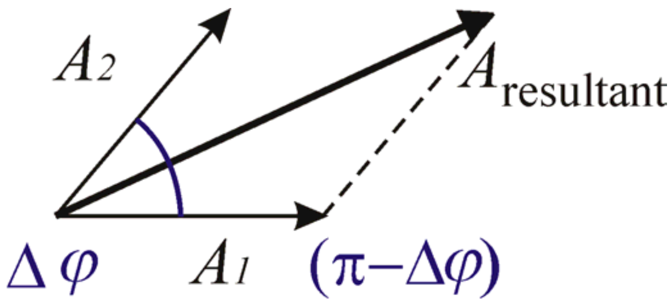


The amplitude of the net vibration ($A_{\mathrm{resultant}}$) is given by the vector sum of the components (A).

Our eyes are sensitive to the light-power (P), that is proportional to the square of the amplitude.

Thus $A_{resultant}^{2} \sim P_{res.}$, and $A_{res.} = A_1 + A_2$ hence $\boldsymbol{P_{res.} \neq P_1 + P_2}$.

Resultant ($A_{resultant}$) of two vectors (A_1, A_2), or the square of it, if the angle between them is $\Delta\varphi$:



$P \sim A^2_{resultant} = A^2_1 + A^2_2 - 2A_1\, A_2\cos(\pi\text{-}\Delta\varphi\,)$ (cosine theorem)

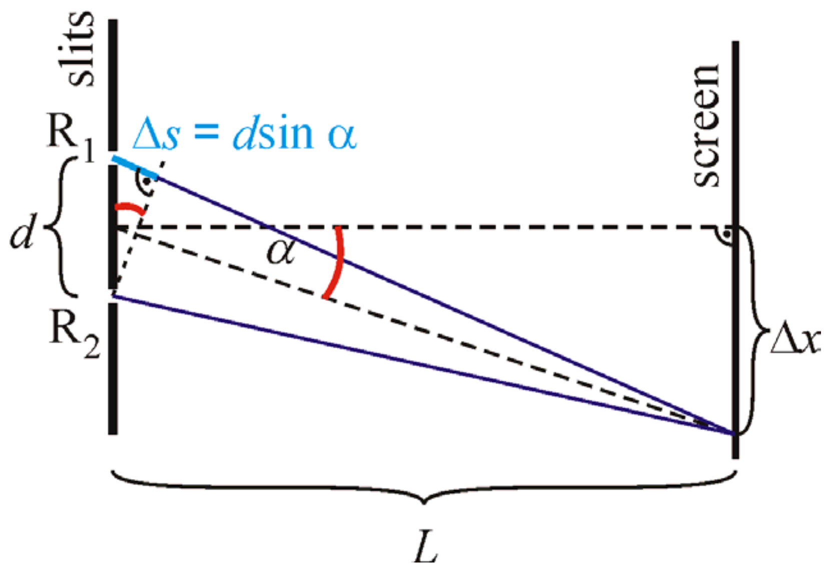
$P \sim A^2_{resultant} = A^2_1 + A^2_2 + 2A_1\, A_2\cos\Delta\varphi$

If $\quad A_1 = A_2 = A, \quad$ than $\quad A^2_{resultant} = 2A^2\,(1 + \cos\Delta\varphi)$

The difference in phase ($\Delta\varphi$) is determined by the relation of difference in path length (Δs) and the wavelength (λ).

If $\quad L >> d,$

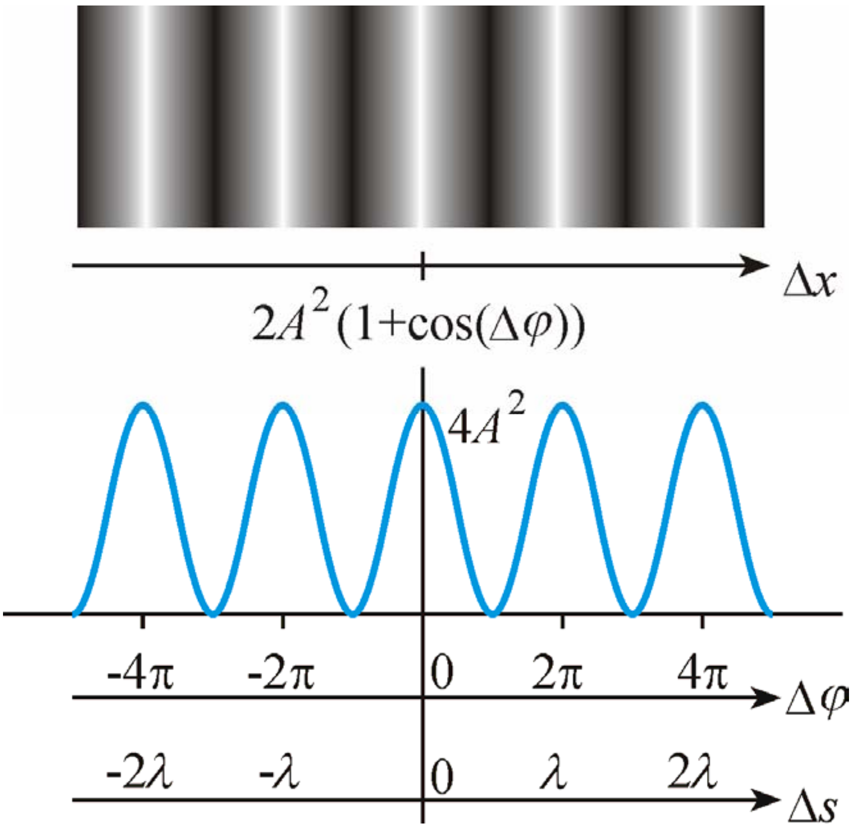
the difference in path length
$\Delta s = d\sin\alpha.$



The difference in phase is given as:

$$\Delta\varphi = \frac{2\pi}{\lambda}\Delta s = 2\pi\,\frac{d\,\sin\alpha}{\lambda} \approx 2\pi\,\frac{d\Delta x}{\lambda L}$$

Demonstration:



In the case of many uniform slits, namely optical grating, very sharp maxima can be observed at places correspond to $\Delta\varphi = 2k\pi$ or $\Delta s = k\lambda$; k = 0, 1, 2,… condition.

$$2k\pi = \Delta\varphi \approx 2\pi \frac{d\Delta x}{\lambda L}$$

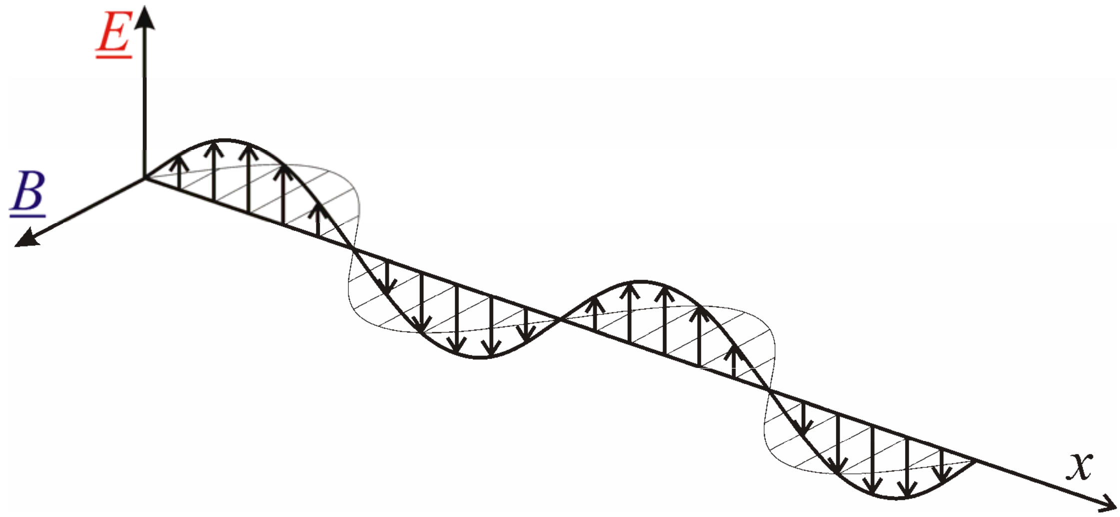
L and Δx macroscopically measurable. If λ is known, the microscopic d can be determined, consequently in general:

we can get microscopic data from macroscopic diffraction pattern.

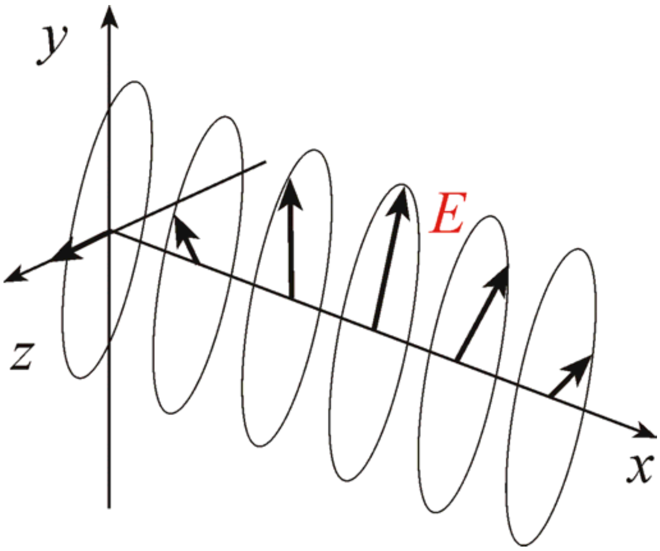
Applications: determination of the resolving power of microscopes, but this is the bases of any diffraction methods as well (x-ray diffraction; determination of protein structure).

Light is electromagnetic wave transversal

thus can be polarized **linearly** polarized light
or **plane** polarized light



But **elliptically** polarized light also exists.



Optical anisotropy

E.g. in an „anisotropic matter" the speed of a suitably linearly polarized light depends on the direction of propagation.
The reason of it is connected to the structure of matter.

Consequences, applications: double refraction, polarization microscope