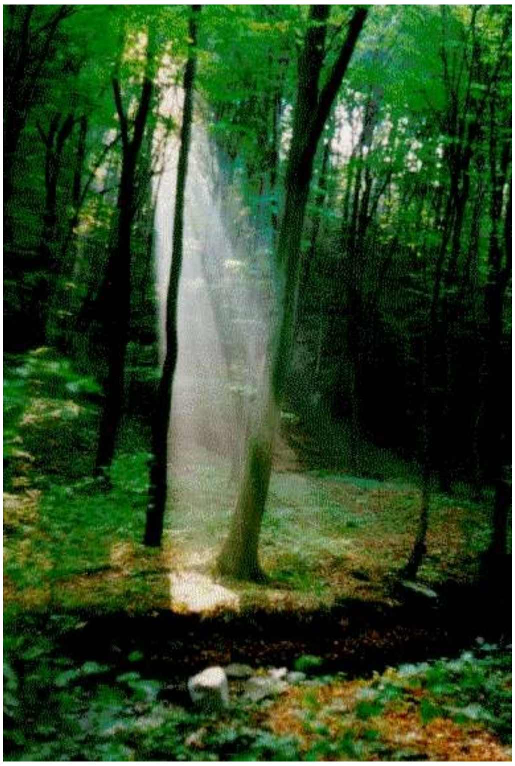
Optics

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 $\alpha = \alpha'$
3. law of refraction

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

The incident ray, the normal and the reflected ray, or refracted ray lie in the same plane.

All the angles are measured from the normal!

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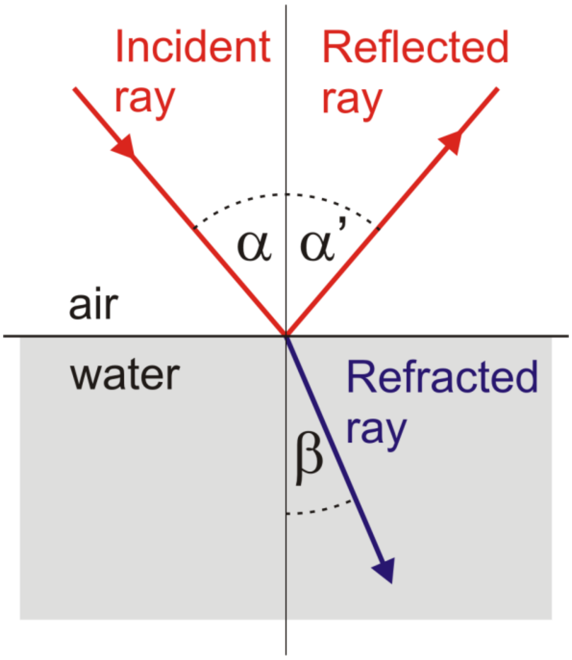
All these laws can be deduced from a single common principle!

Fermat-priciple

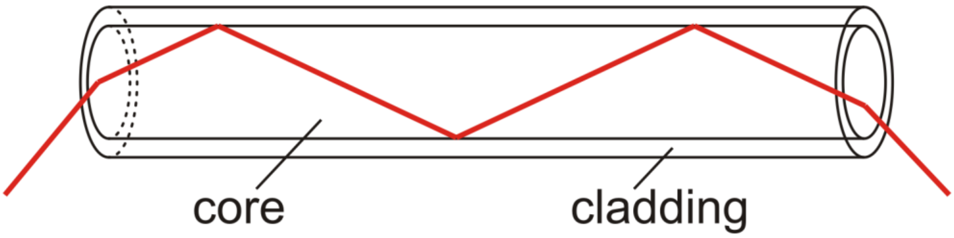
The **'principle of shortest time'**: out of the geometrically possible paths, light will travel along the one that requires the shortest time to pass.



$$\frac{\sin\frac{\pi}{2}}{\sin\beta_{\text{crit.}}} = \frac{1}{\sin\beta_{\text{crit.}}} = \frac{n_2}{n_1}$$

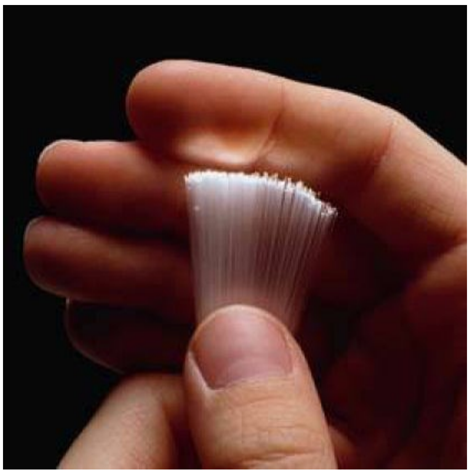
If $\beta > \beta_{\text{crit.}}$

Total reflection



$n_{core} > n_{cladding}$

Application e.g.: Optical fiber (endoscopy), refractometry



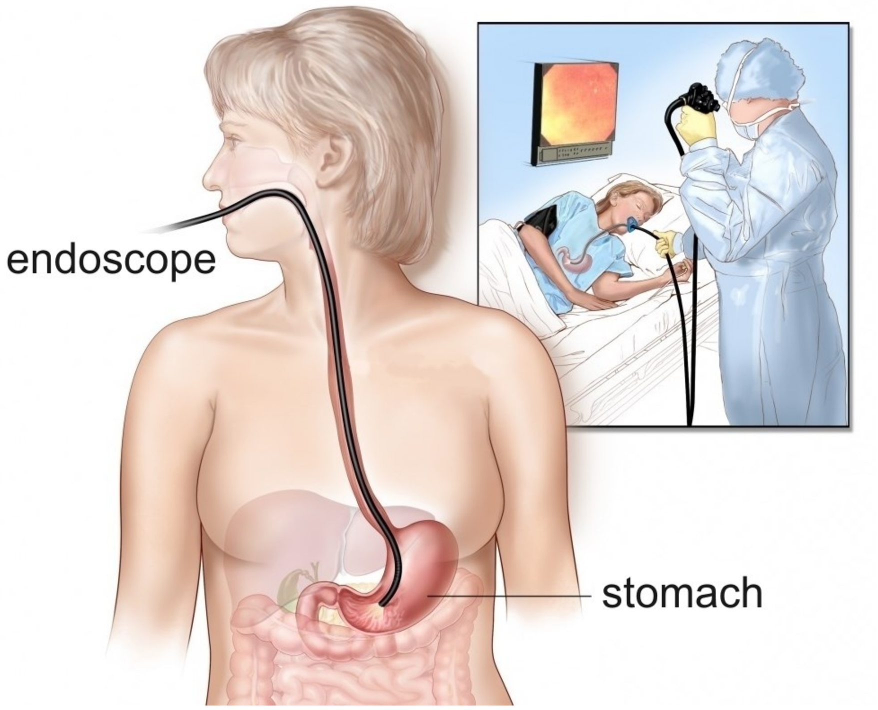


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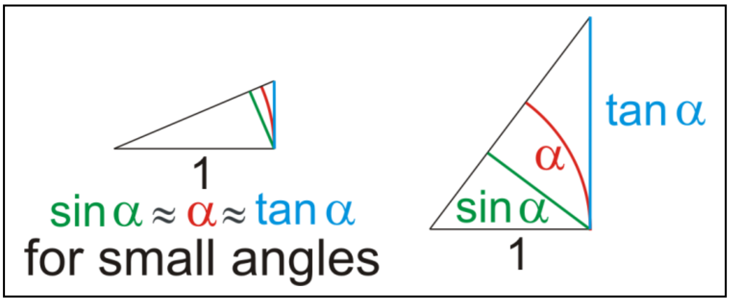
Image formation by simple curved surface (sphere with radius r):

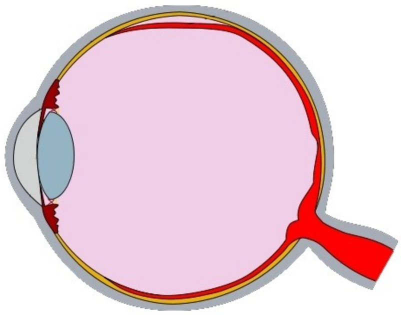
$$\frac{\sin\alpha}{\sin\beta} = \boxed{\frac{n_2}{n_1} \approx \frac{\alpha}{\beta}}$$



The **power** (refractive strength):

$$\frac{n_1}{o} + \frac{n_2}{i} = \frac{n_2 - n_1}{r} = D$$

Application: for the human eye (next week)
e.g. the power of cornea



medium	***r*** [mm]	***n***	n_2-n_1	***D*** [dpt]
air		1		
			0,37	48
cornea	7,7	1,37		

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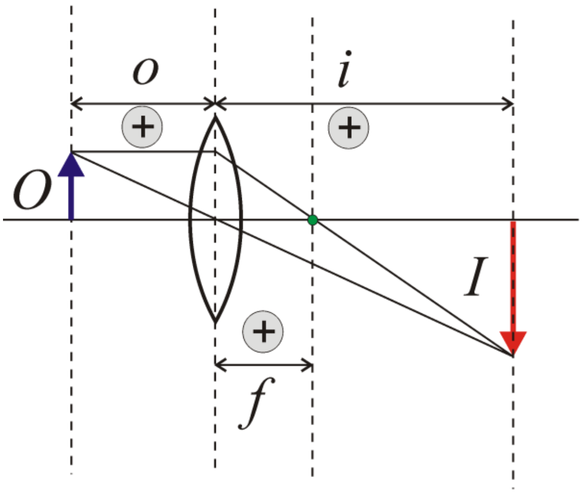
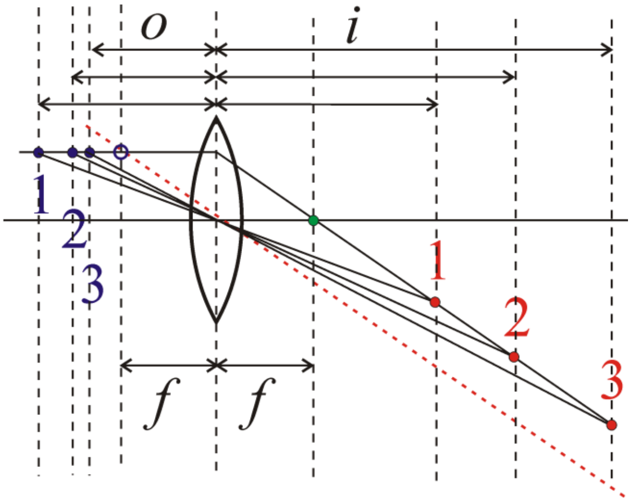
Image formation by two curved surfaces (radii r_1; $-r_2$)
(thin lens approximation):

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

$$\frac{1}{o} + \frac{1}{i} = \frac{1}{f} = (n_{2,1} - 1)\left(\frac{1}{r_1} + \frac{1}{r_2}\right)$$

Image formation by lenses

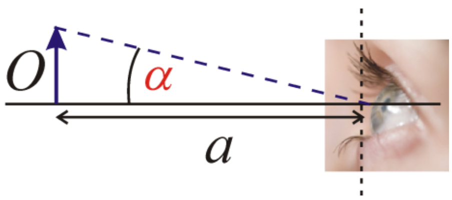




Simple magnifier

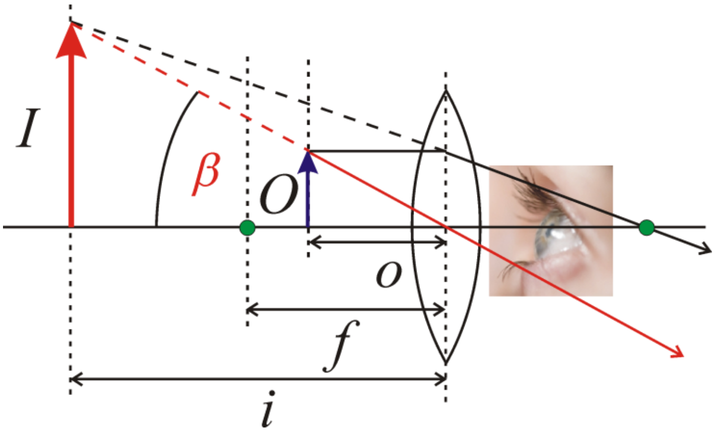
We have to compare two cases: eye looks at the O object

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



2. with lens from the distance o, under the angle of $\boldsymbol{\beta}$

I virtual image



Angular magnification:

$$N = \frac{\tan\beta}{\tan\alpha}$$

and we use

$$\frac{1}{o} = \frac{1}{f} - \frac{1}{i}$$

In the case of simple magnifier:

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

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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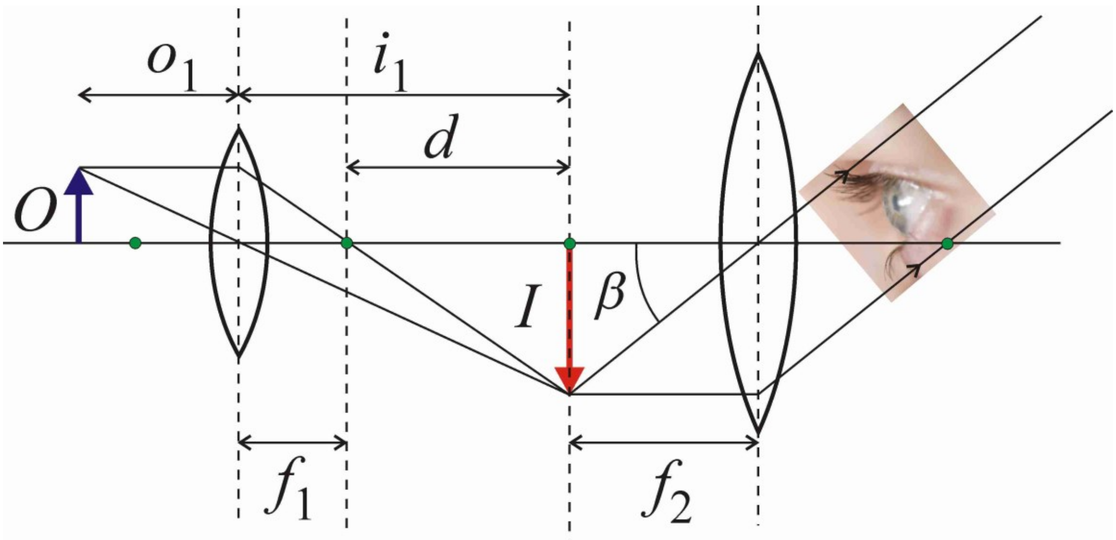
Lens systems (1) microscope



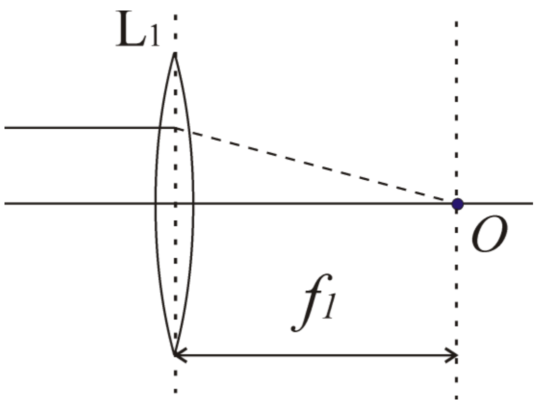
Without accommodation, eye is focused at infinity.

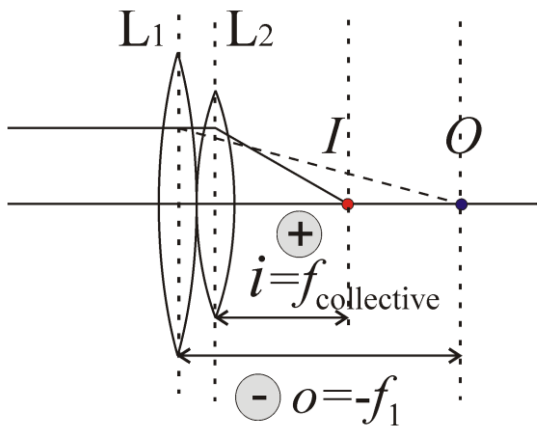
Angular magnification of microscope:

$$N = \frac{\tan\beta}{\tan\alpha} = \frac{da}{f_1 f_2}$$

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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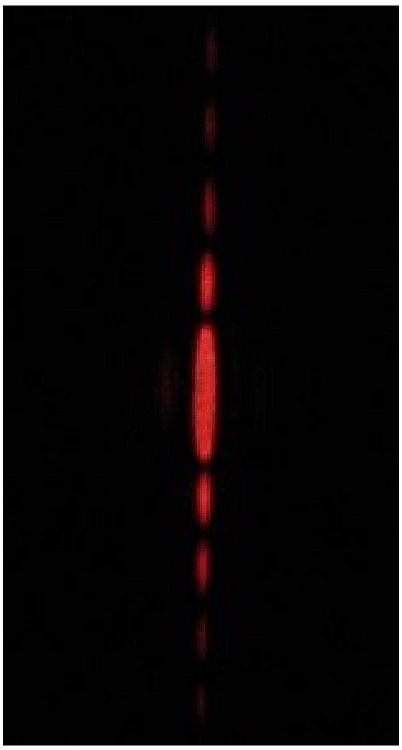
There are phenomena that cannot be explained by this model.



Interference (two or more waves meet)

the most important phenomenon in connection with waves

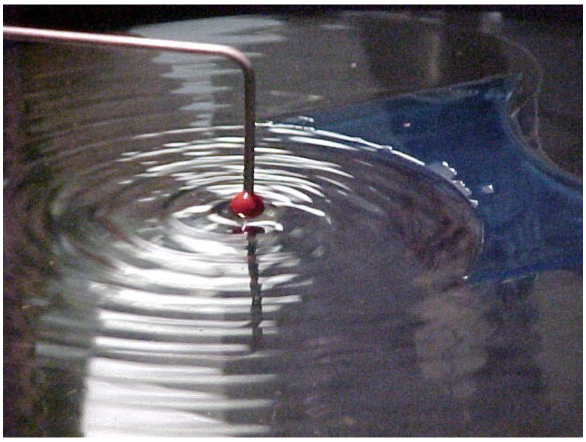
E.g. „water wave": it can be observed directly.
Because it changes slowly enough (low frequency, f) and the typical (wave) size is large enough (long wavelength, λ).

„Light waves" are different.

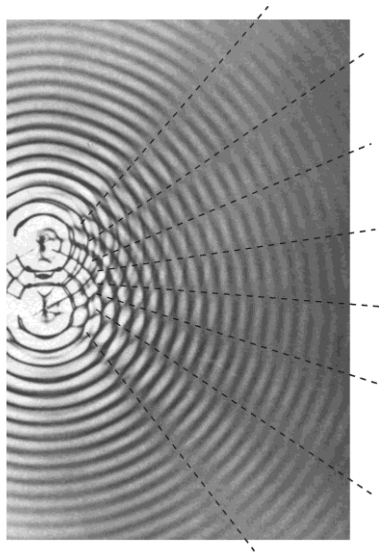
Microscopic (short wavelength, λ); quick change (high frequency, f)

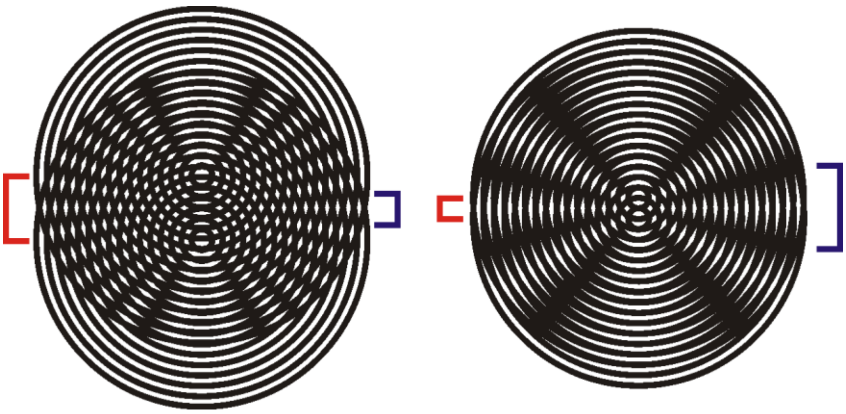
At certain conditions patterns can be formed, which don't change in time, and their size is much larger than the wavelength, λ.

Incoherent and coherent waves



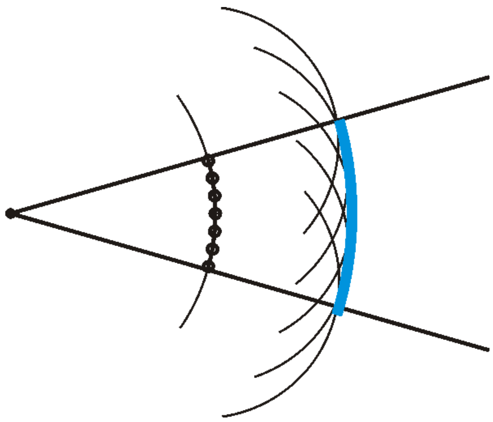
Rise of coherent waves is controlled in space and time, they are synchronized somehow.





Physical or wave optics (other model)

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



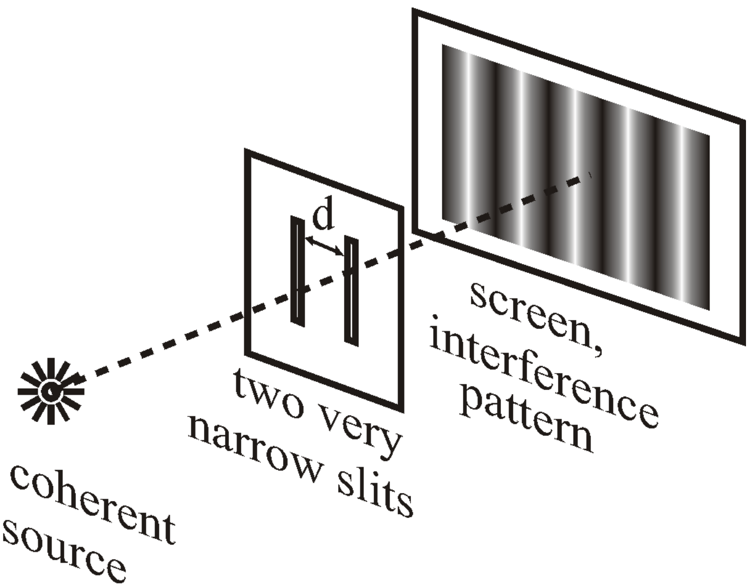
According to the Huygens principle, elementary waves originate from every point of a wavefront, and the new wavefront is the common envelope of these elementary waves.

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.

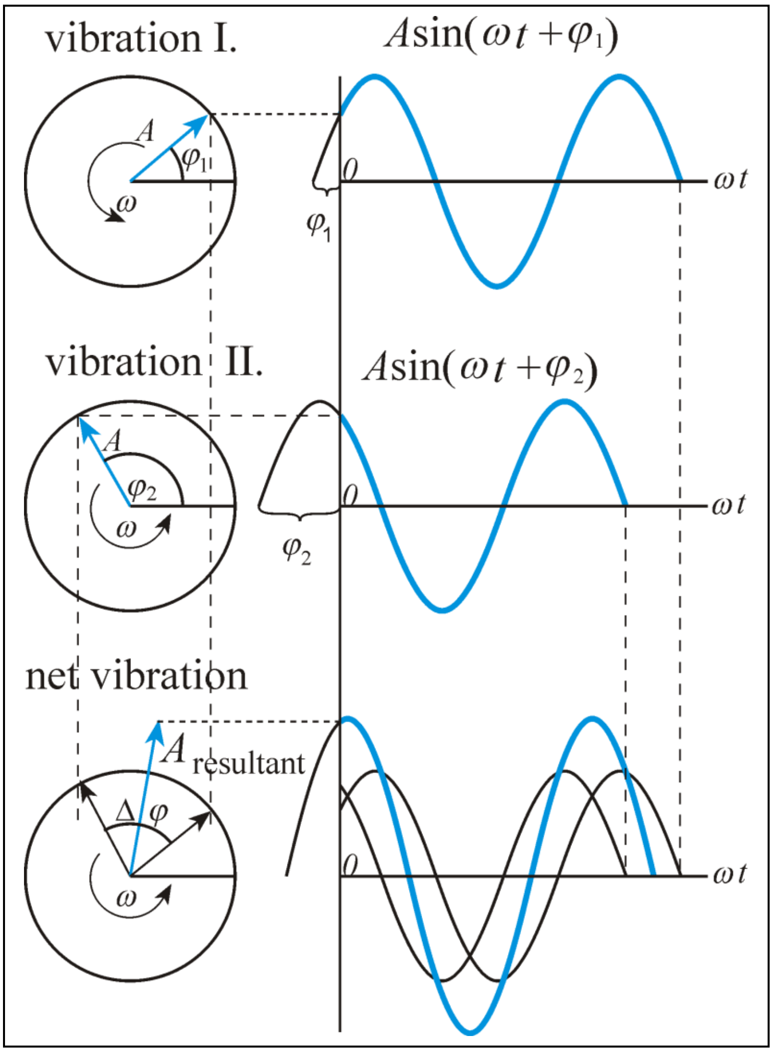
Typical experiment and pattern of light interference

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:

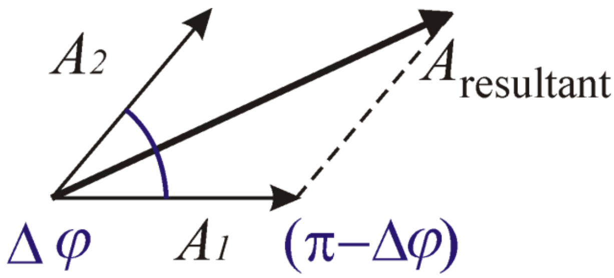


The amplitude of the net vibration ($A_{resultant}$) is given by the vector sum of the components (A).

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 $\mathbf{P_{res.} \neq P_1 + P_2}$.

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



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

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

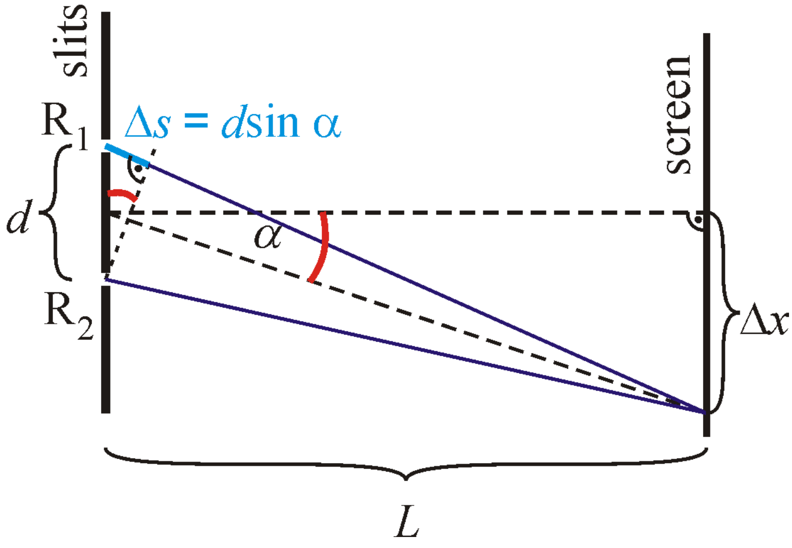
If $A_1 = A_2 = A$, than $A^2_{resultant} = 2A^2 (1 + \cos\Delta\varphi)$

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

If $L >> d$,

the difference in path length

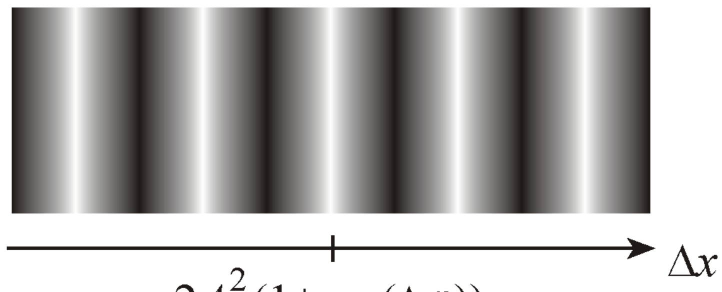
$\Delta s = d\sin\alpha$.

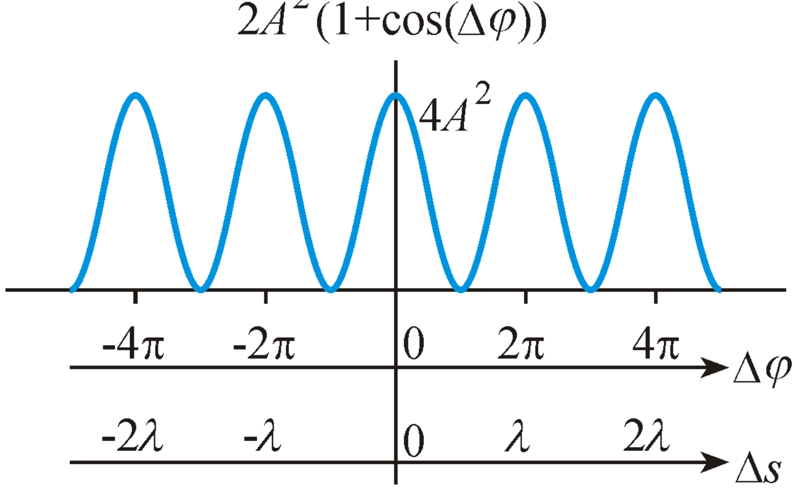


The difference in phase is given as:

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

Demonstration:



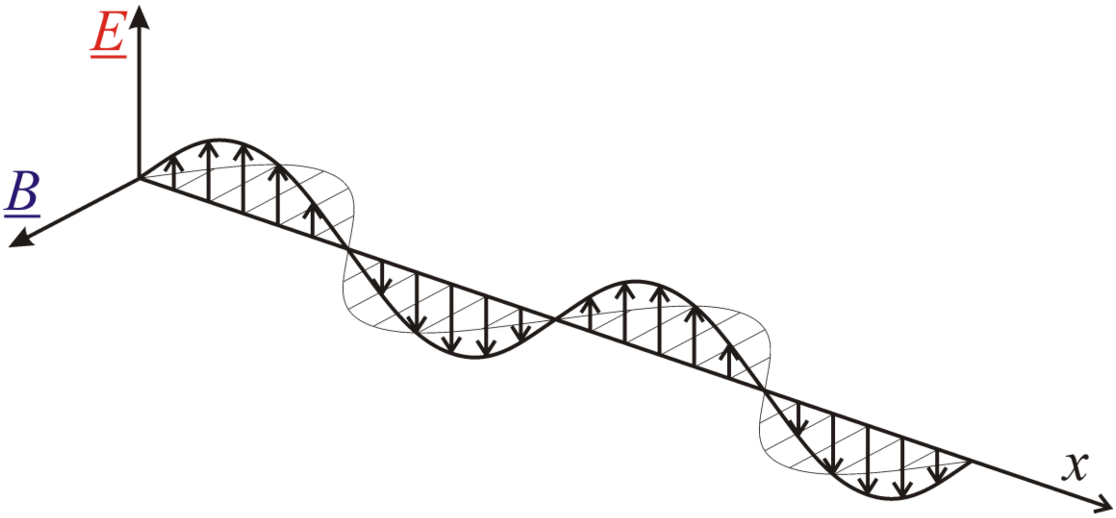


Maxima can be observed at places correspond to

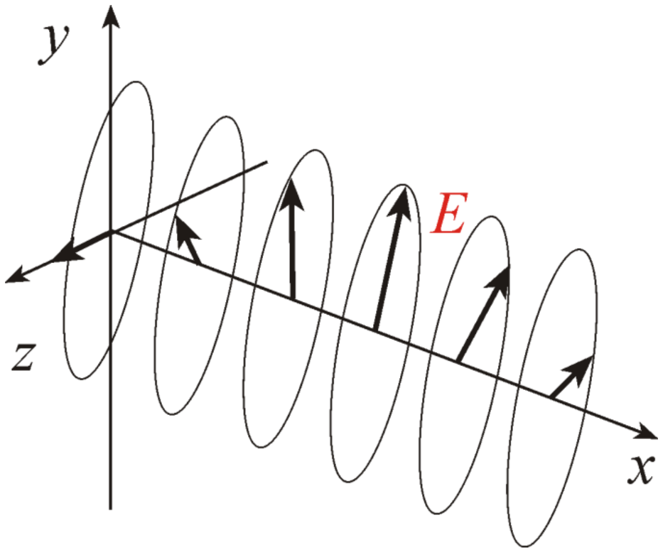
$\Delta\varphi = 2k\pi$ or $\Delta s = k\lambda$; k = 0, 1, 2,… condition.

Applications: determination of the resolving power of microscopes, 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