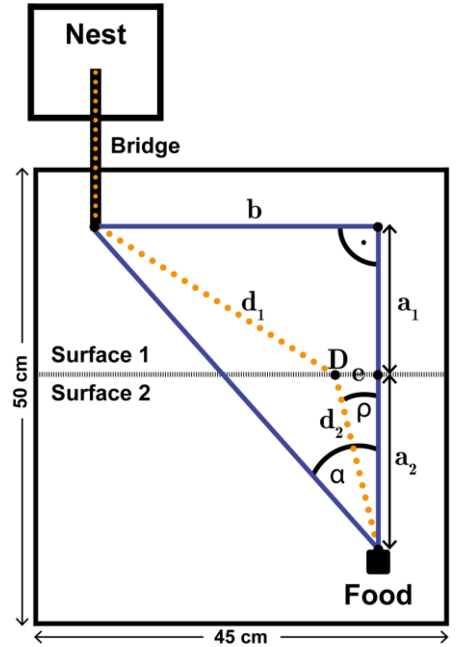
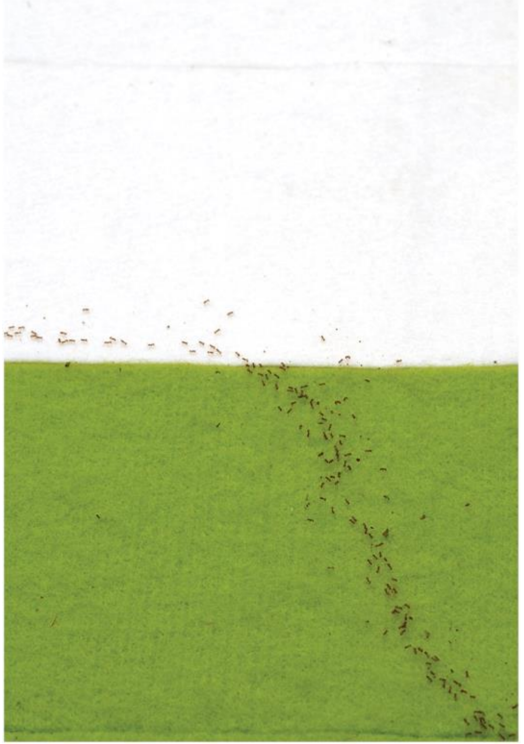
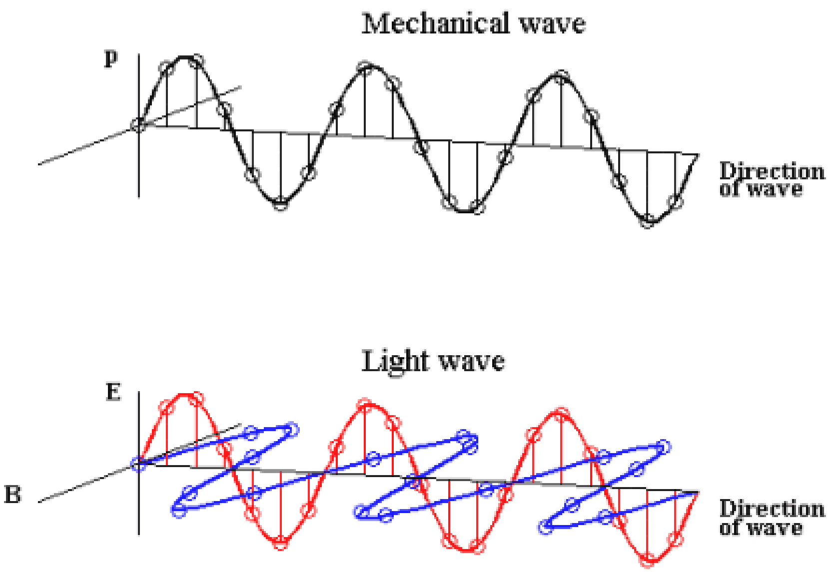
Basics of geometrical optics

Fermat-principle, refraction, imaging by lenses, microscope.

Schay G.





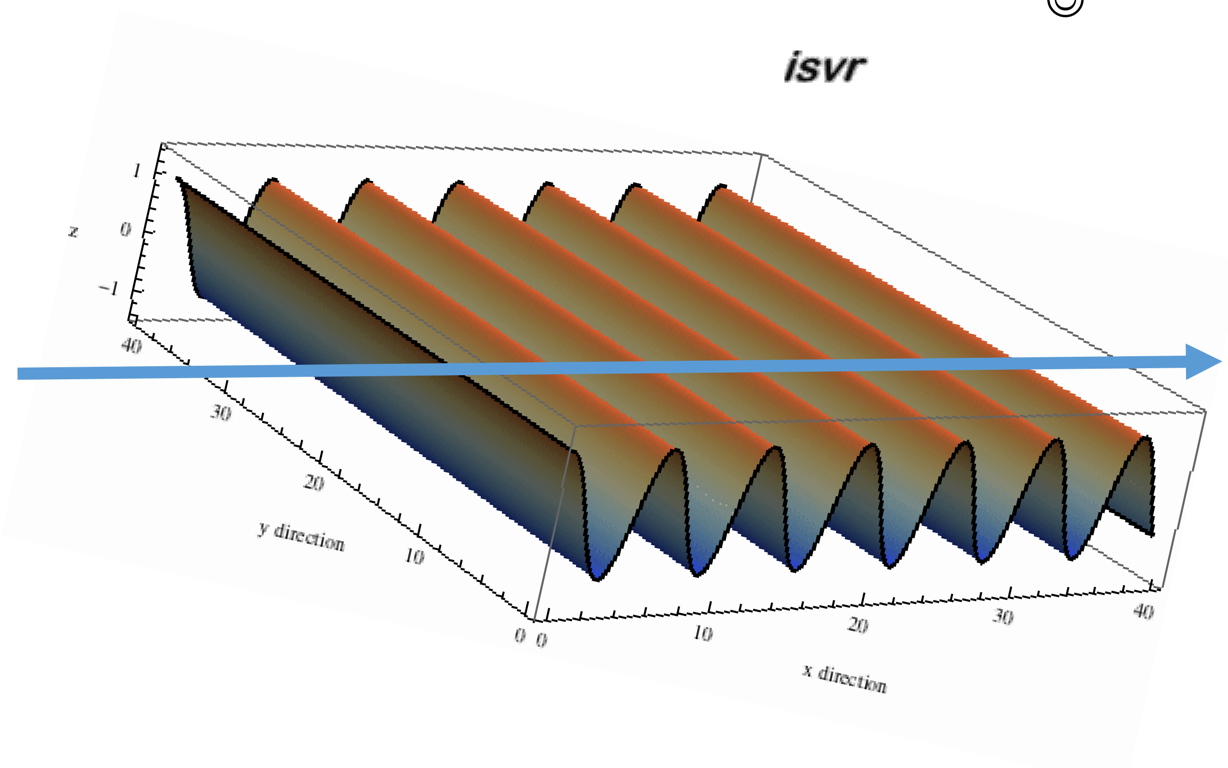


geometrical optics is a **simplification**

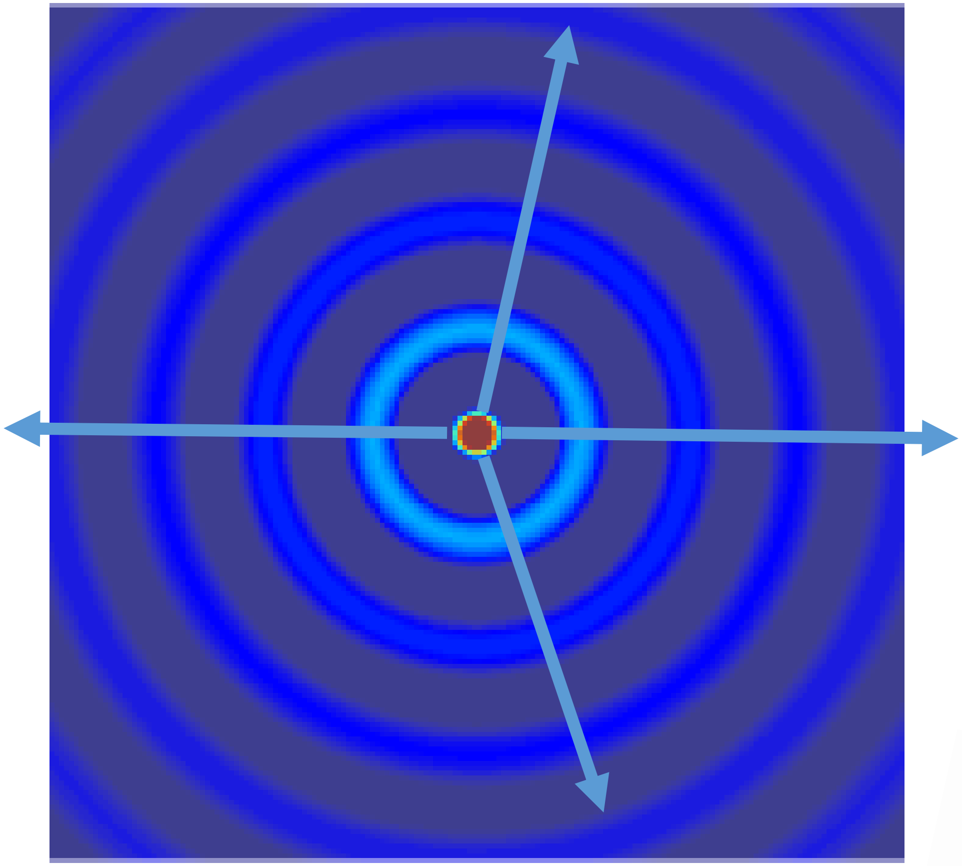
it can be used in some cases, but not all phenomena can be explained by this

BUT

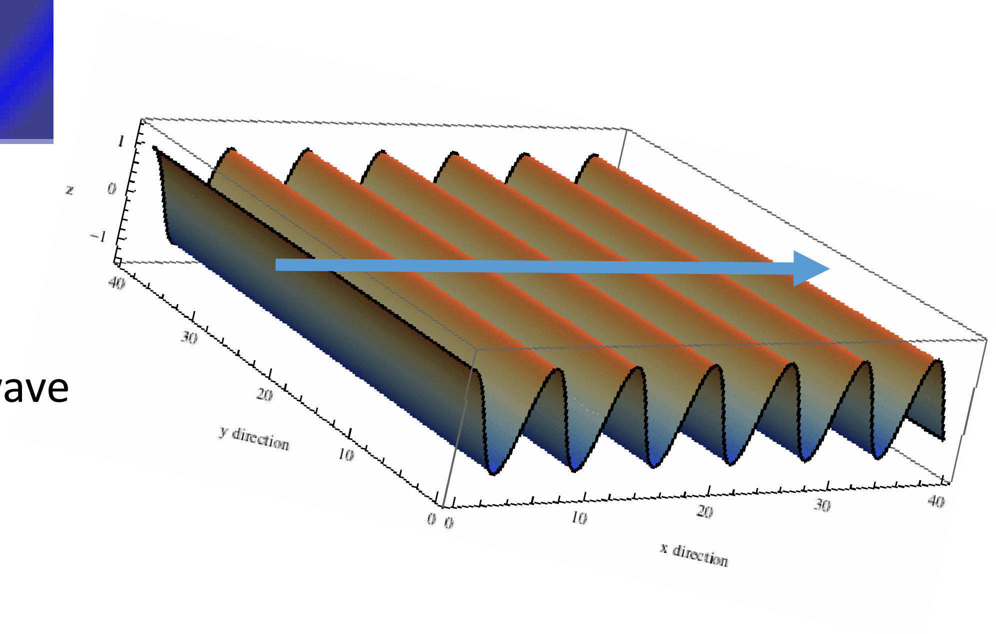
it is MUCH simpler than wave theory ☺



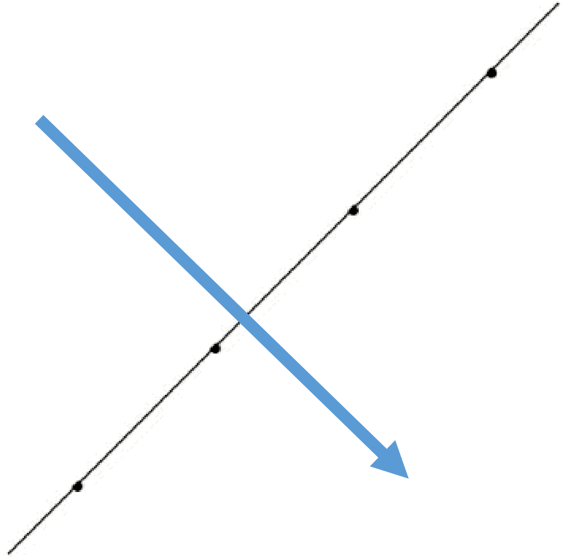
propagation direction

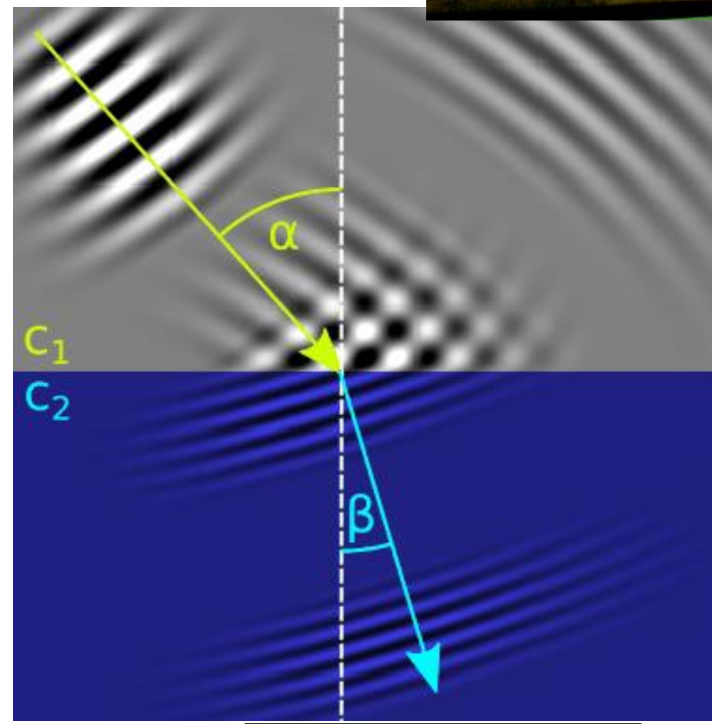


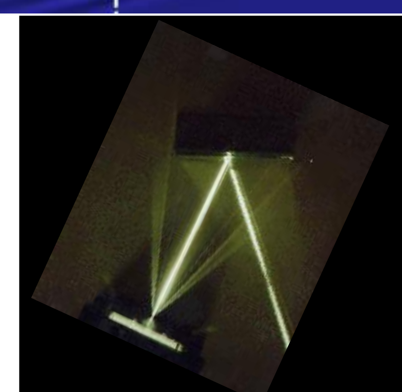
circular (or spherical) wave

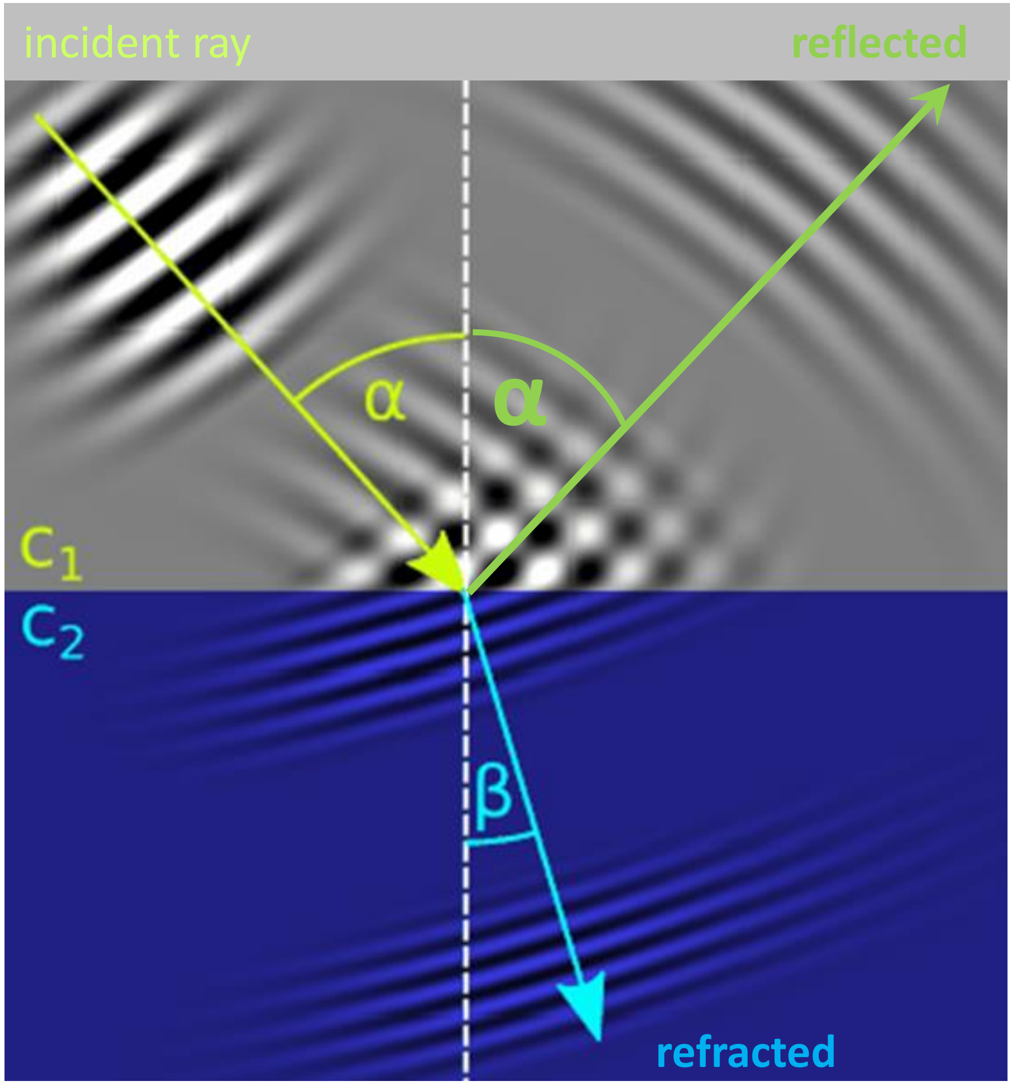


planar wave



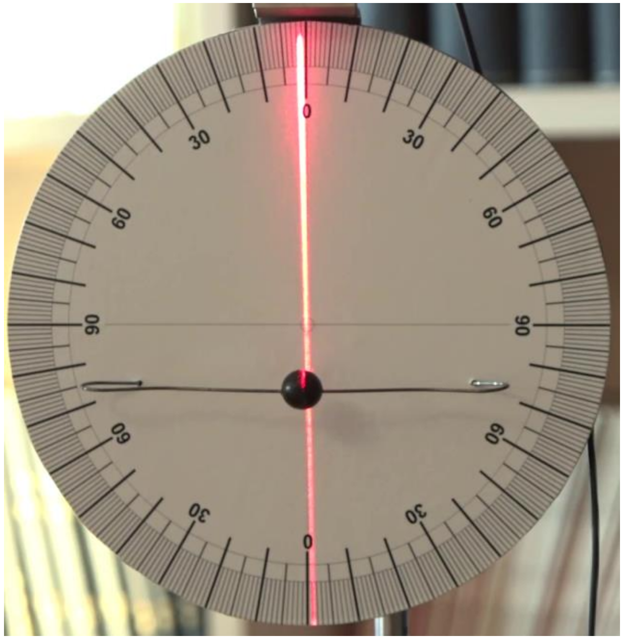
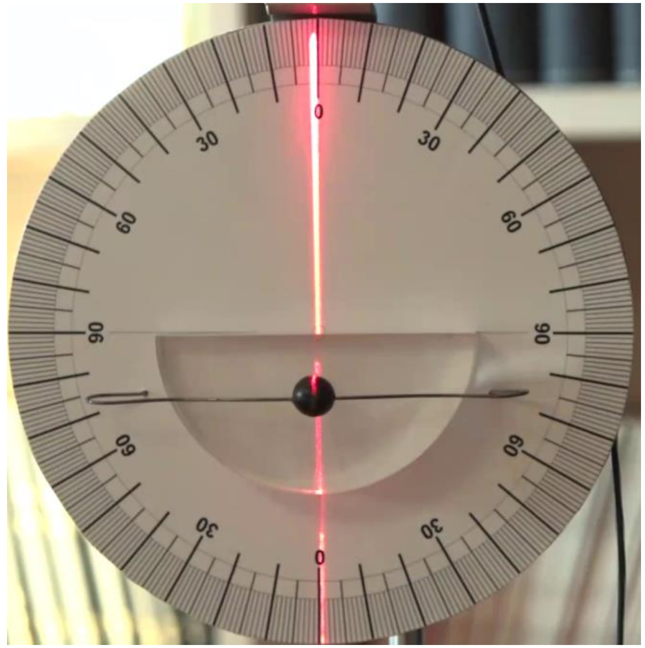
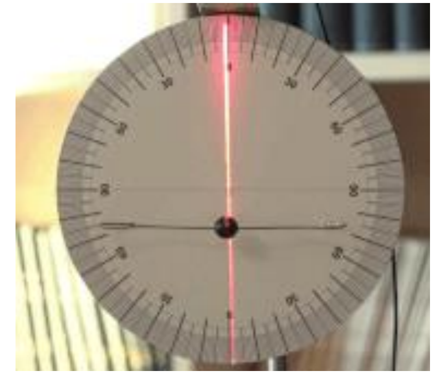
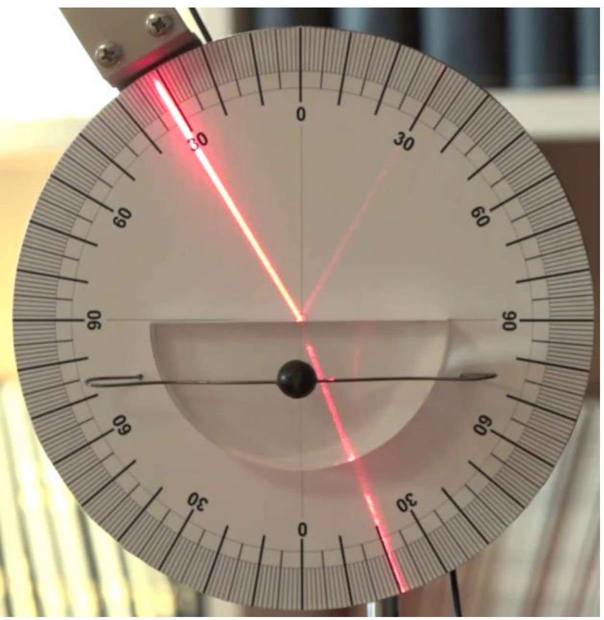
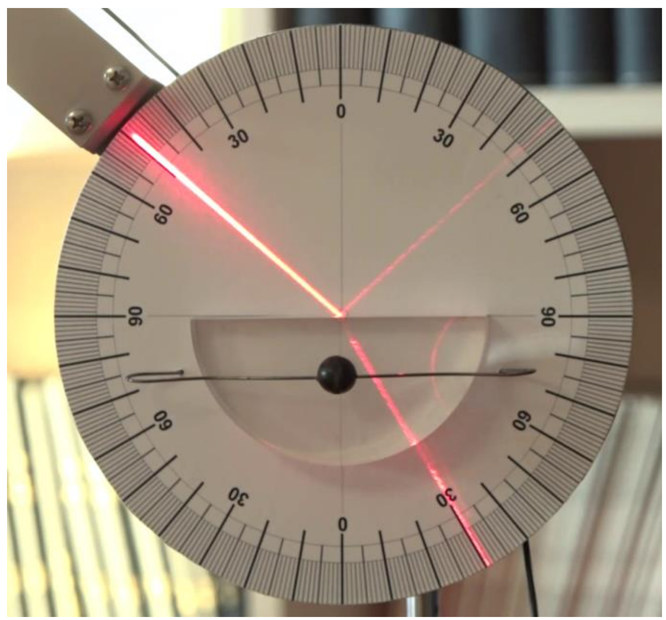
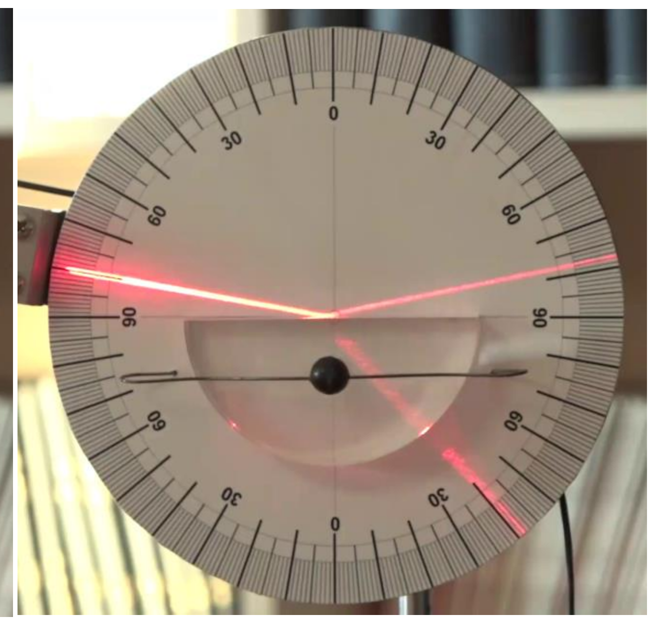

α
c_1
c_2
β

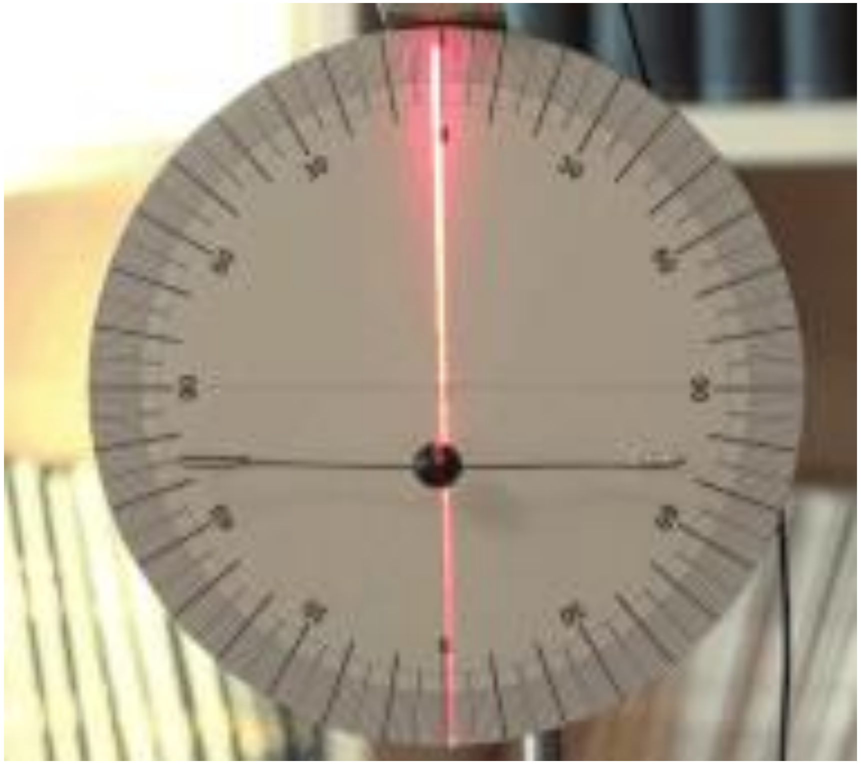




instead of the WAVE picture, we try to set up equations based on the angles and rays

We need to take some information from the wave (like color, speed).



Rules of refraction/ reflection **based on LOT of measurements**:

$$\alpha_{in} = \alpha_{reflected}$$

$$\sin(\alpha_{in}) \cdot n_1 = \sin(\beta_{refracted}) \cdot n_2$$

AND
all the rays are in one plane.

Snellius-Descartes

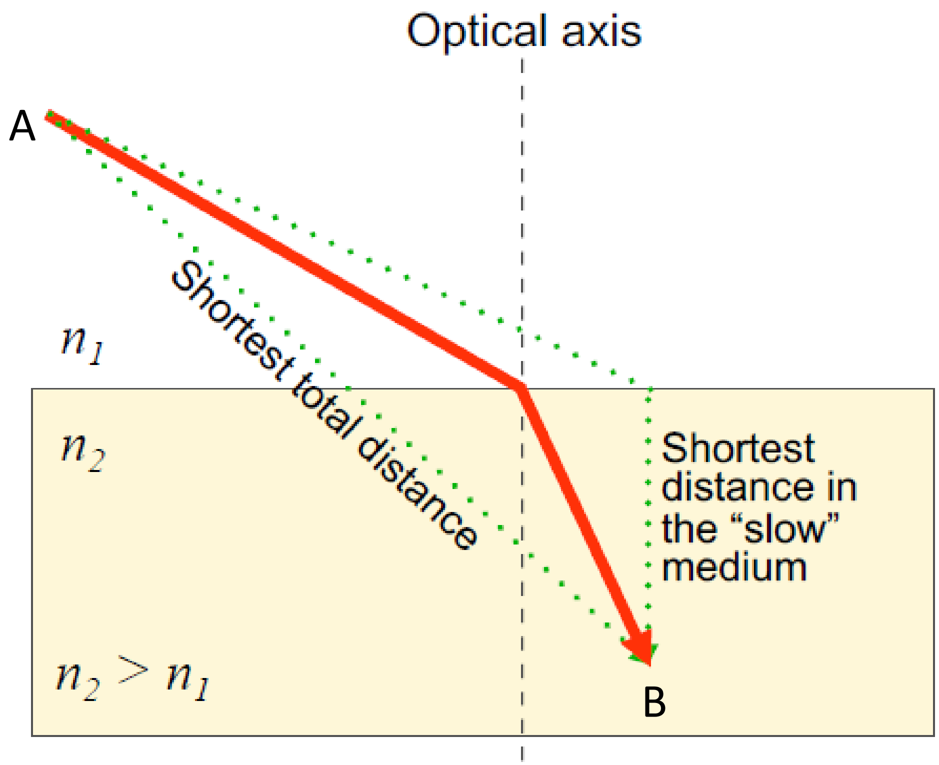
n is a material and light color dependent number, the **refractive index.**
For vacuum it is 1.

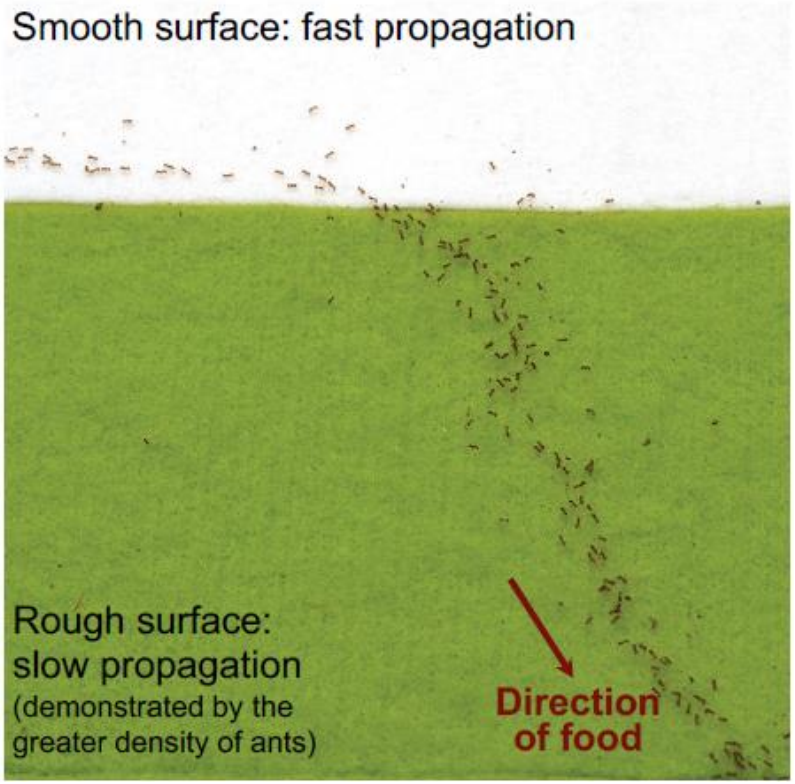
the Fermat principle can explain this with one sentence.

a principle is a statement from which mathematical formulas can be derived.

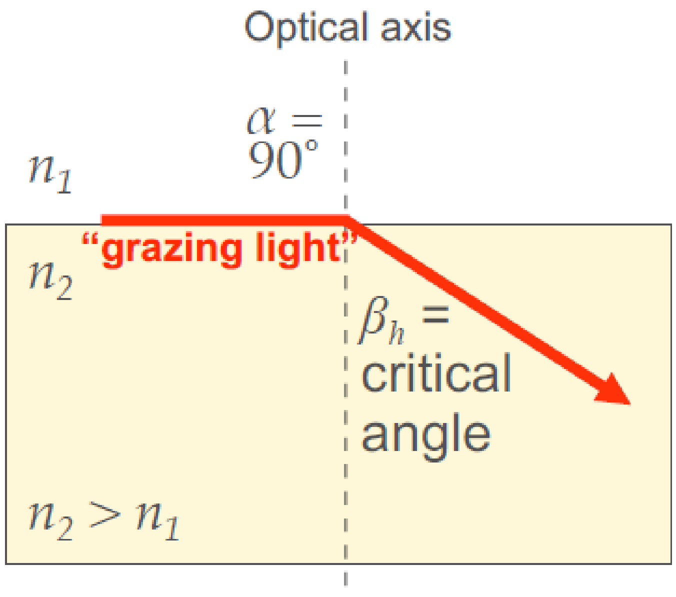
The light ray takes that path between two (known) points, which requires the least time.

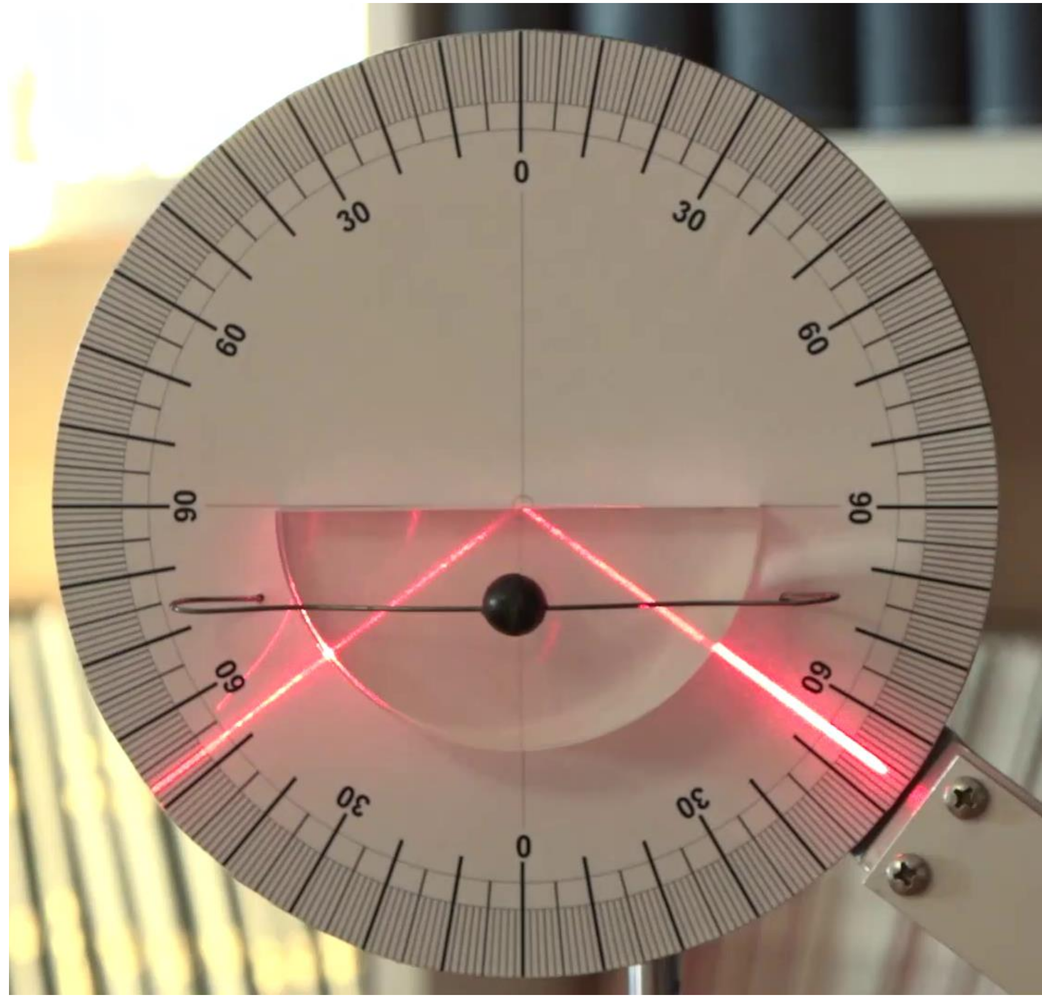
(principle of least time)





not too practical> we must know A,B in advance…

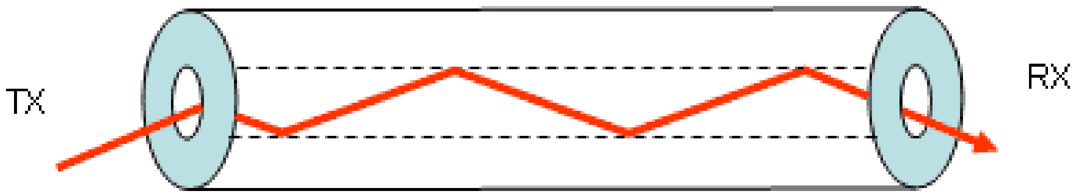


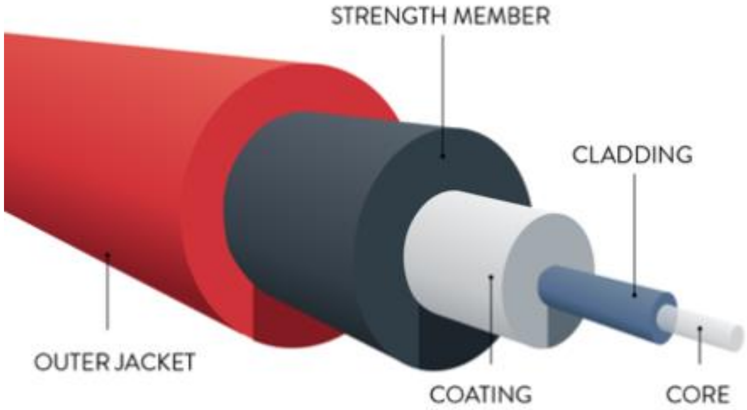


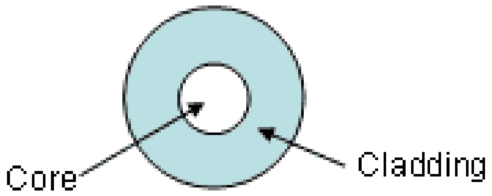
Since $\sin(90°) = 1$, according to Snell's law:

$$n_1 = n_2 \sin \beta_h$$

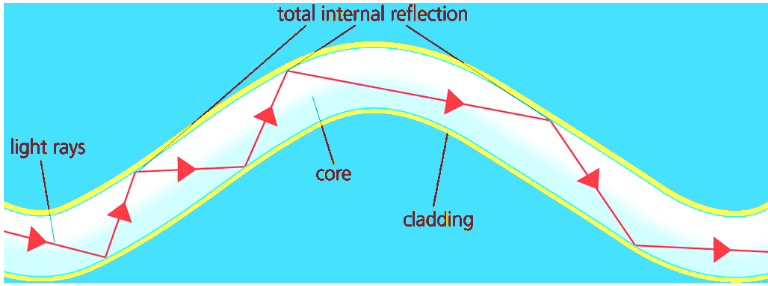
Total (internal) reflection:
since SD law is reversible, we can send light from the other sidem now controlling β, and can set it to greater value than the limiting angle. Then SD for refraction has no solution, so only REFLECTION is possible. Hence we get a perfect, 100% mirror in this incident angle range.

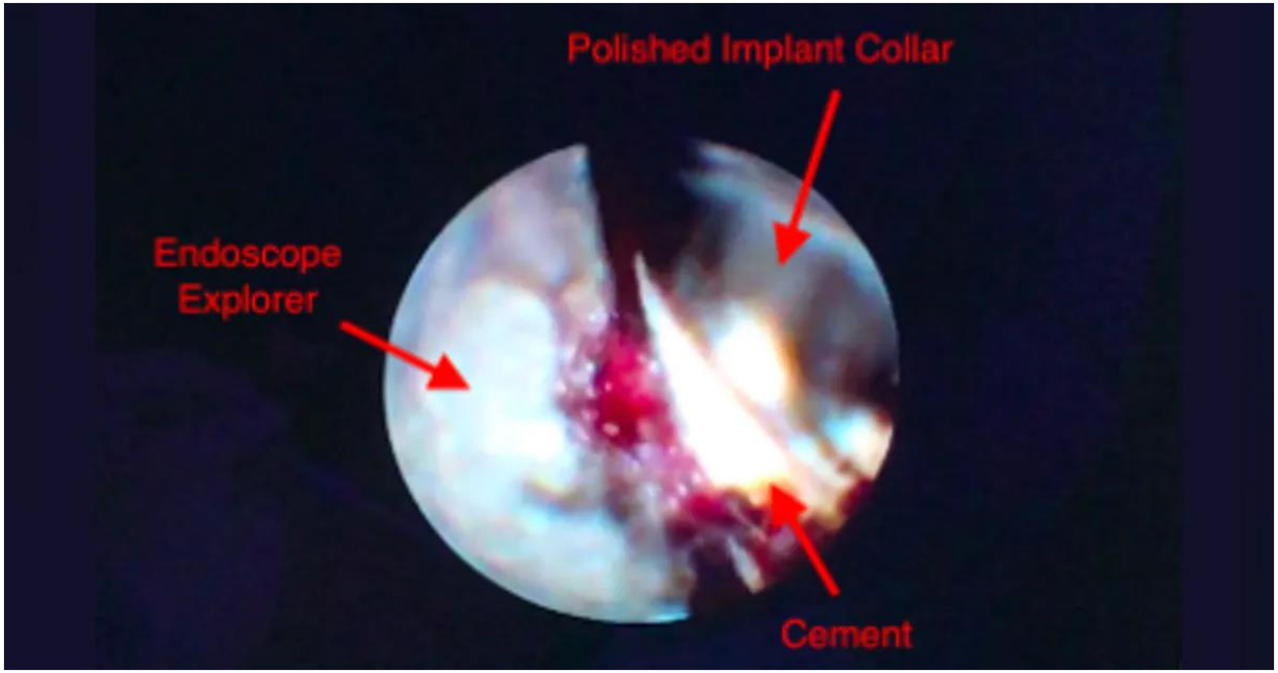




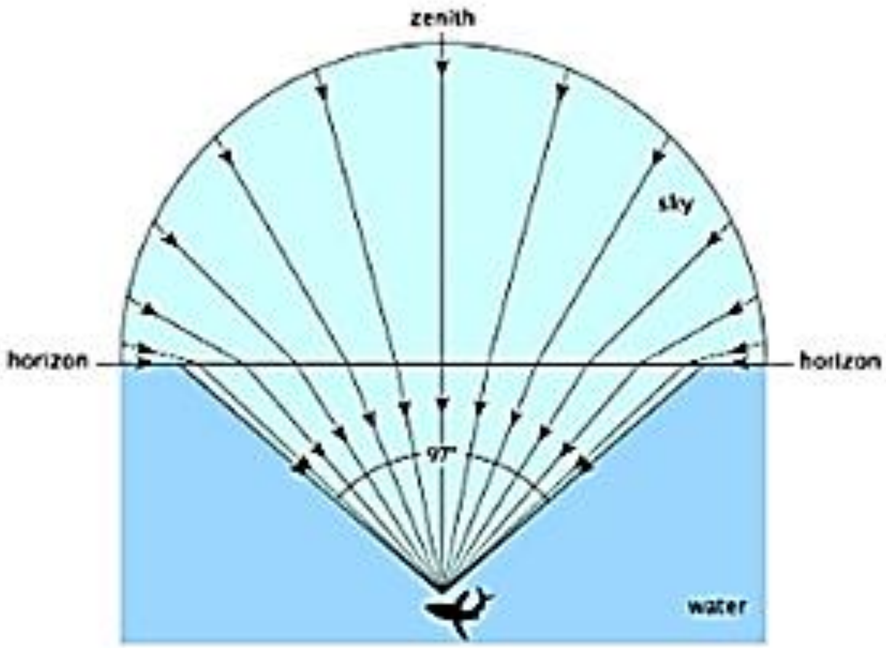


Optical Glass Index of Refraction
Core = 1.458
Cladding = 1.440

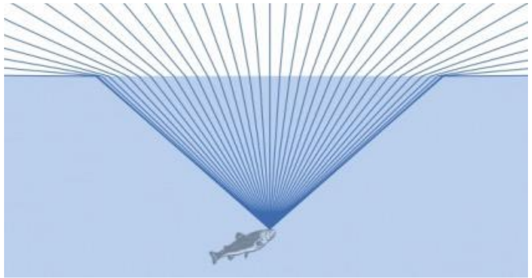



Polished Implant Collar
Endoscope
Explorer
Cement


STORZ
telecam

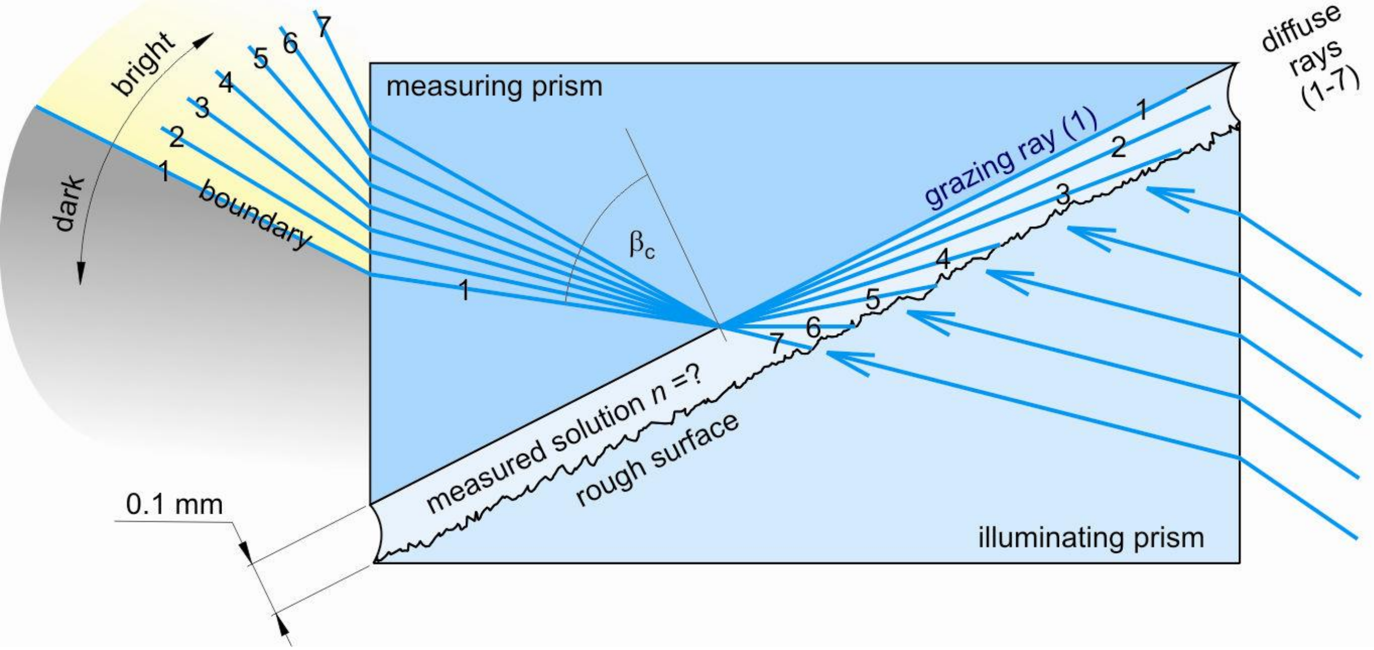

zenith
sky
horizon
horizon
97°
water

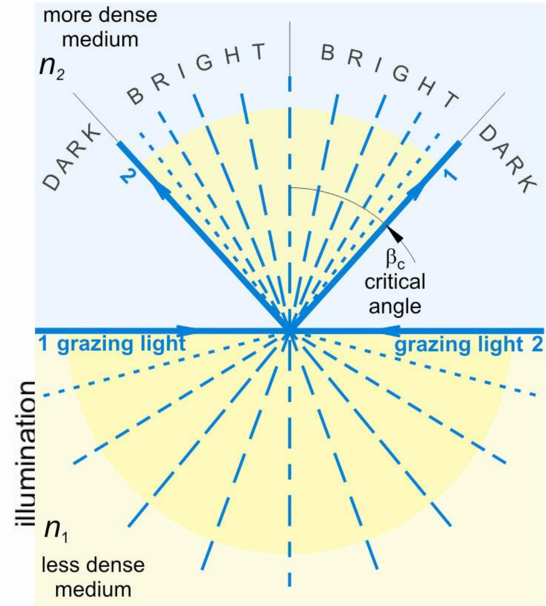

© Andrew Marriott

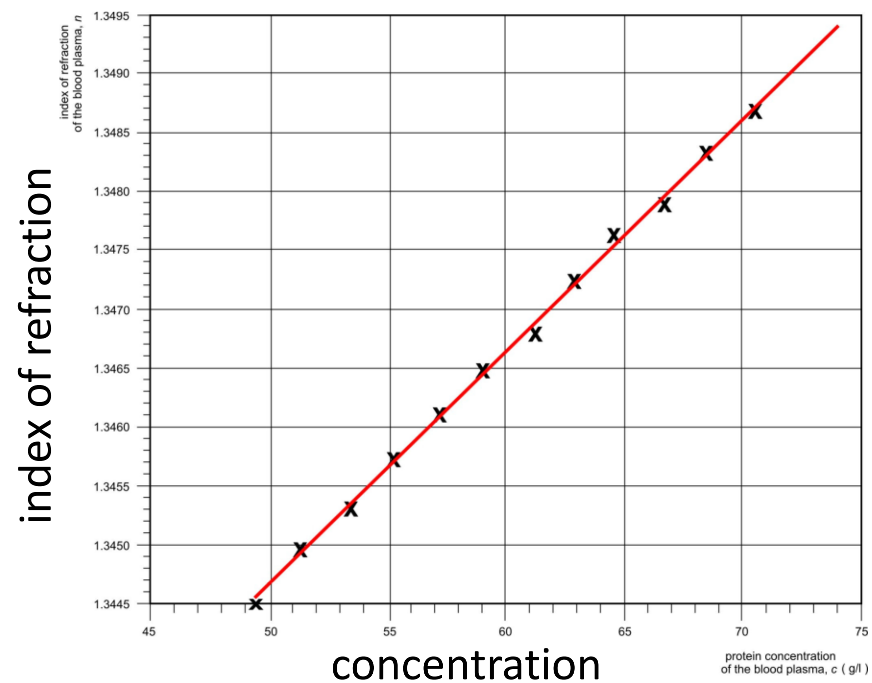


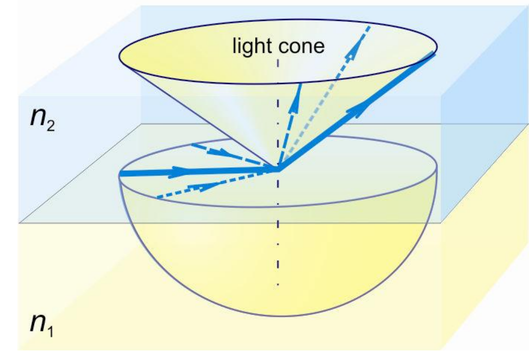

© Interceptor121

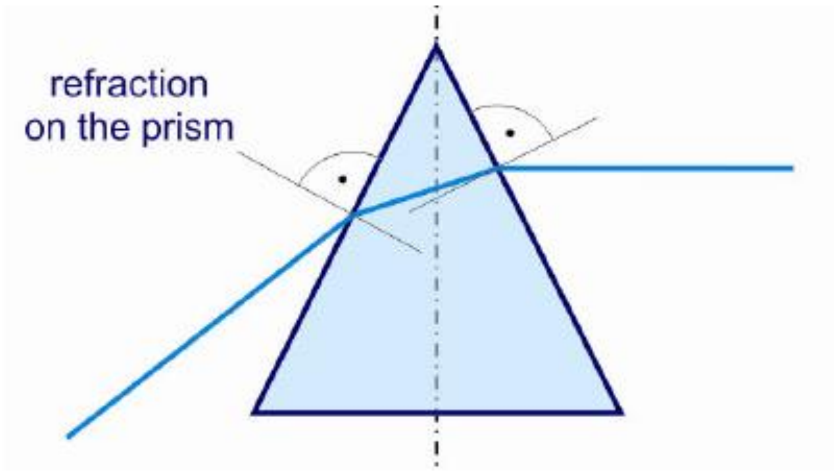
refractometry





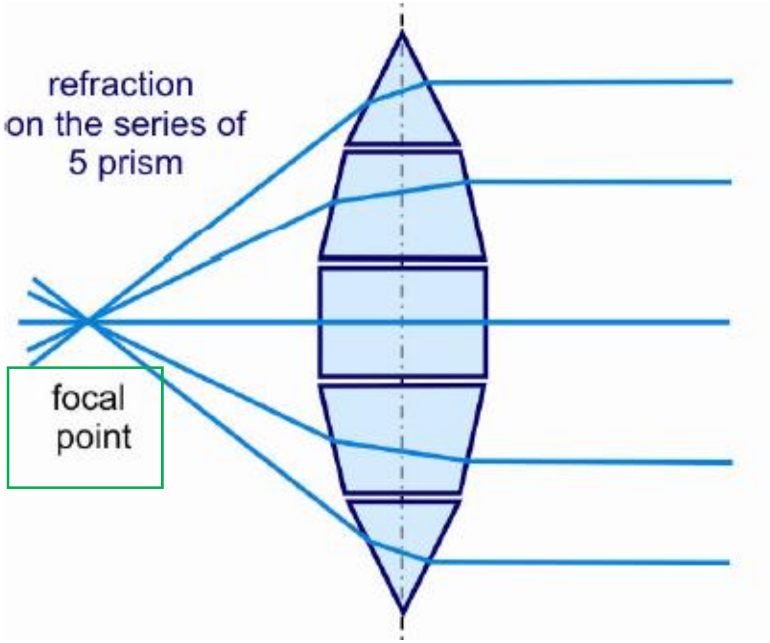




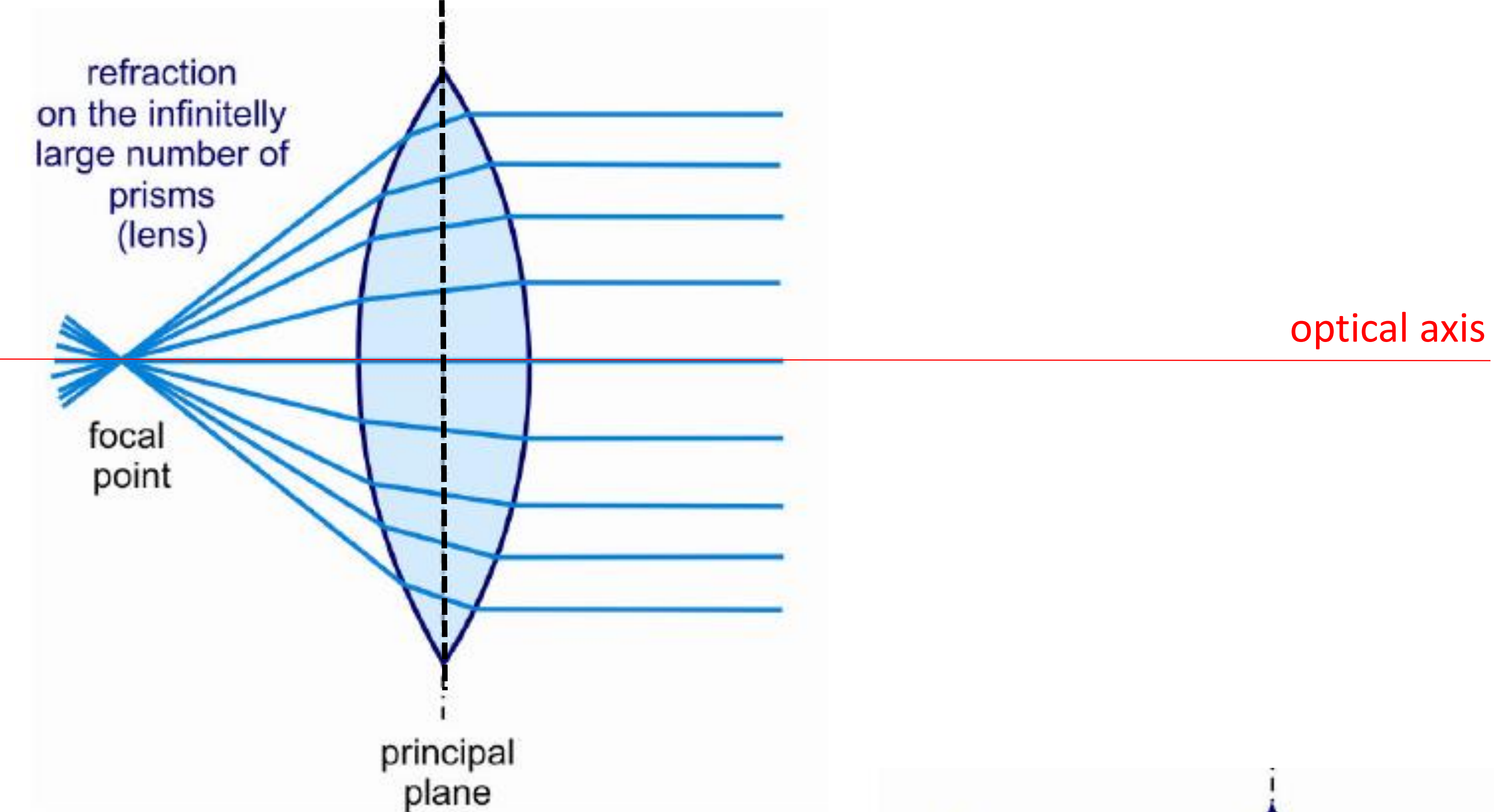


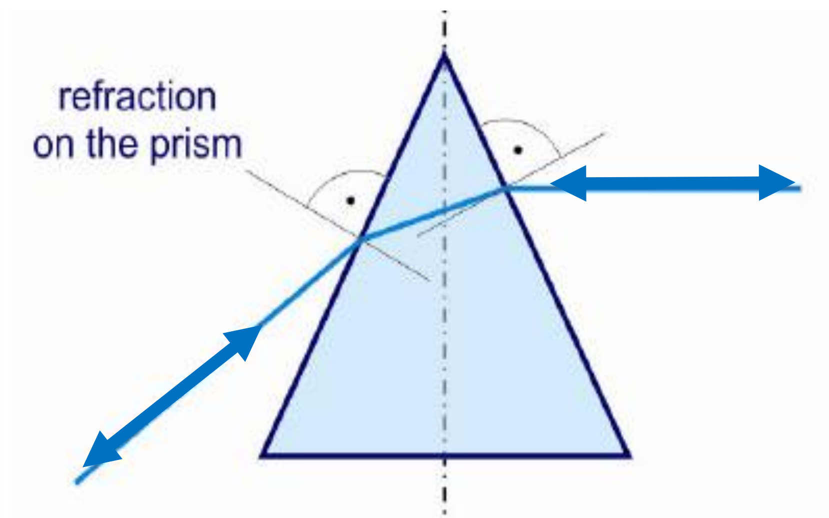
We have to apply SD twice
(and additionally *a LOT of geometrical calculations*, to get the angles and the normals)

-> ***geometrical*** optics



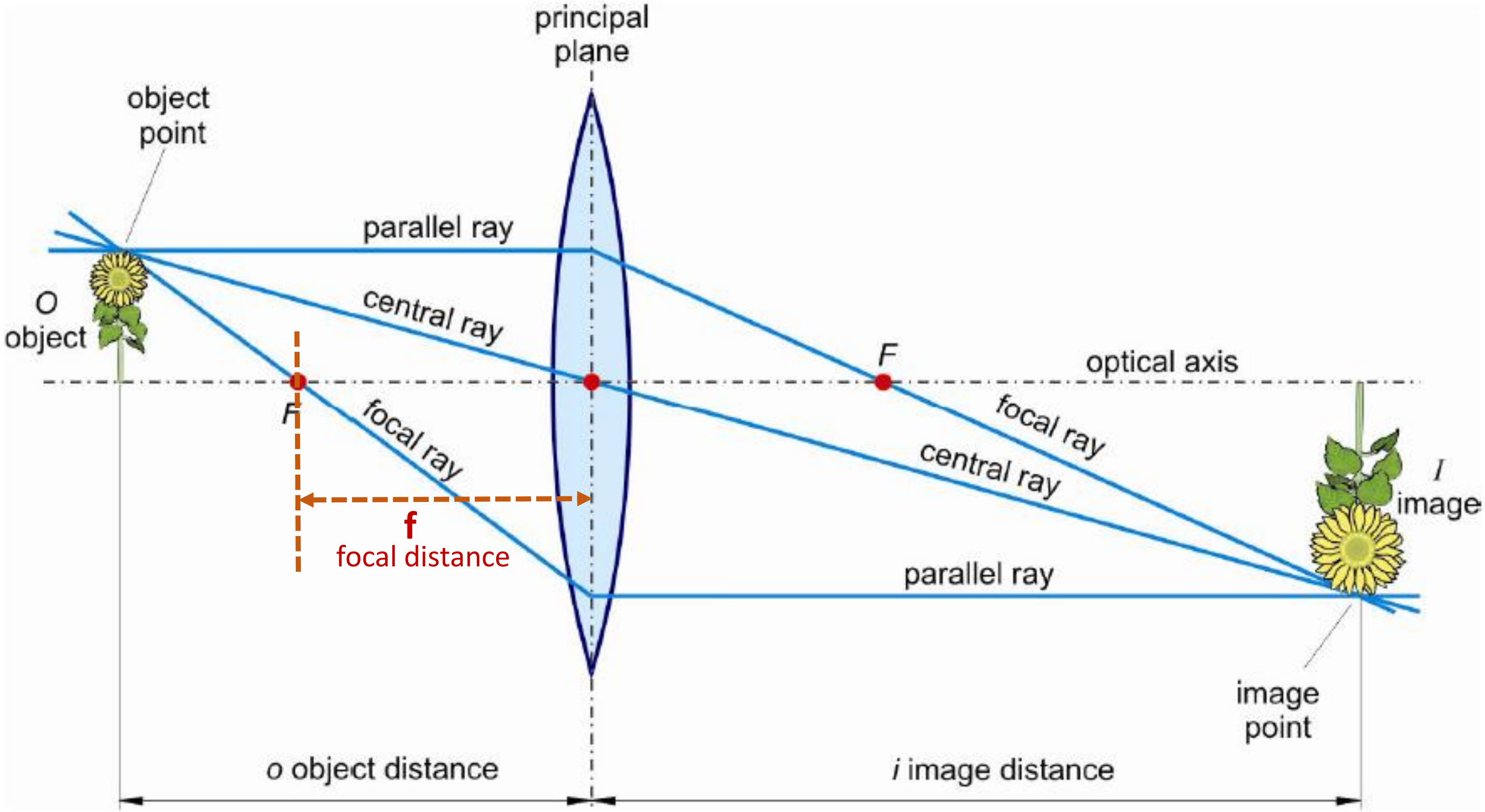
with a suitable arrangement rays originating (or coming) out of one point will become parallel, and vica versa.





the SD law, and the Fermat principle are REVERSIBLE, as are the ray paths.

parallel rays ←→Focal point rays



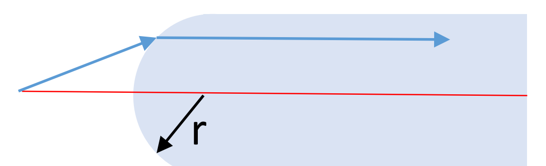
$$M = \frac{I}{O} = \frac{i}{o}$$

linear magnification

$$D = \frac{1}{f} = \frac{1}{i} + \frac{1}{o}$$

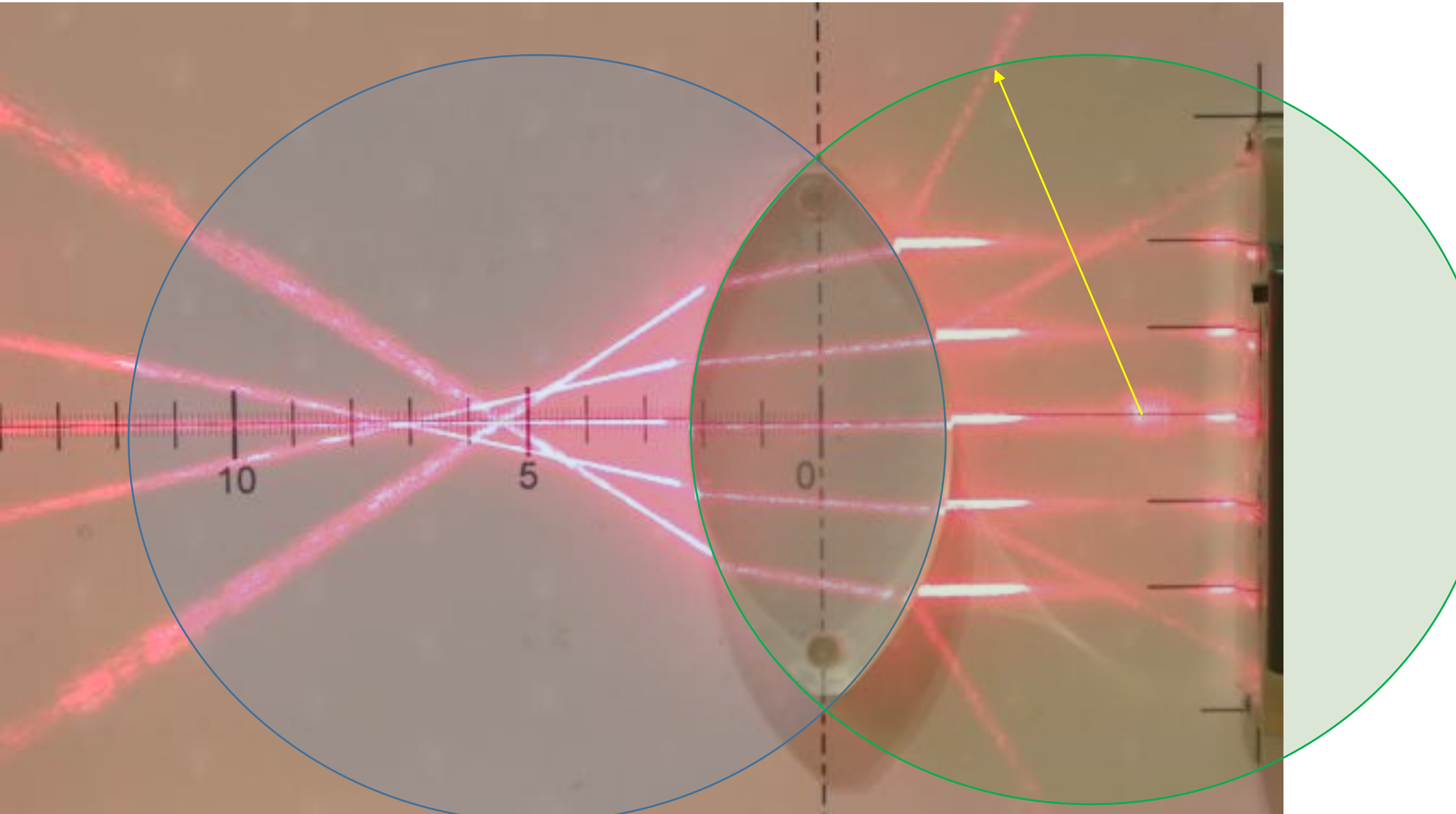
power of the lens : diopters (dpt, 1/m)

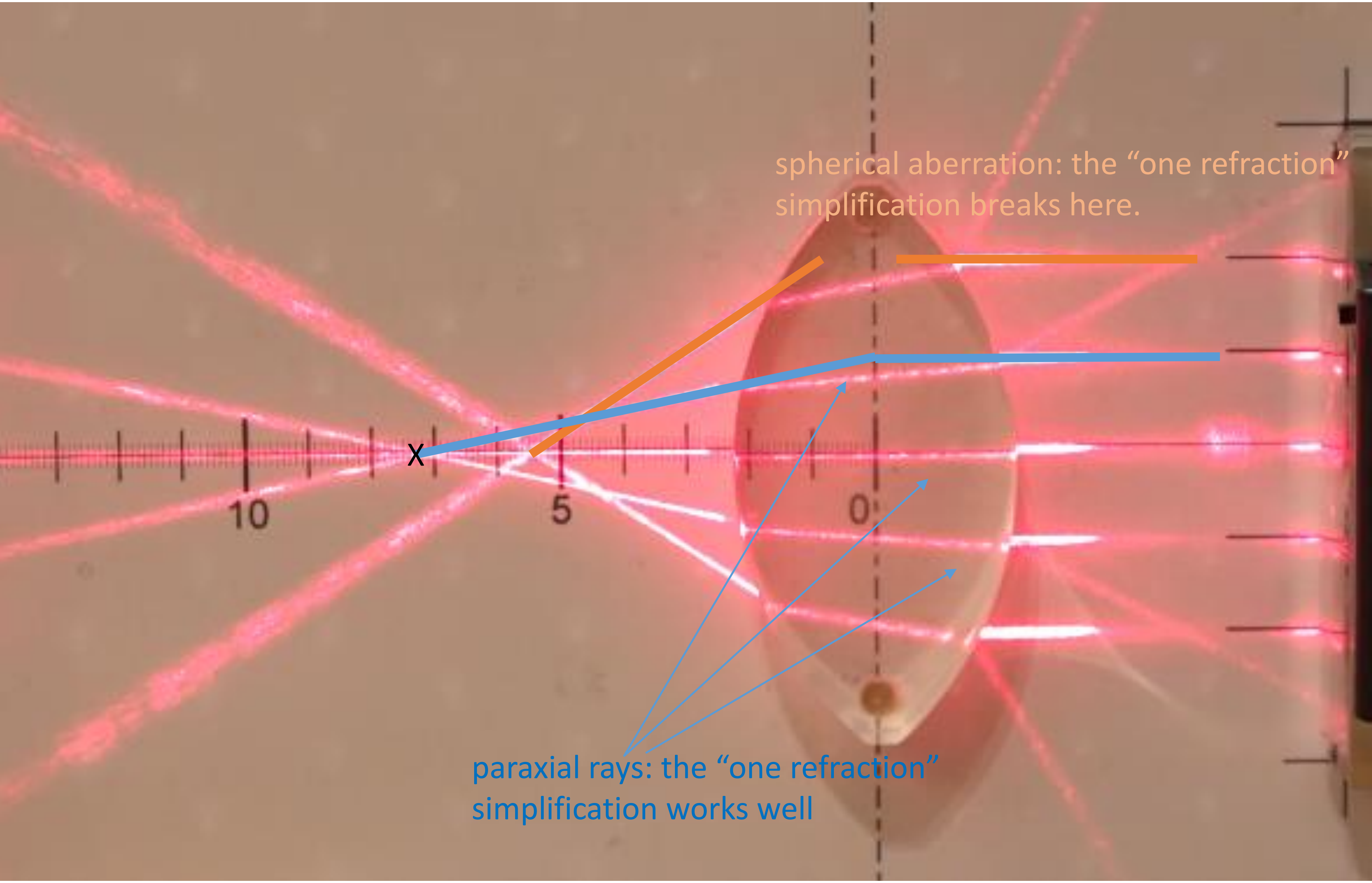
one curved surface

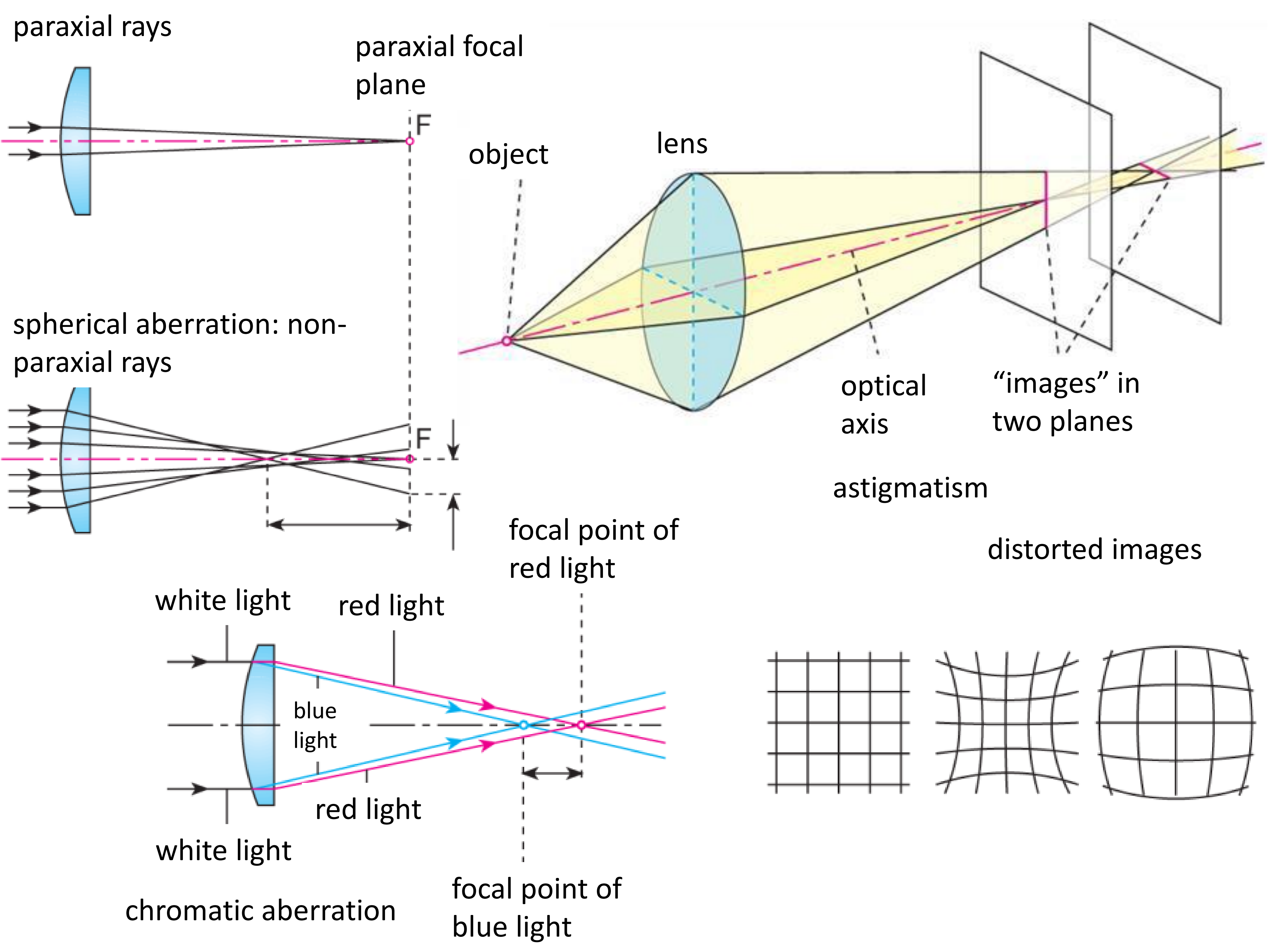


$$D = \frac{n - n'}{r}$$

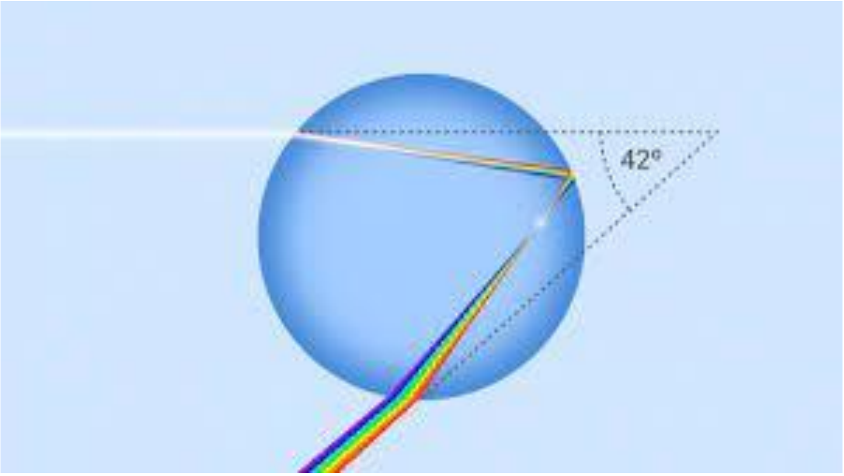
Radius of curvature of the lens, Spherical aberration

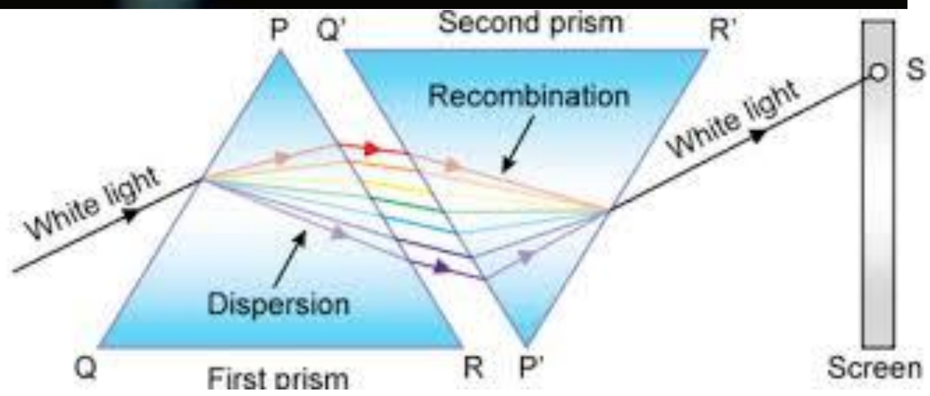


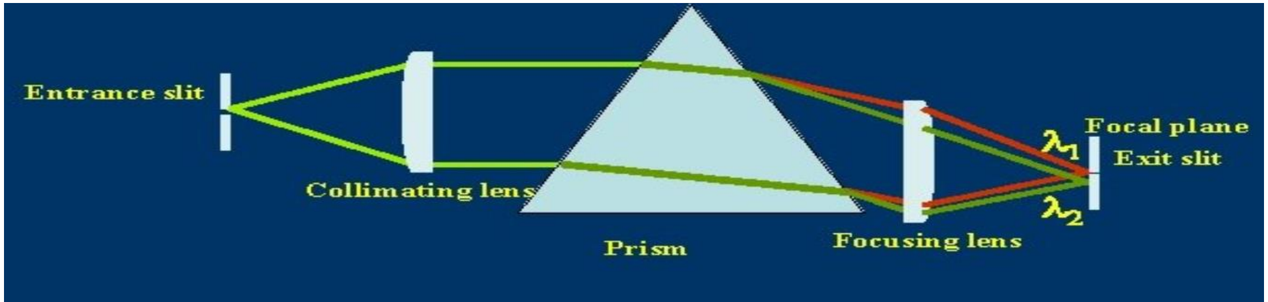

spherical aberration: the "one refraction" simplification breaks here.
X
10
5
0
paraxial rays: the "one refraction" simplification works well


paraxial rays
paraxial focal plane
F
spherical aberration: non-paraxial rays
F
object
lens
optical axis
"images" in two planes
astigmatism
focal point of red light
white light
red light
blue light
red light
white light
chromatic aberration
focal point of blue light
distorted images

dispersion: the index of refraction depends on the color (frequency) of the light







prism
monochromator

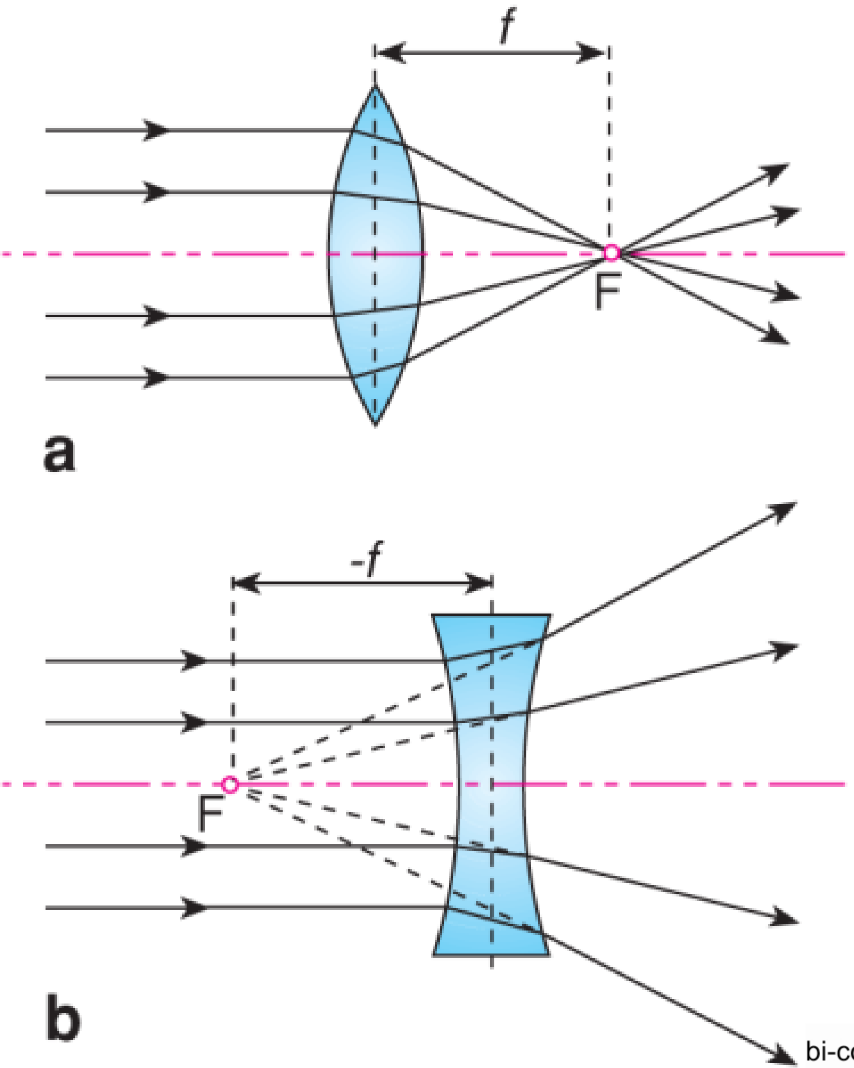
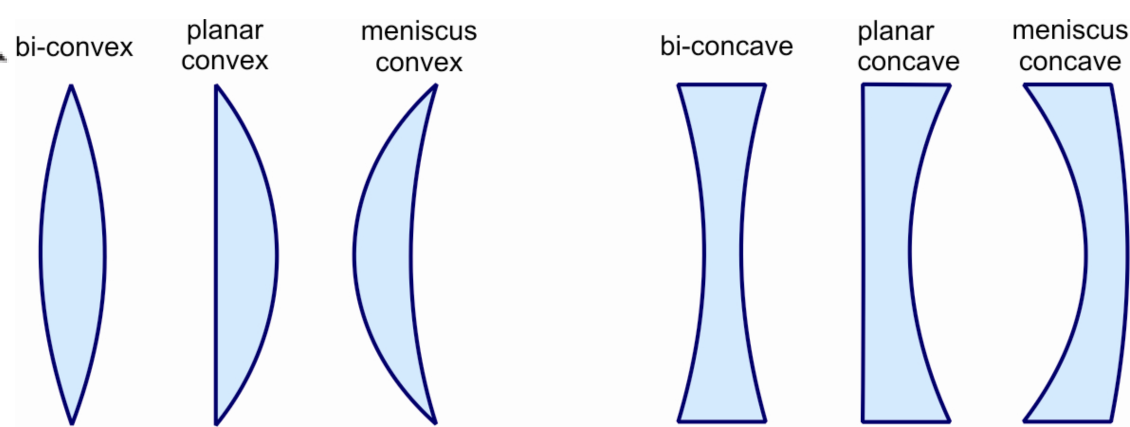


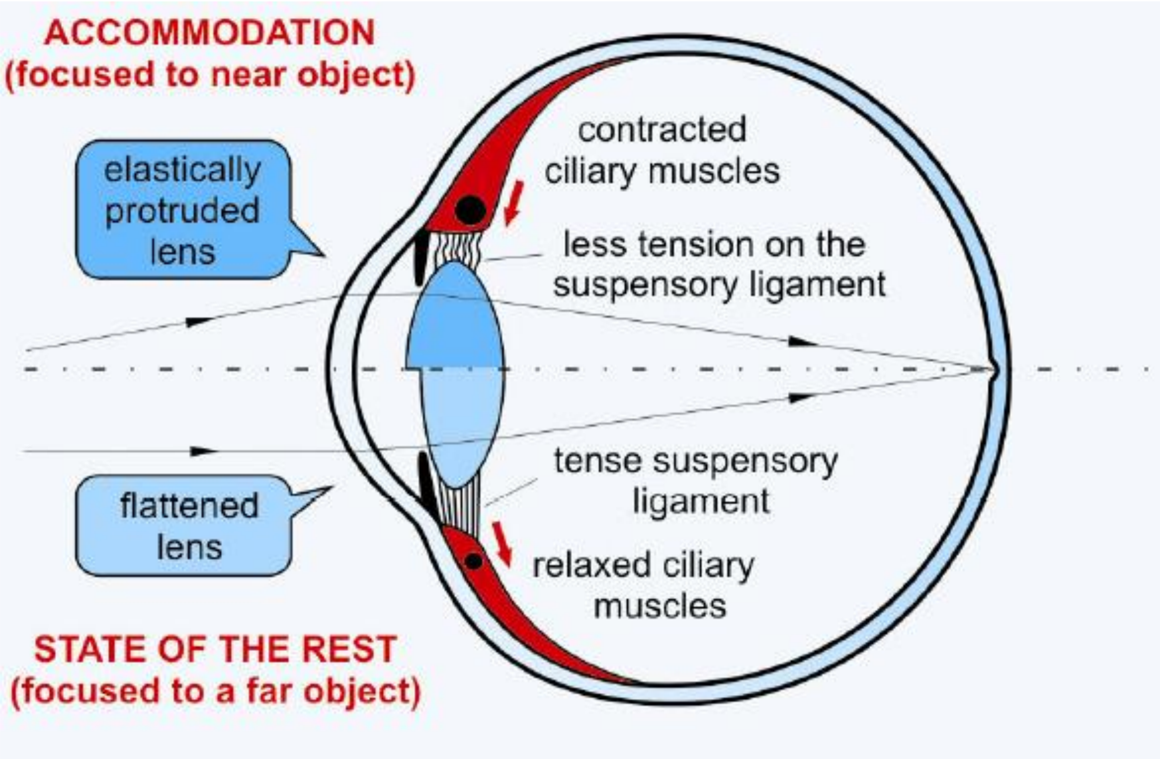
image formation of the diverging lens

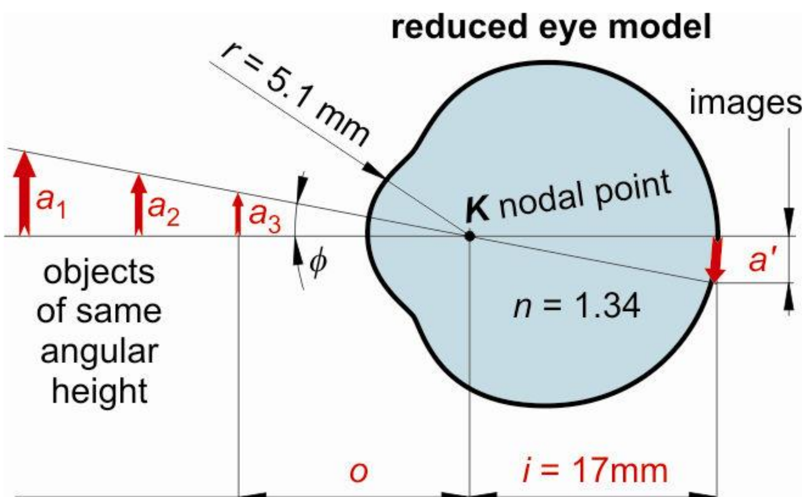


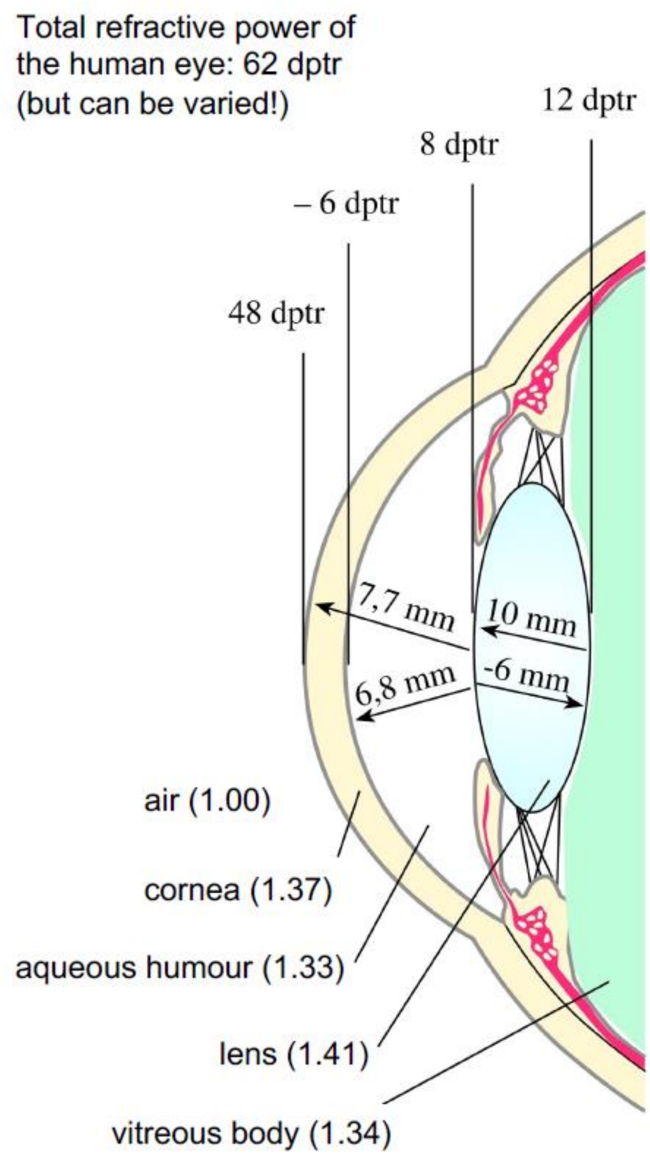
accommodation power

$$\Delta D = D_\mathrm{p} - D_\mathrm{r} = \frac{1}{t_\mathrm{p}} - \frac{1}{t_\mathrm{r}}$$

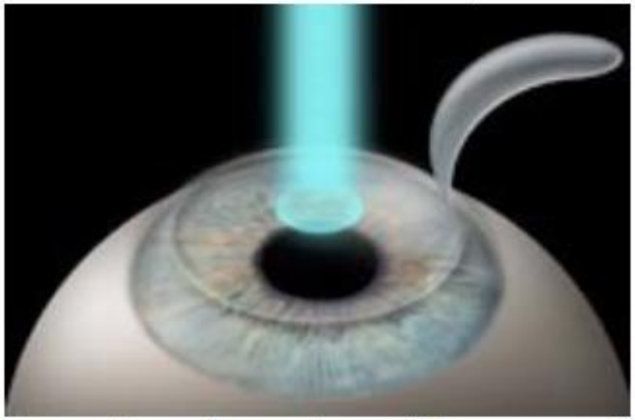
The eye is an adaptive optical system





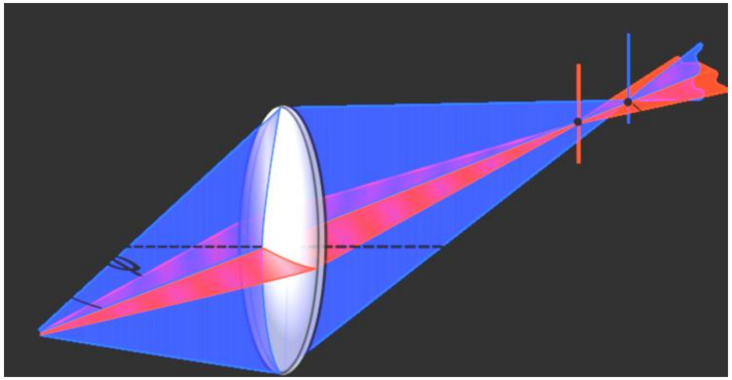


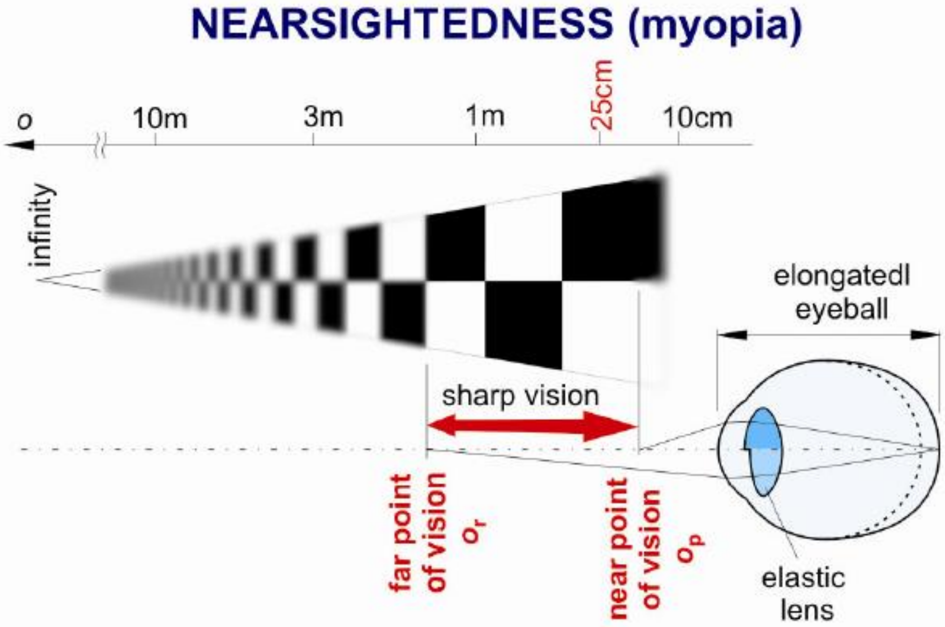
Permament correction of refractive problem: LASIK (Laser Assisted In Situ Keratomileusis)

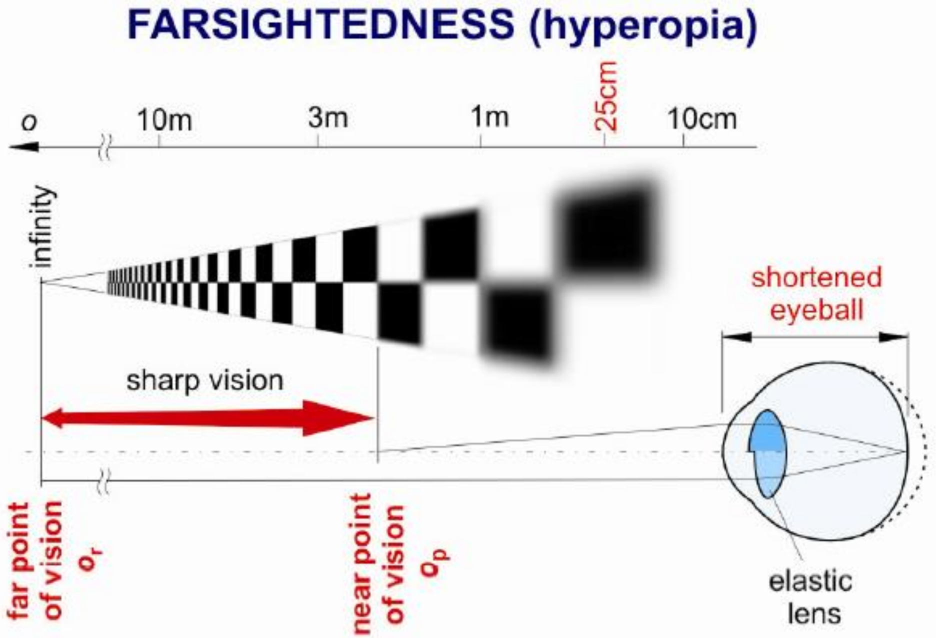


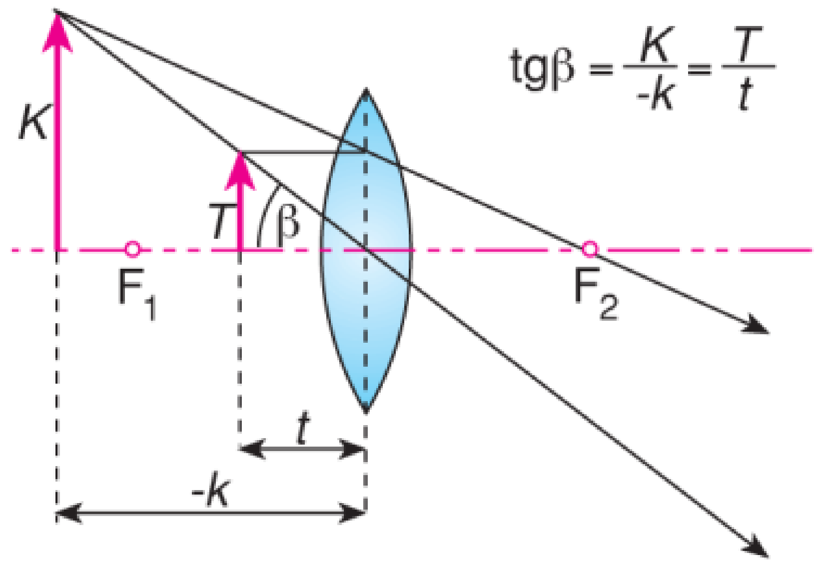
The radius of curvature of the cornea is changed (with laser surgery)

astigmatism -> „cylindrical eye”









converging lens as a simple magnifier

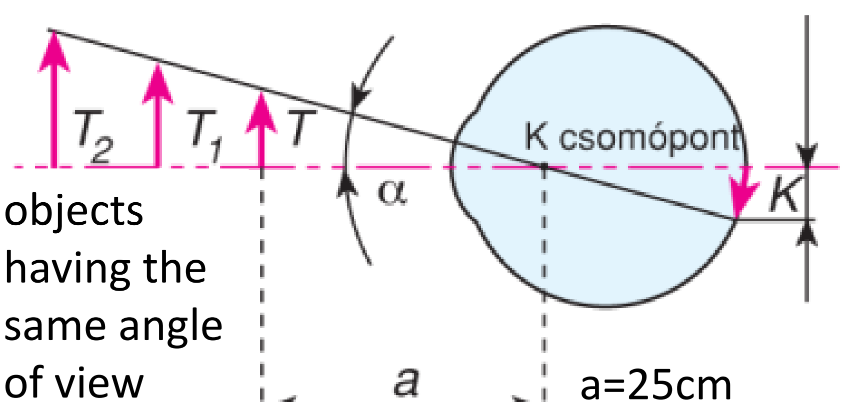
if we look at the object without the magnifier glass then it shows under a certain angle (at an object distance equal to the close point of the eye, a=25cm).

If the rays are refracted, this viewing angle is increased:
angular magnification

$$N_{angular} = \frac{\text{tg}\beta}{\text{tg}\alpha} = \frac{K}{-k}\,\frac{a}{T} = \frac{T}{t}\,\frac{a}{T} = a\left(\frac{1}{f} - \frac{1}{k}\right)$$

$$\text{tg}\alpha = \frac{T}{a}$$

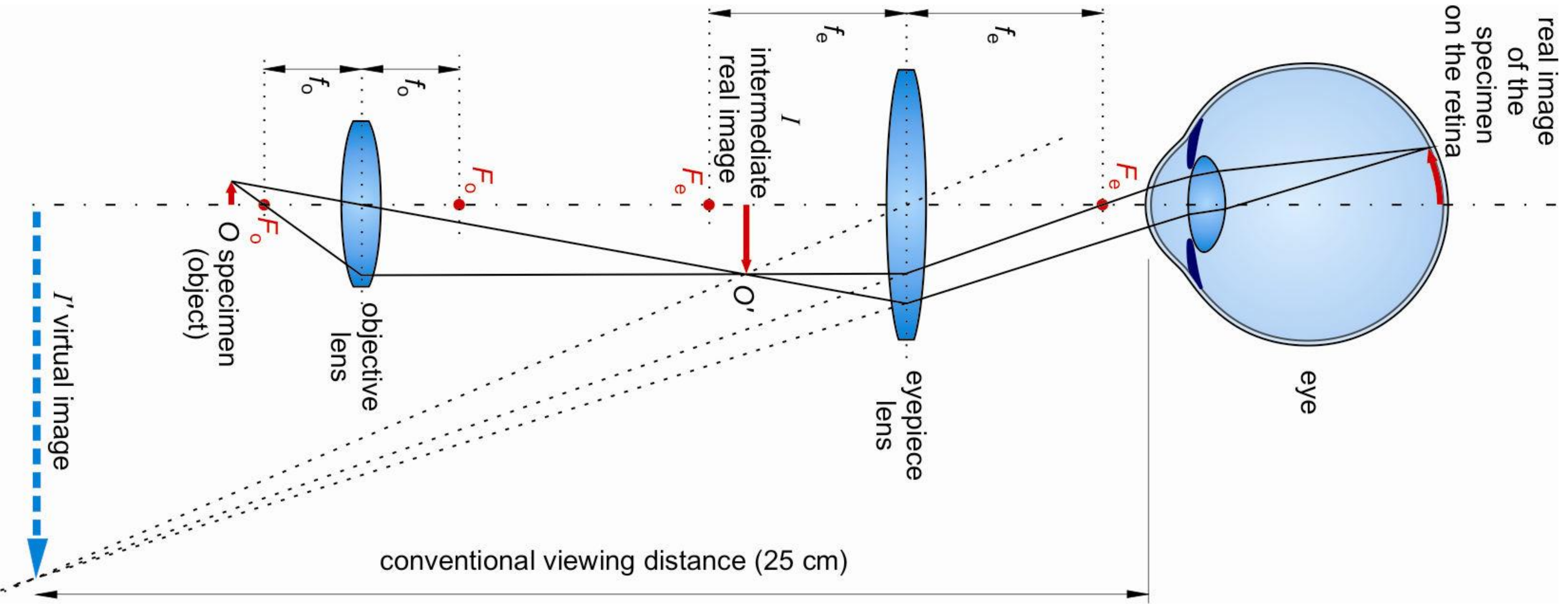
image of the objects



objects having the same angle of view

a=25cm

image formation in the microscope



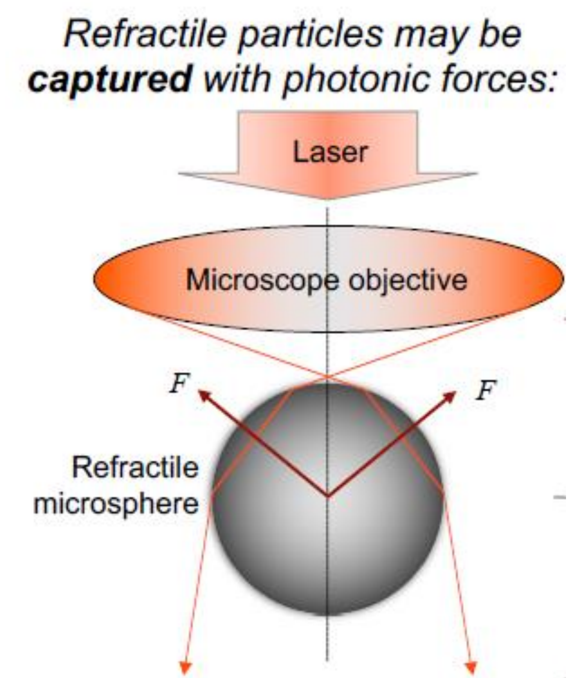
The rays are refracted by two consecutive lenses, one generating a magnified real image, and the other a further magnified virtual image. Ray tracing can be used to follow the rays, the viewing angle is increased.

The microscope can be set to see the virtual image at the reading distance of 25 cm, but also to accommodate to infinity (like looking at the sky). The magnification will be different.

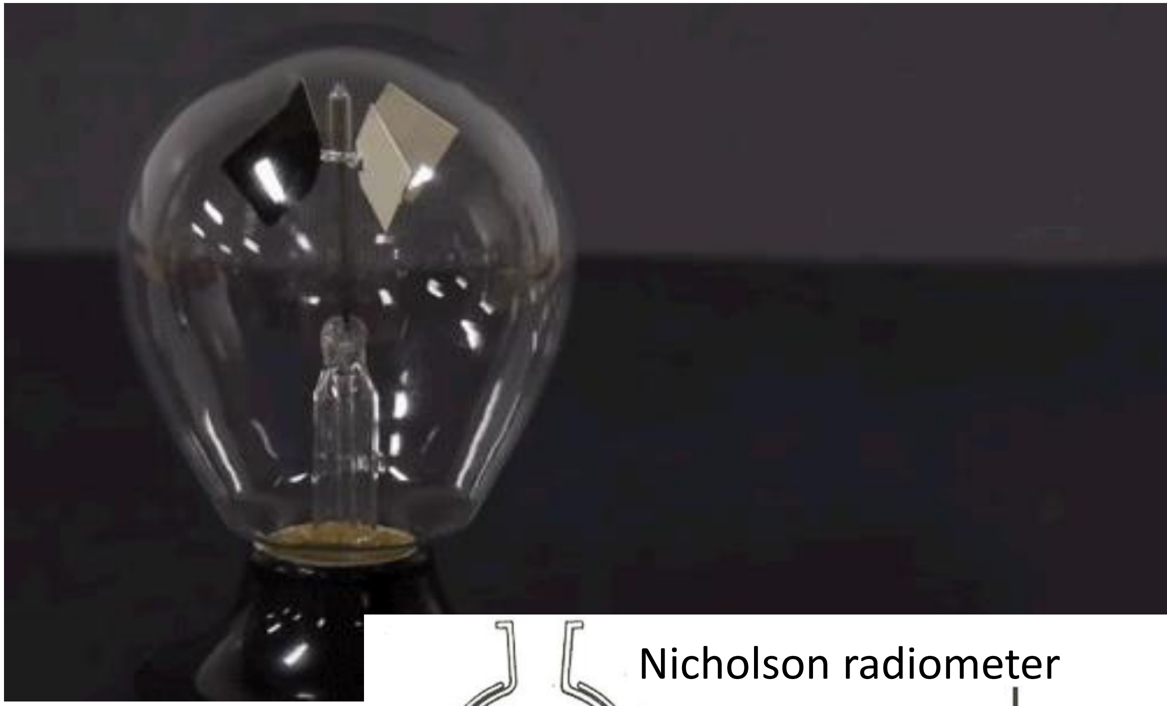
Either the linear magnification or the angular magnification can be calculated.

light can exert a force (photons have momentum)

optical „tweezer”

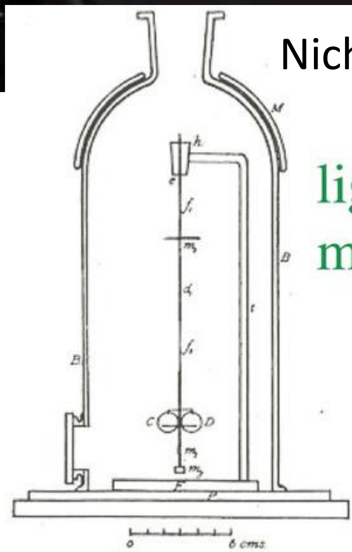


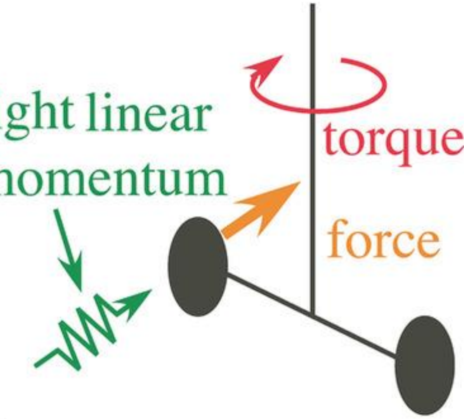
Crookes light mill



at refraction or reflection the wave exerts a very small force on the object. But if the object is very small (µm-sized bead under the microscope) or an easy to move almost frictionless object in vacuum then the force is enough to make them move (Nicholson radiometer)!

Nicholson radiometer





Crookes is a heat engine! light delivers energy feedback code