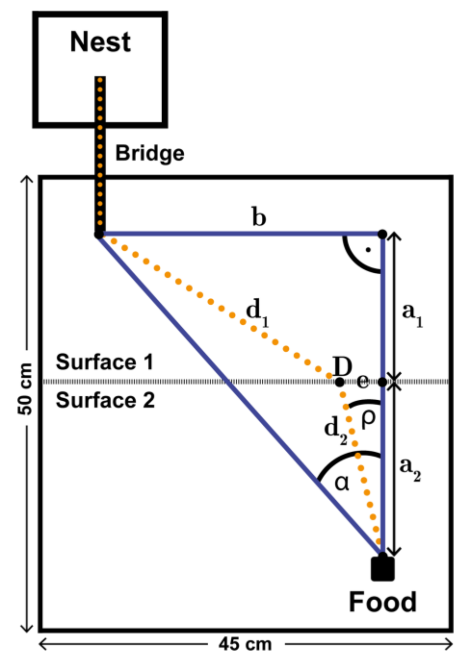
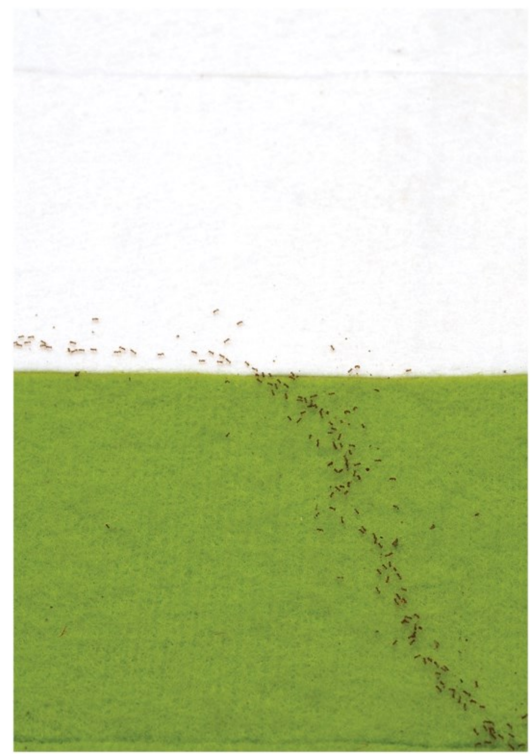
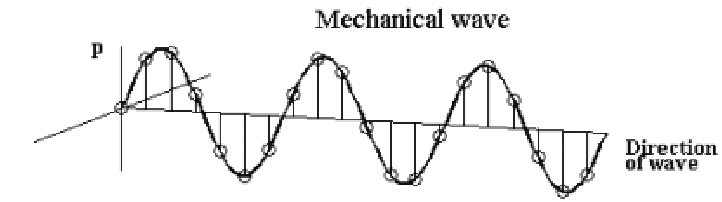
Basics of geometrical optics

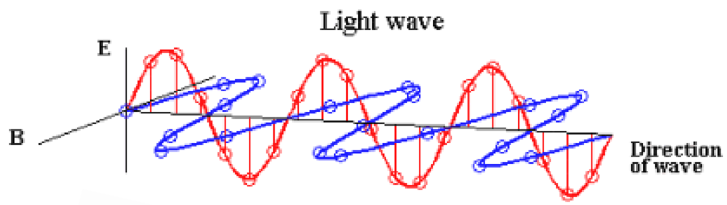
Fermat-principle, refraction,
imaging by lenses,
microscope.

Schay G.







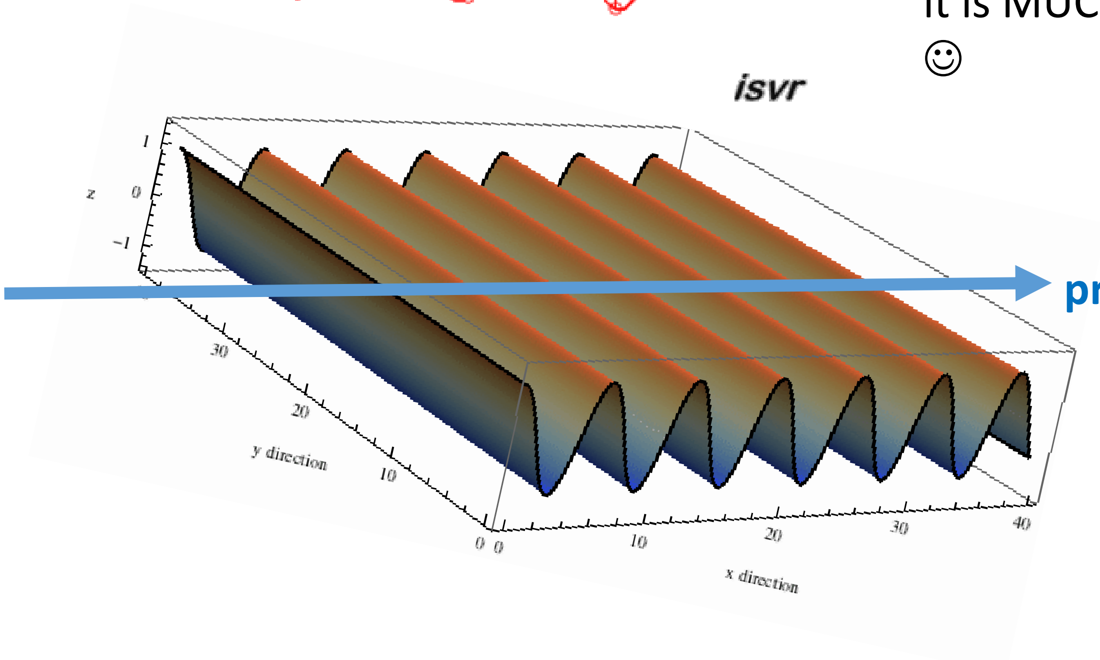


geometrical optics is a **simplification**

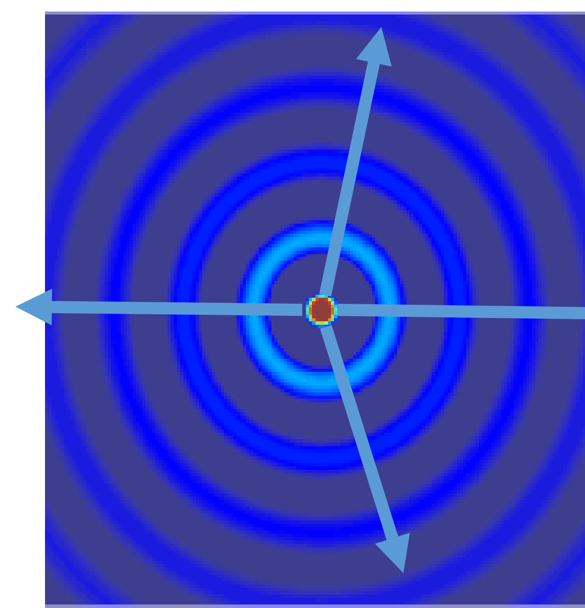
it can be used in some cases, but not all phenomena can be explained by this

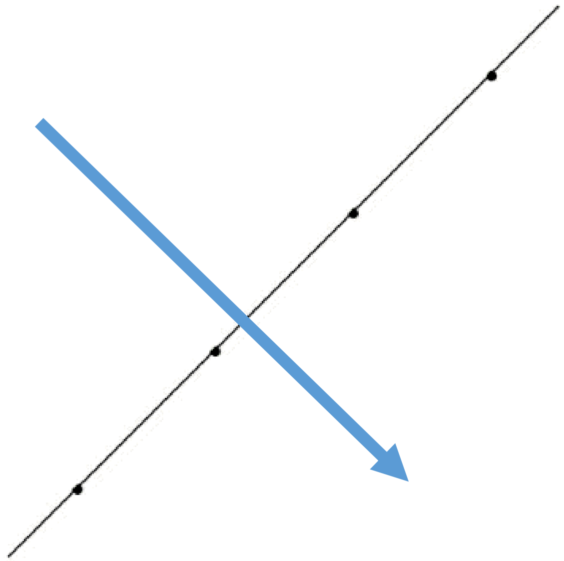
BUT

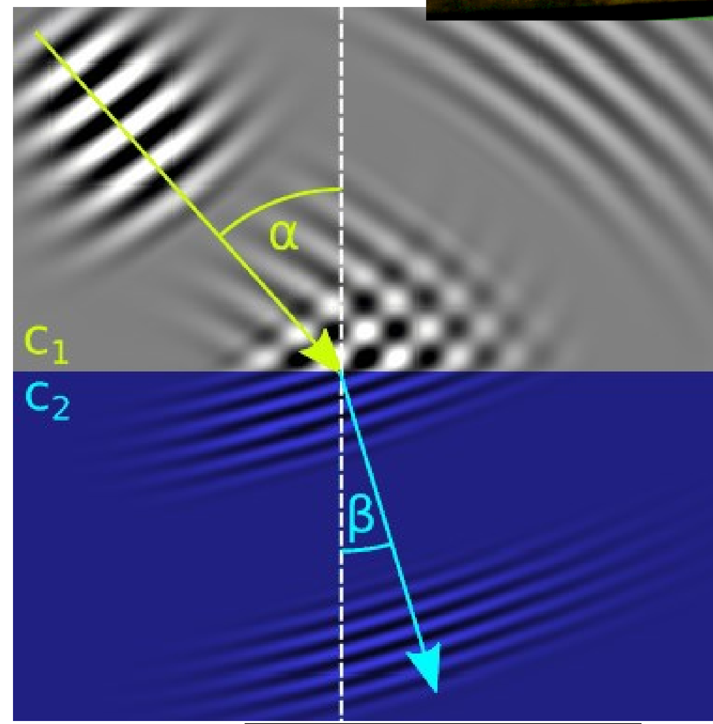
it is MUCH simpler than wave theory ☺

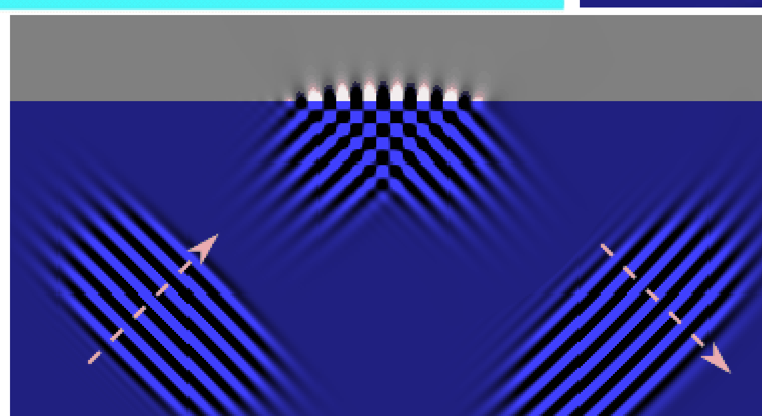


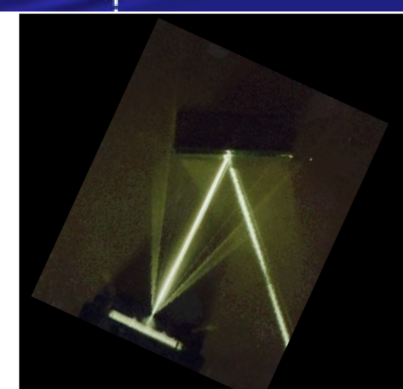
propagation direction

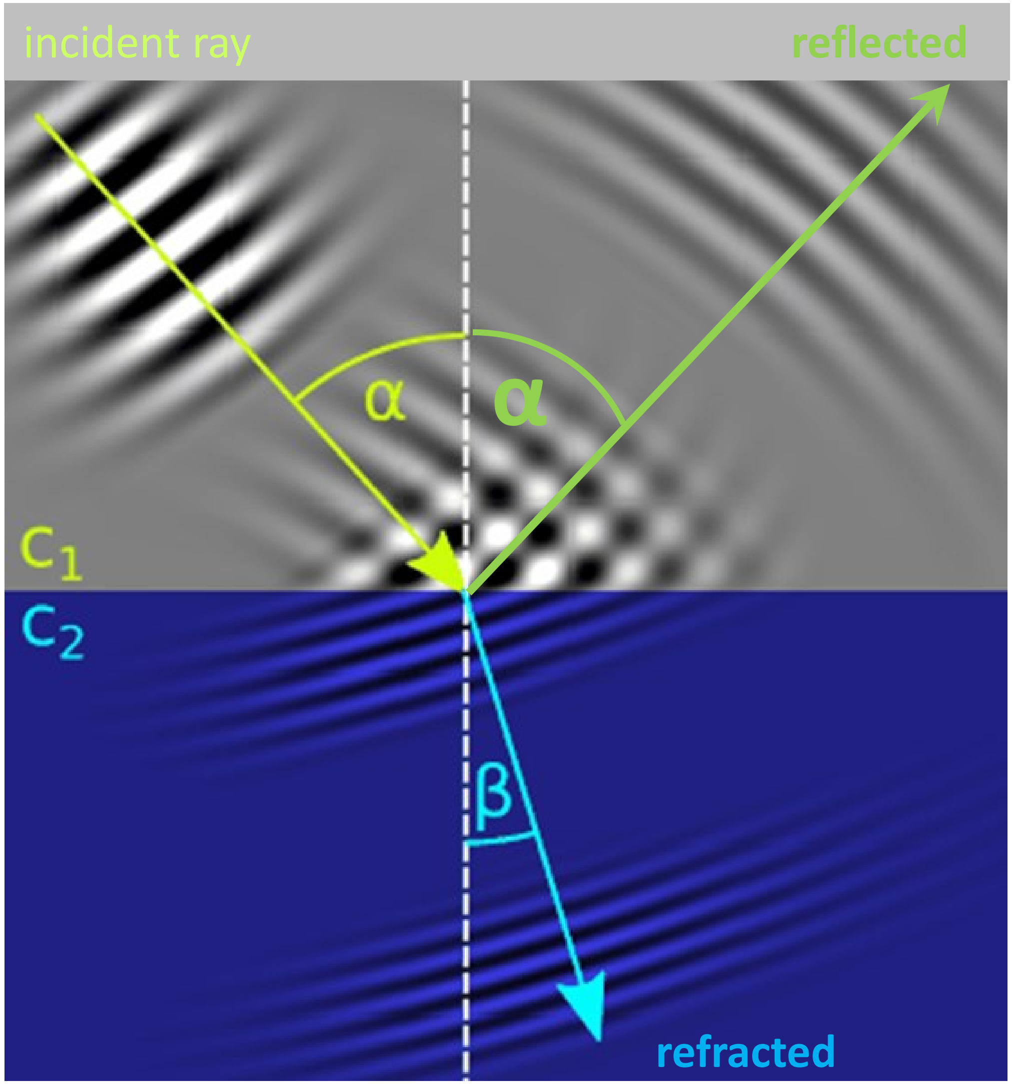





α
c_1
c_2
β

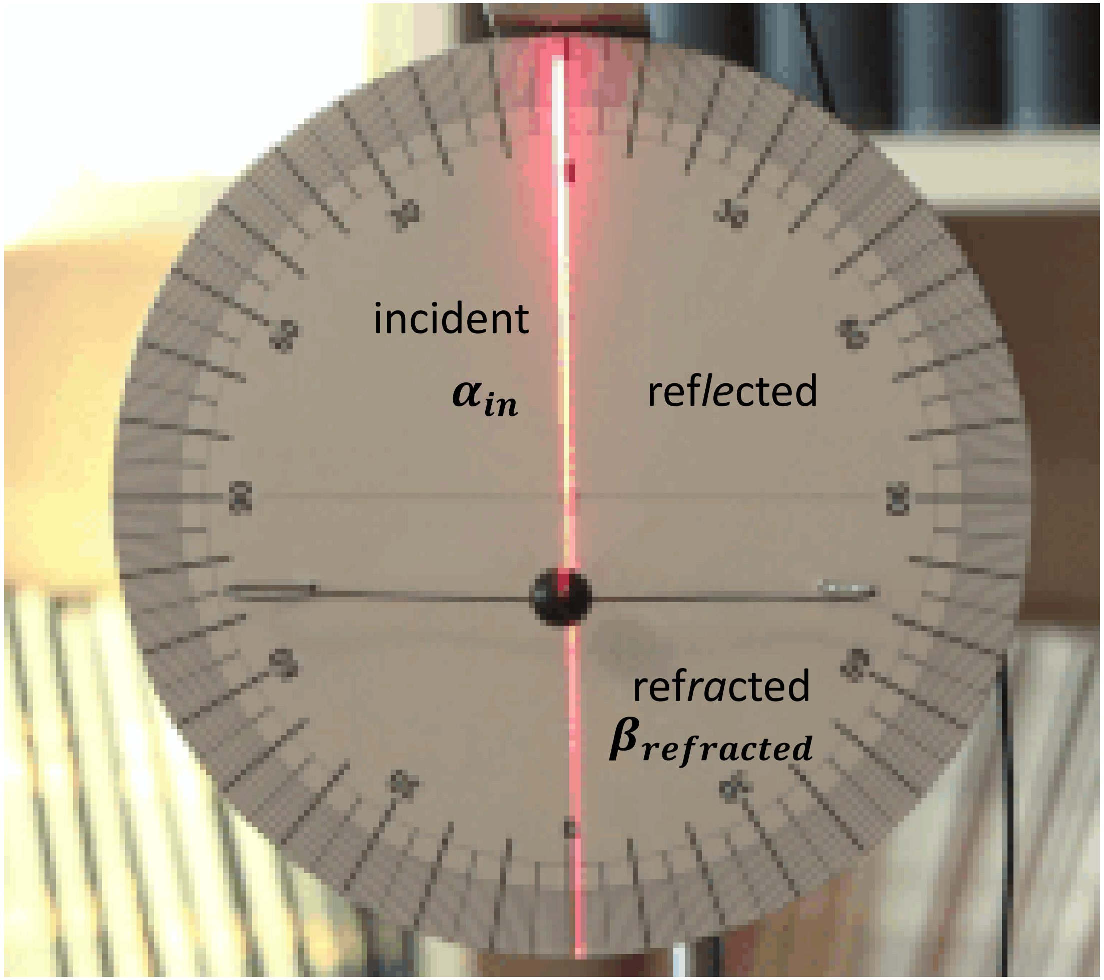


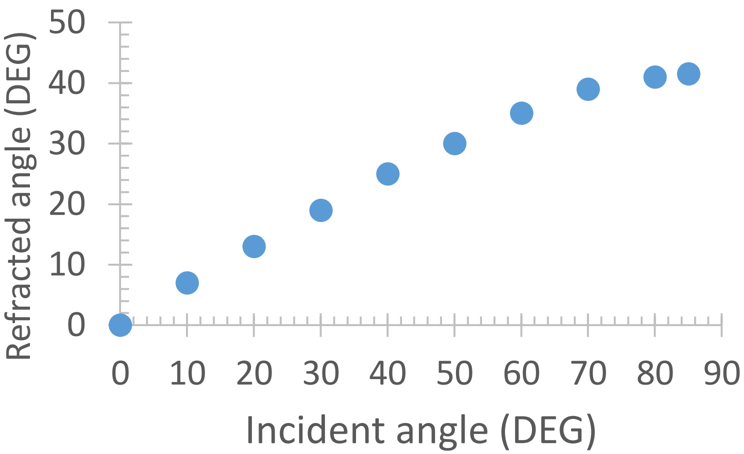


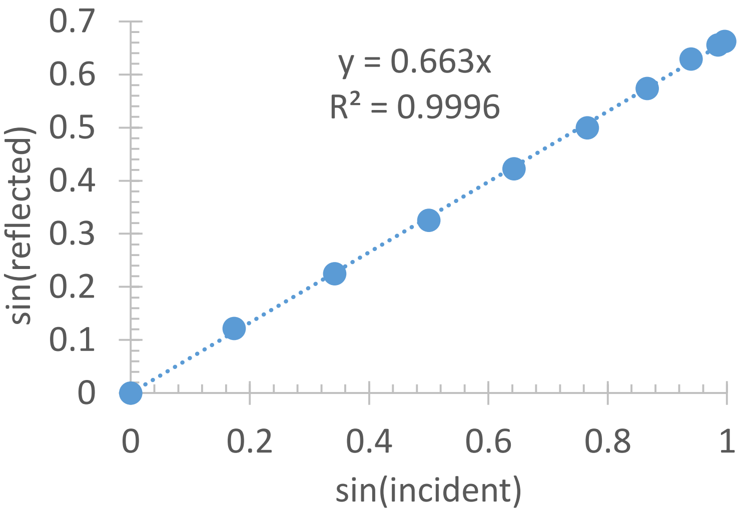


instead of the WAVE picture, we try to set up equations based on the angles and rays

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







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

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

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

Snellius-Descartes

AND
all the rays are in one plane.

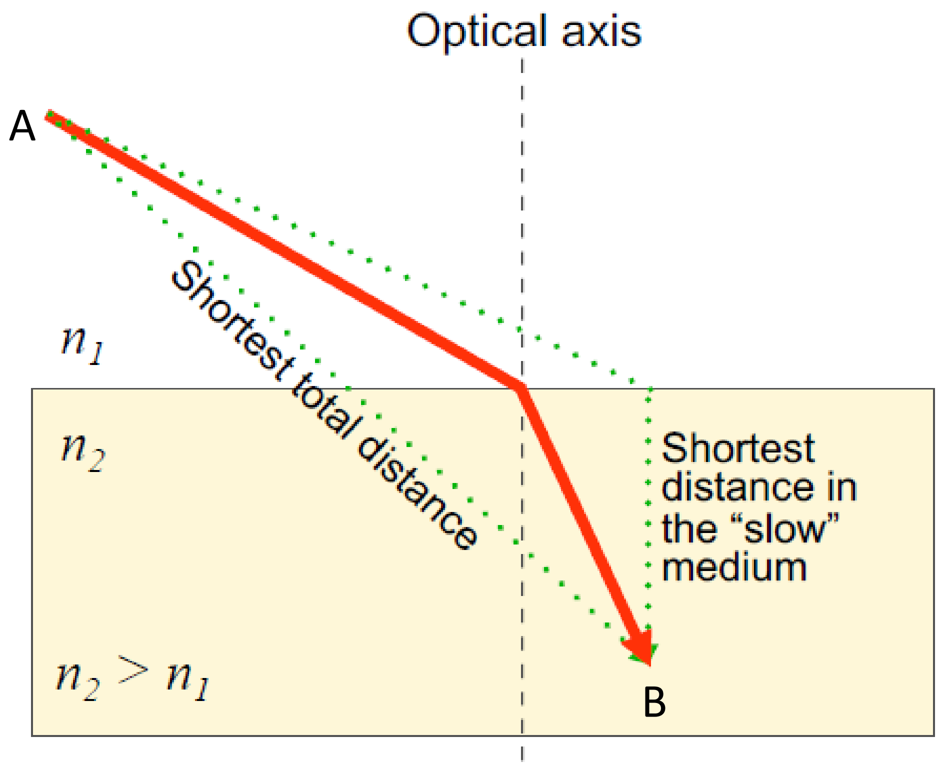
n is a material and light color dependent number, the **refractive index.** For vacuum it is 1.

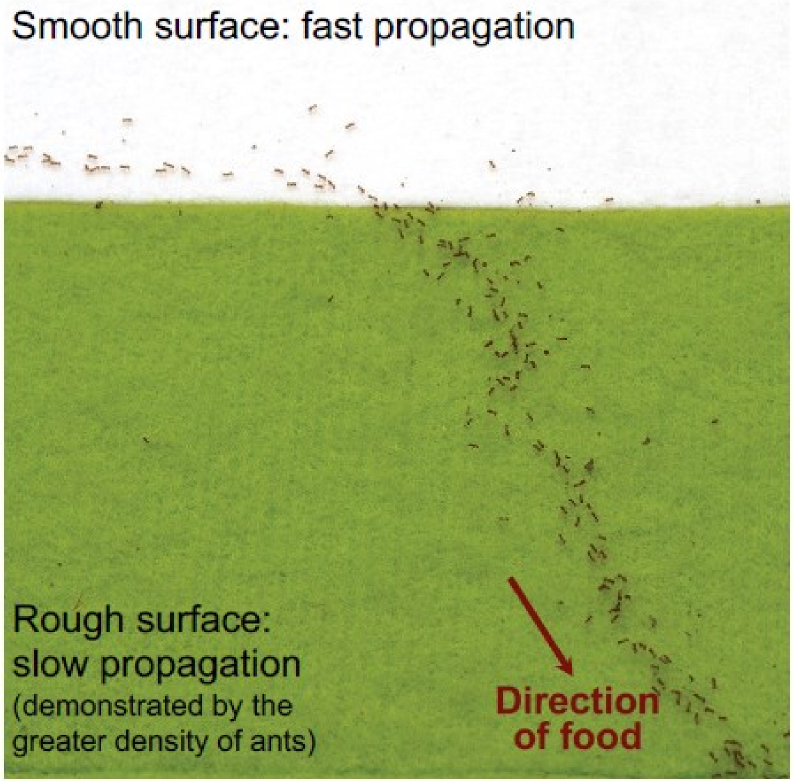
the Fermat principle can explain this with one sentence.

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

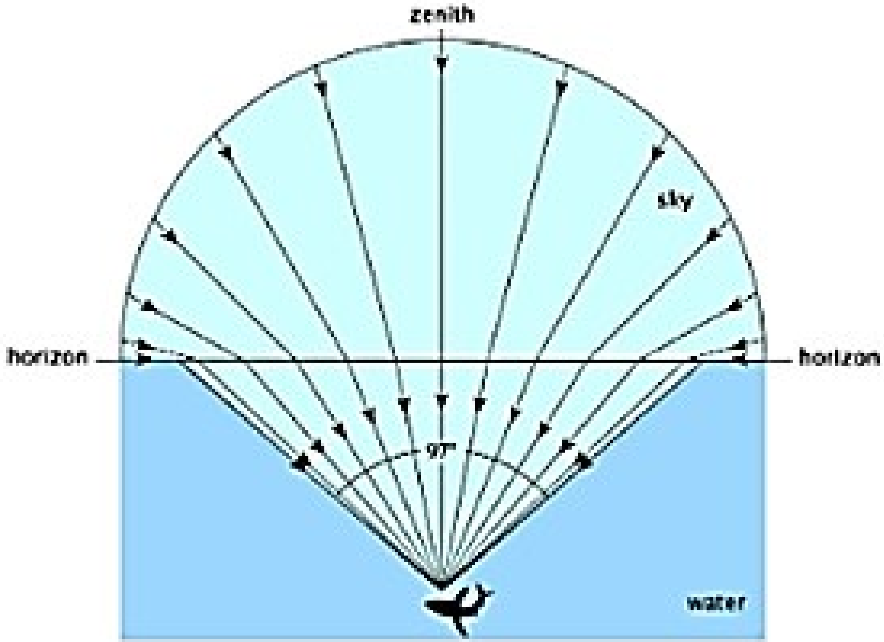
The light ray takes that path between two (known) points, which requires the least time.

(principle of least time)

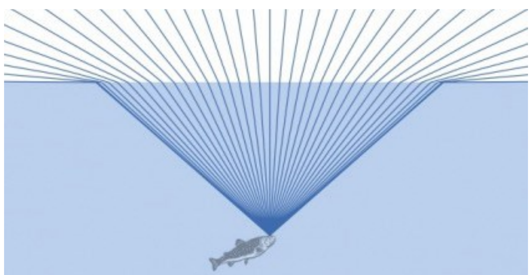




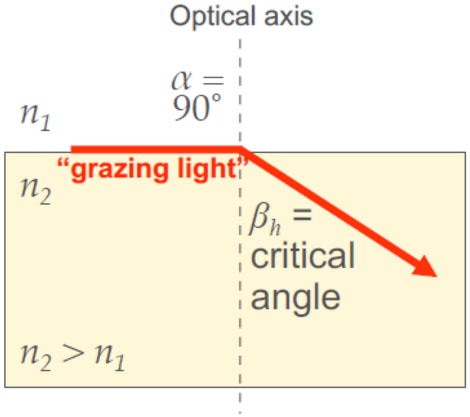
not too practical> we must know A,B in advance…


zenith
sky
horizon
horizon
97°
water


© Andrew Marriott

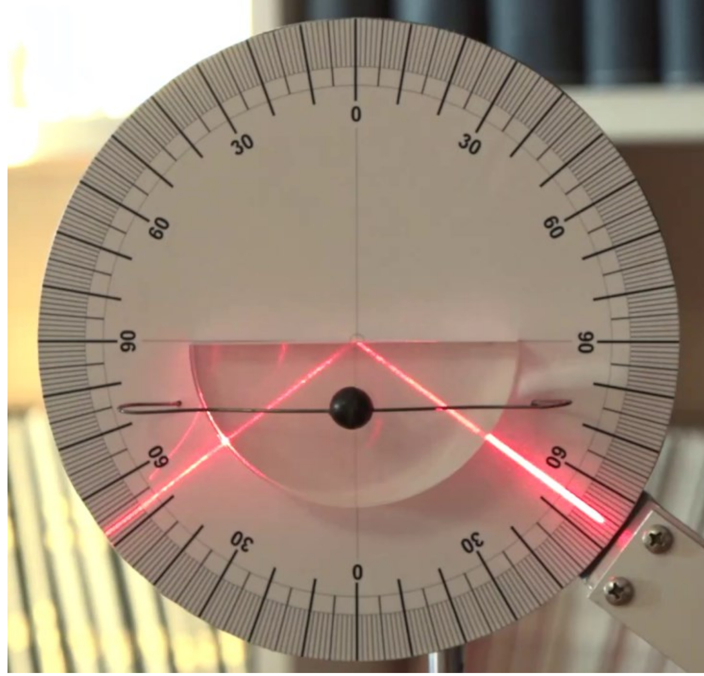


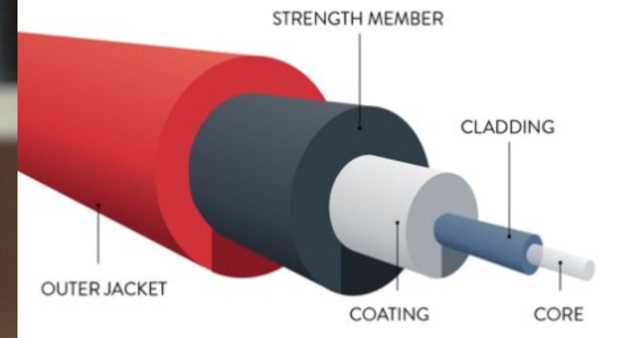

© Interceptor121

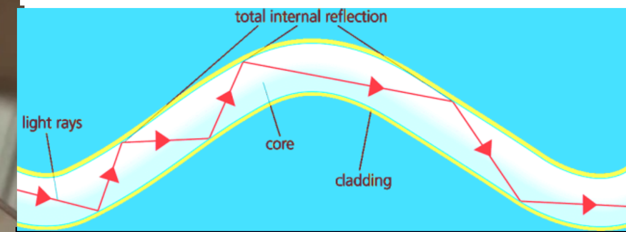


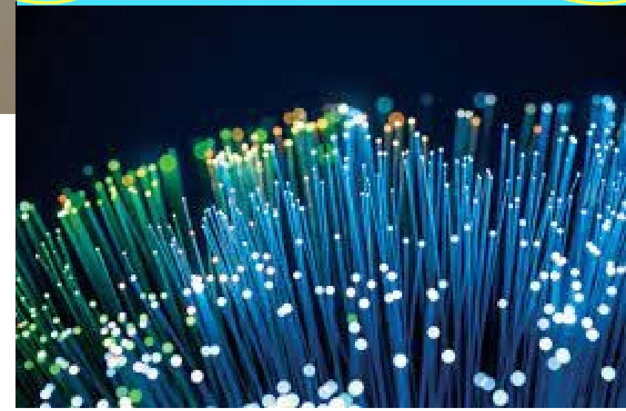
Since $\sin(90°) = 1$, according to Snell's law:

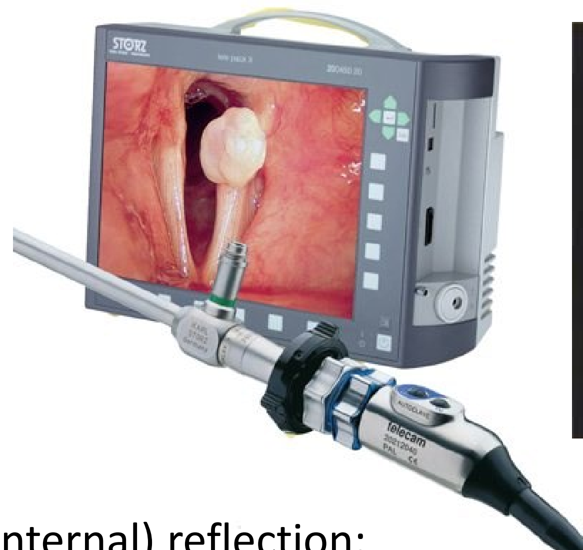
$$n_1 = n_2 \sin \beta_h$$









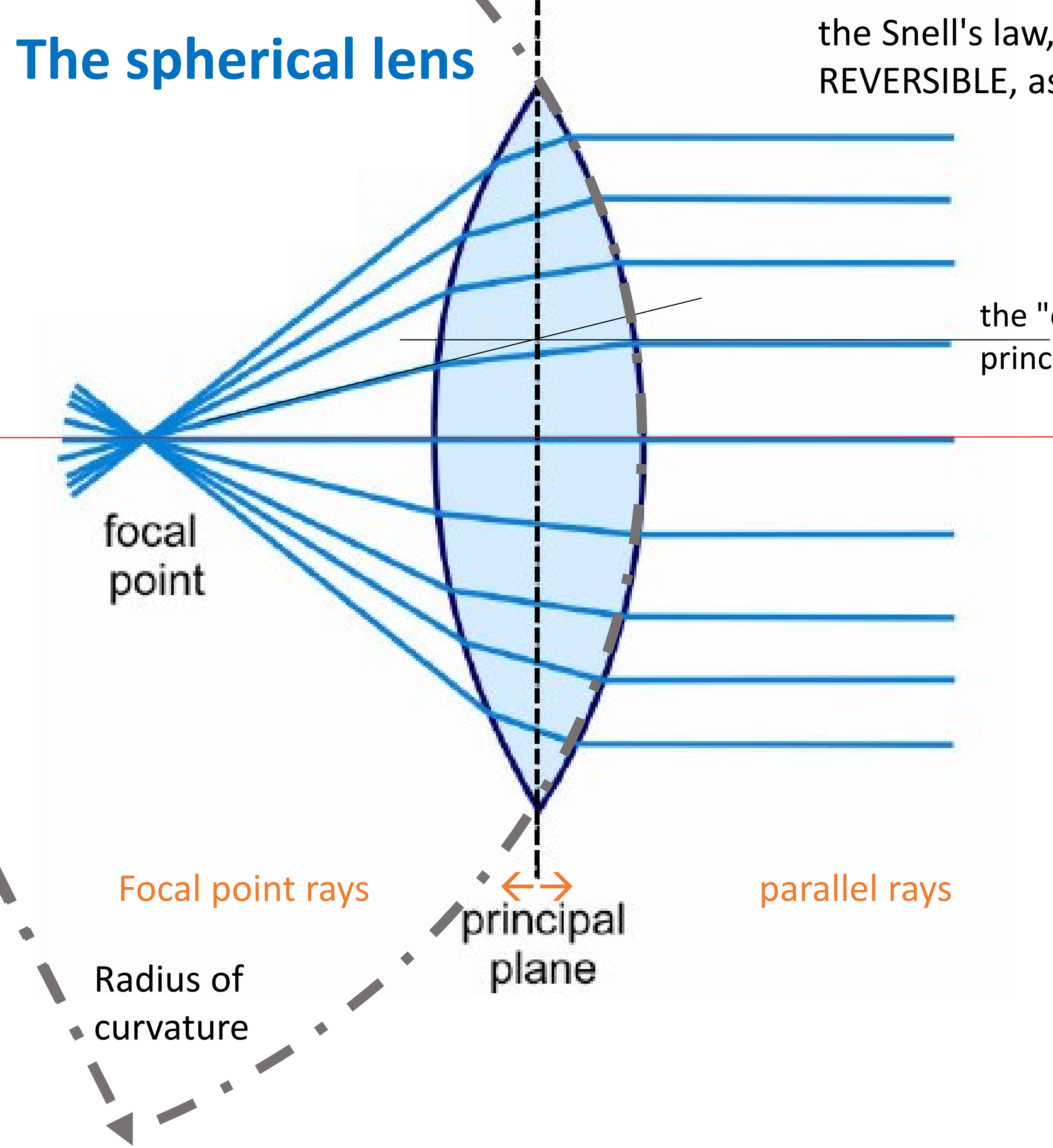


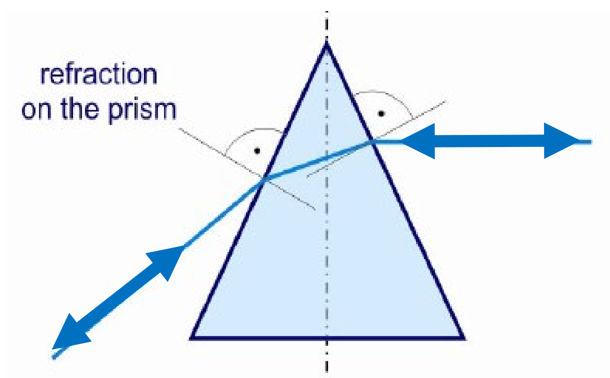
Total (internal) reflection:

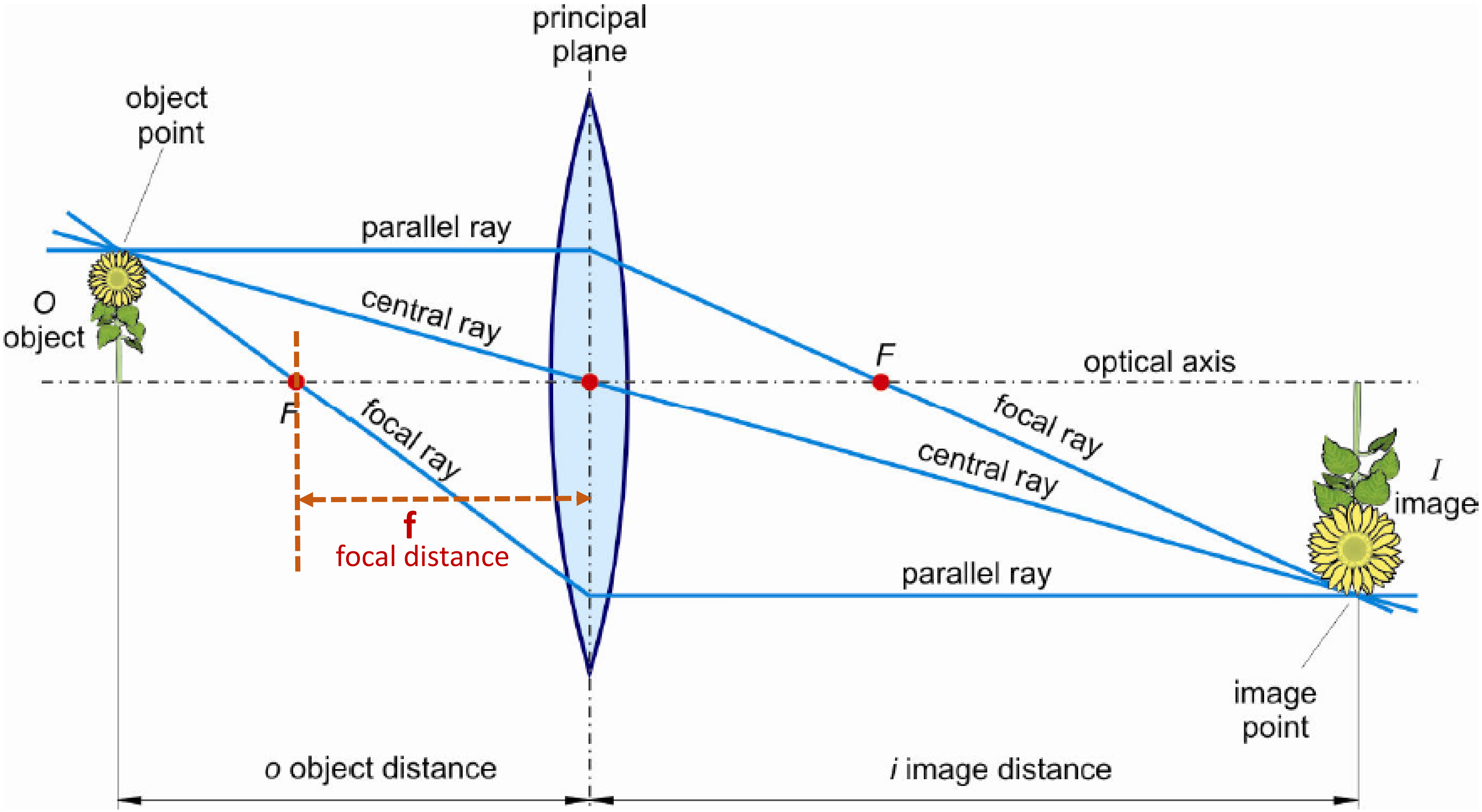
since SD law is reversible, we can send light from the other sidem now controlling β, and can set it to greater value than the limiting angle. Then SD for refraction has no solution, so only REFLECTION is possible. Hence we get a perfect, 100% mirror in this incident angle range.

The spherical lens

the Snell's law, and the Fermat principle are REVERSIBLE, as are the ray paths.







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

linear magnification

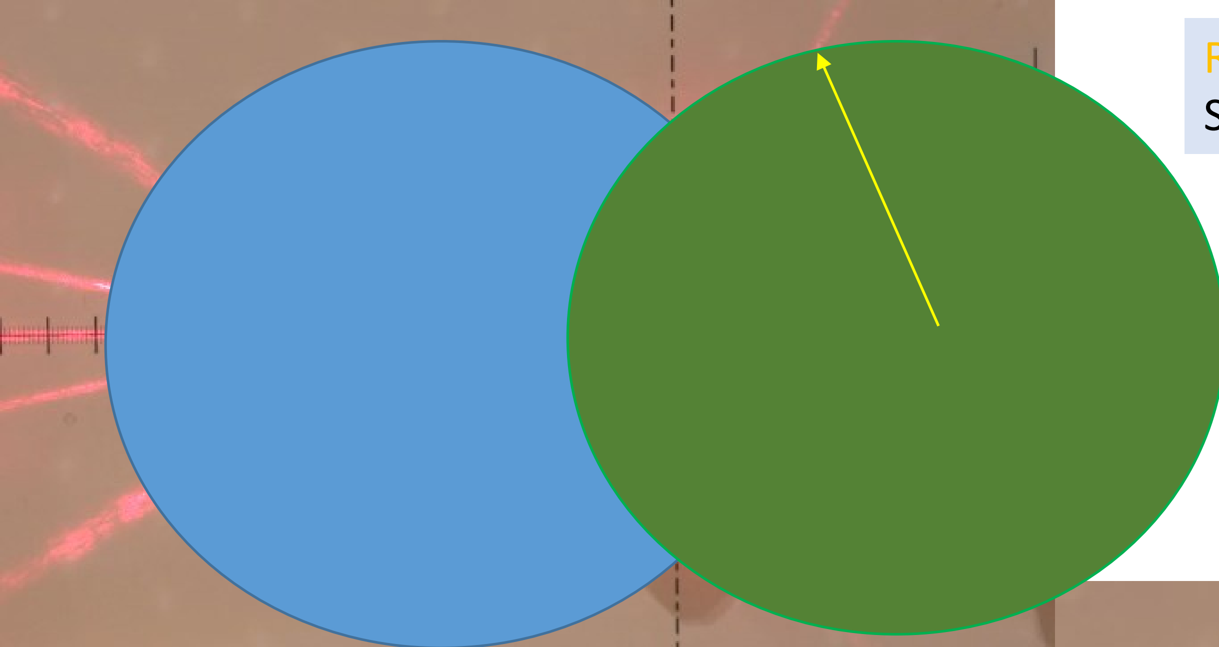
$$D = \frac{1}{f} = \frac{1}{i} + \frac{1}{o}$$

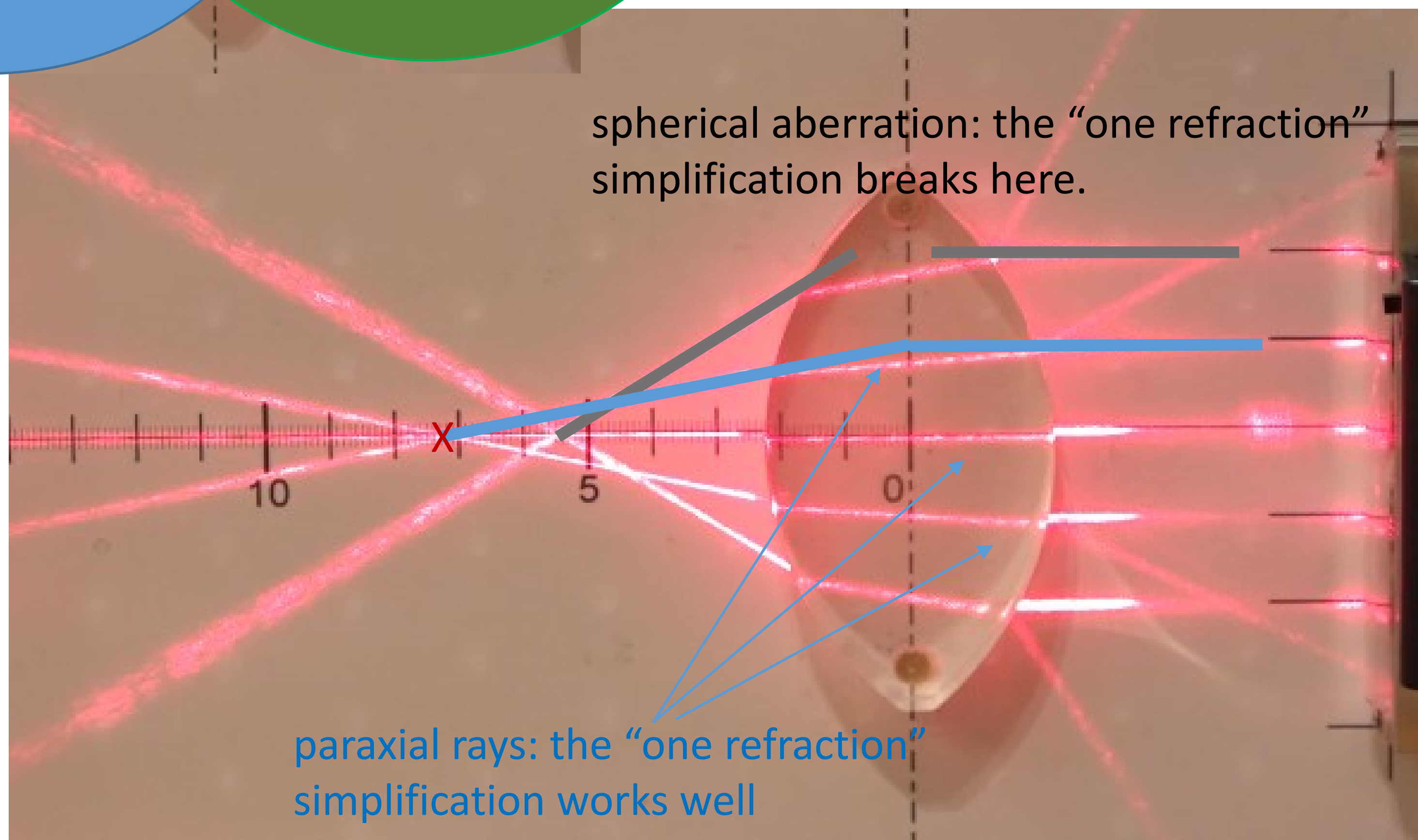
power of the lens
diopters (dpt, 1/m)

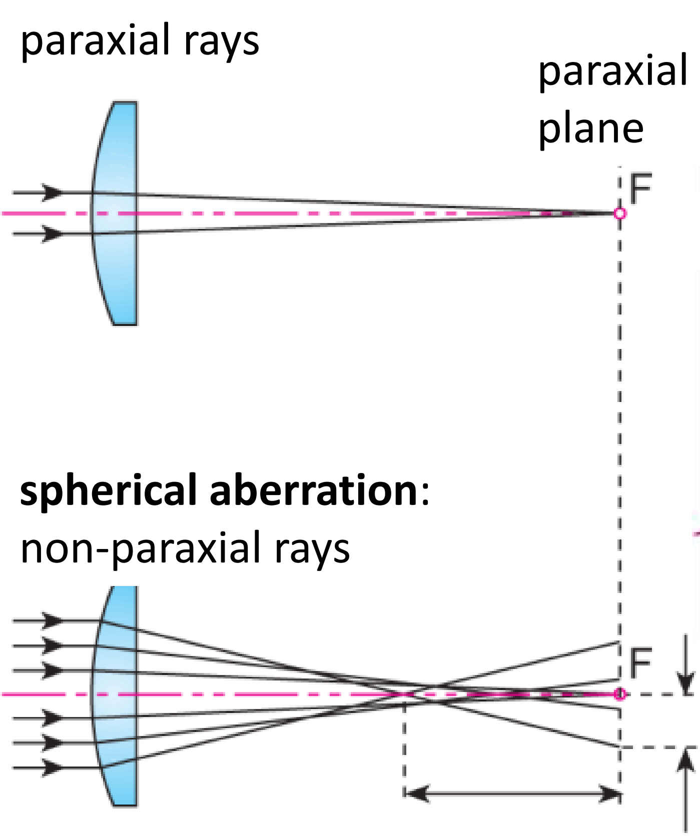
$$D = (n-1) \cdot \frac{2}{\boldsymbol{R}}$$

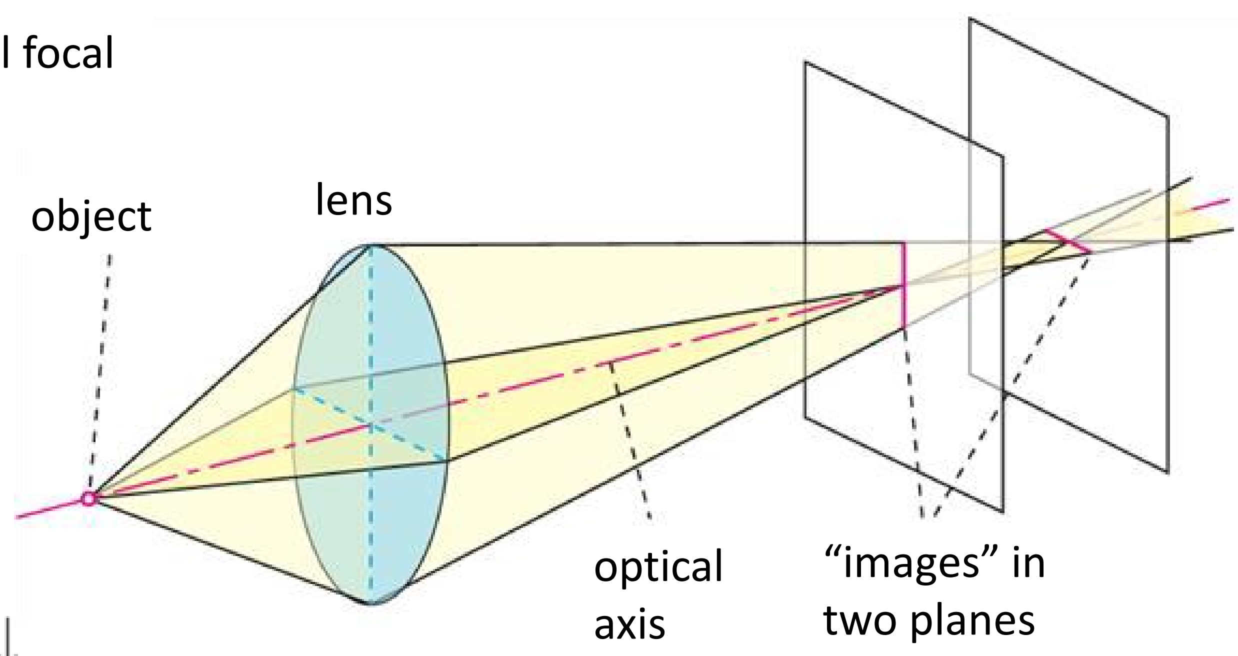
for symmetrical lens
R is the radius of curvature

Radius of curvature of the lens, Spherical aberration

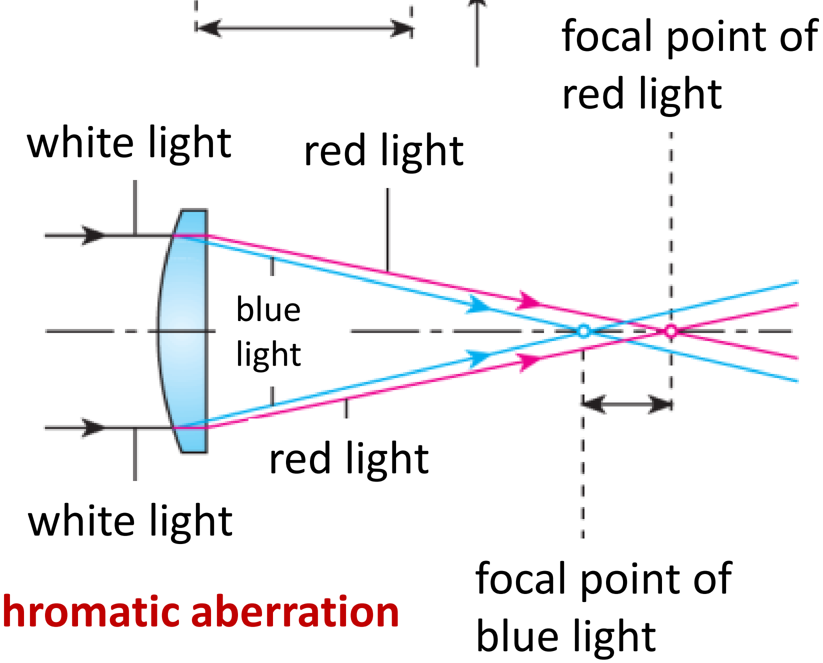






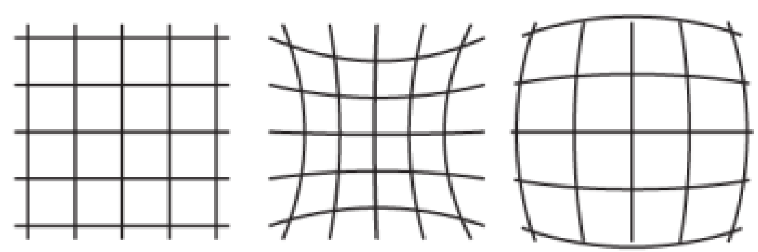


astigmatism

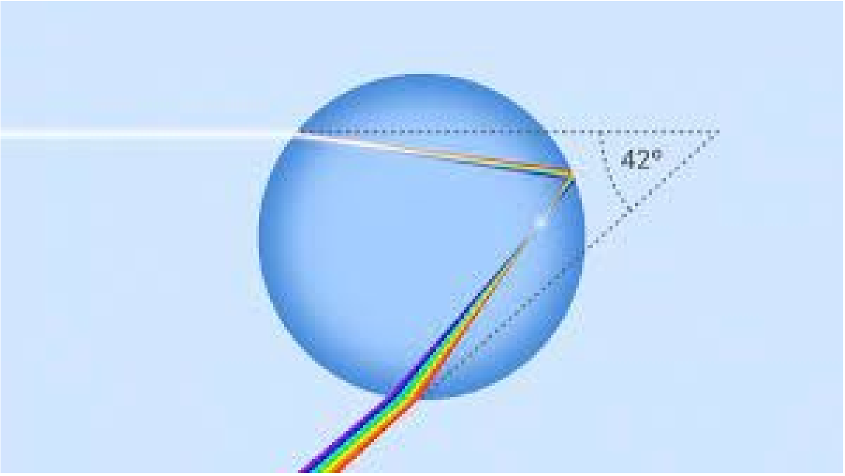


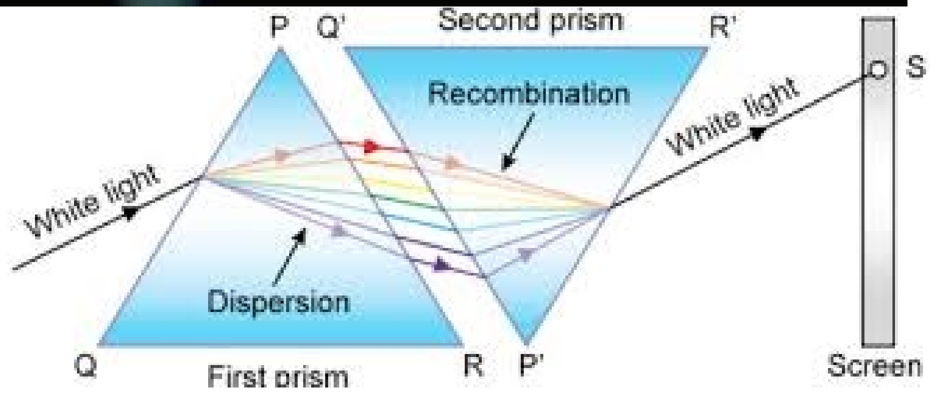
chromatic aberration

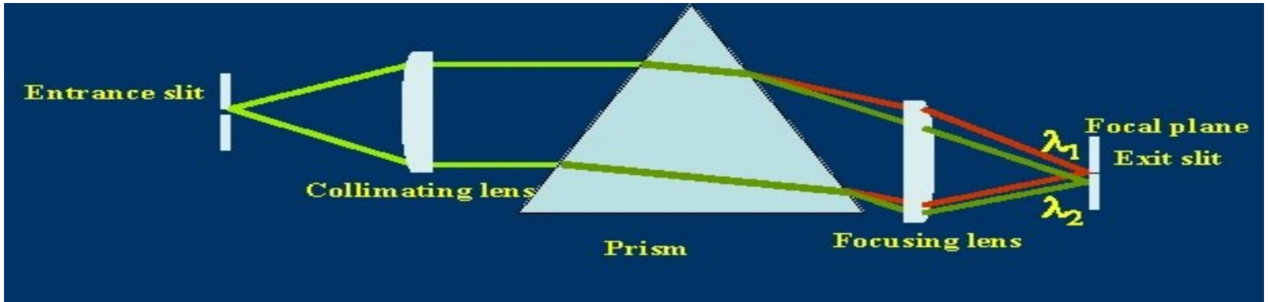
distorted images



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







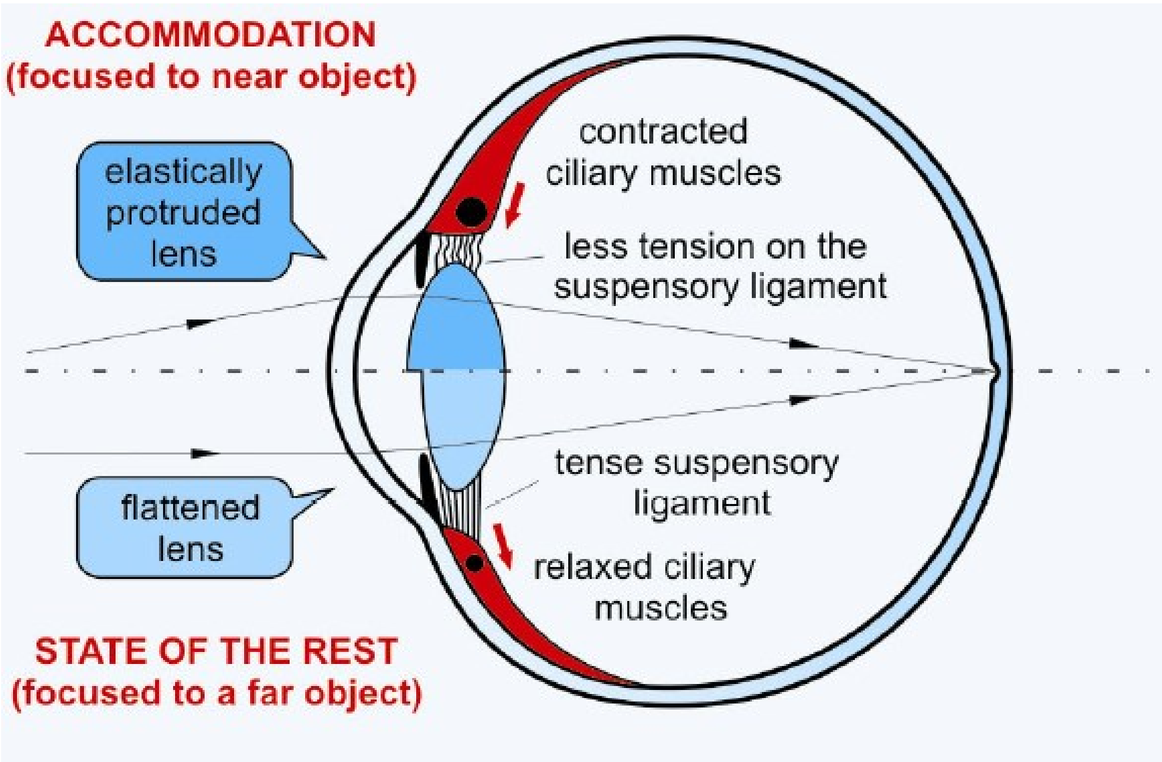
prism monochromator

The eye is an adaptive optical system

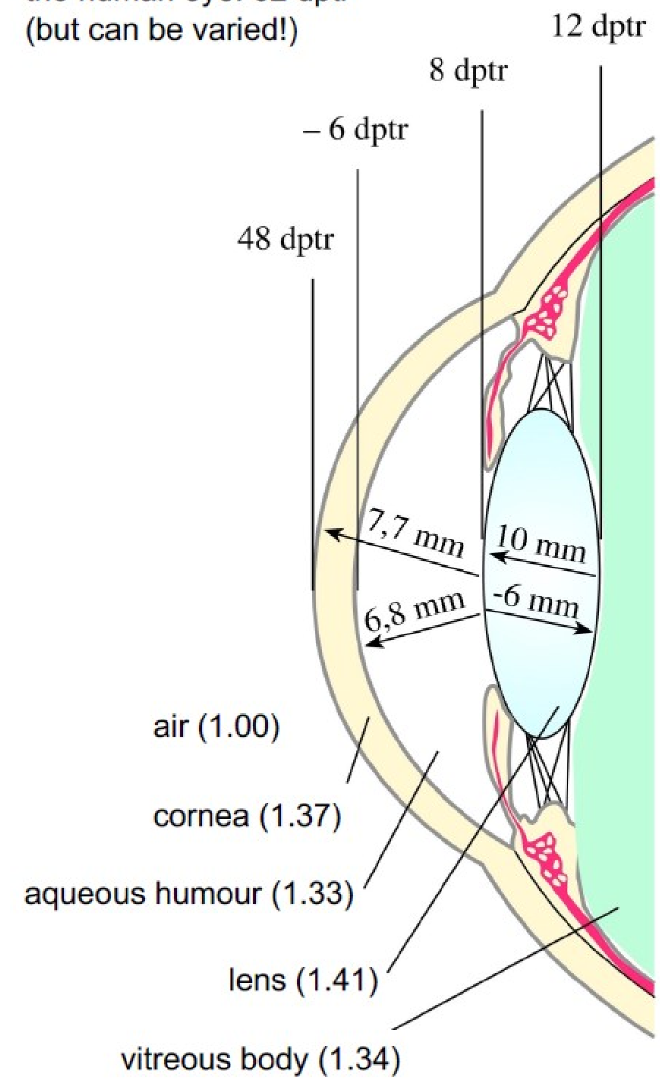
accommodation power

$$\Delta D = D_p - D_r = \frac{1}{t_p} - \frac{1}{t_r}$$

near point, far point



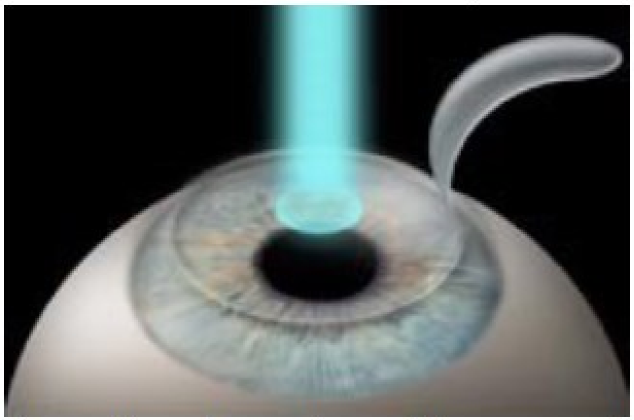
Total refractive power of the human eye: 62 dptr (but can be varied!)



Optical problems can be solved by altering the diopter ->

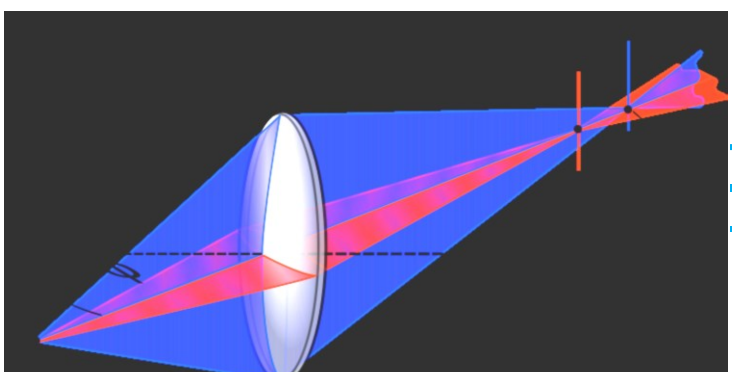
glasses and/or LASIK

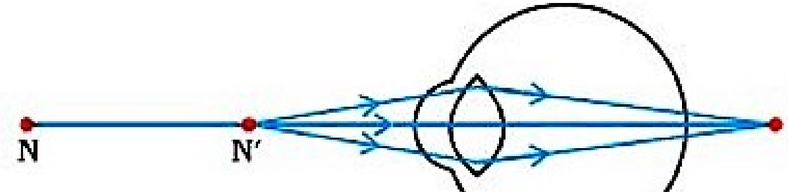
Permament correction of refractive problem: LASIK (Laser Assisted In Situ Keratomileusis)



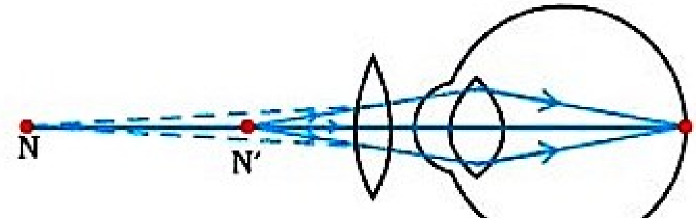
The radius of curvature of the cornea is changed (with laser surgery)

astigmatism -> „cylindrical eye”

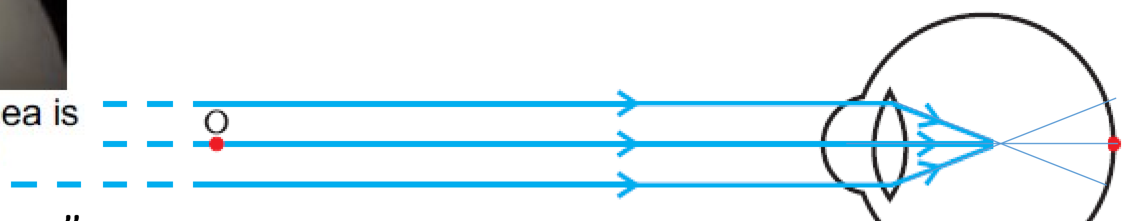




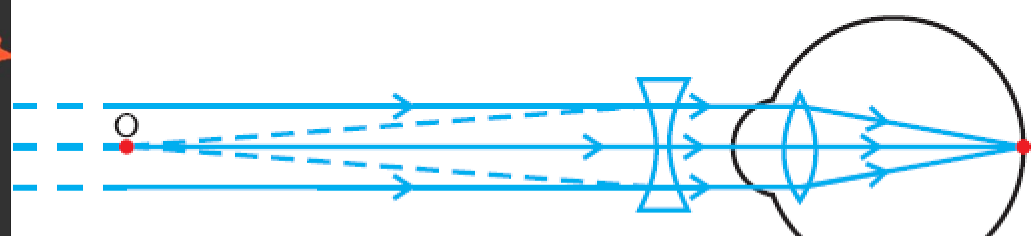
uncorrected hyperopia near vision



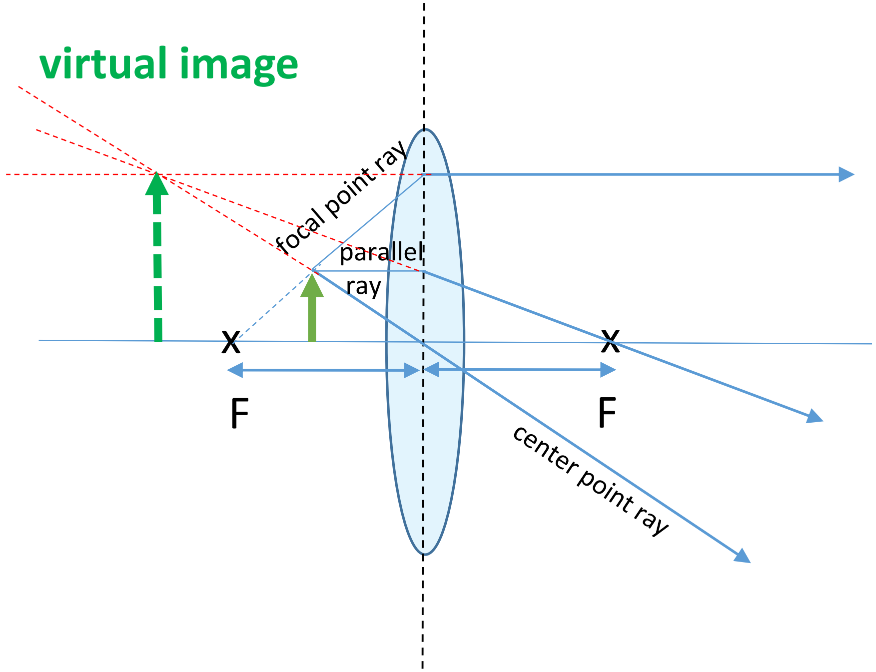
correction with +D lens



uncorrected myopia far vision



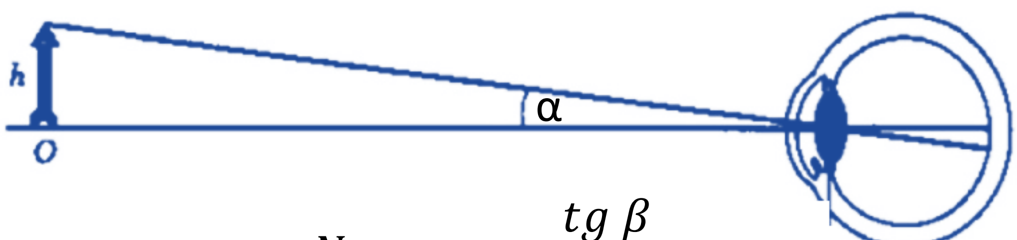
correction with –D lens



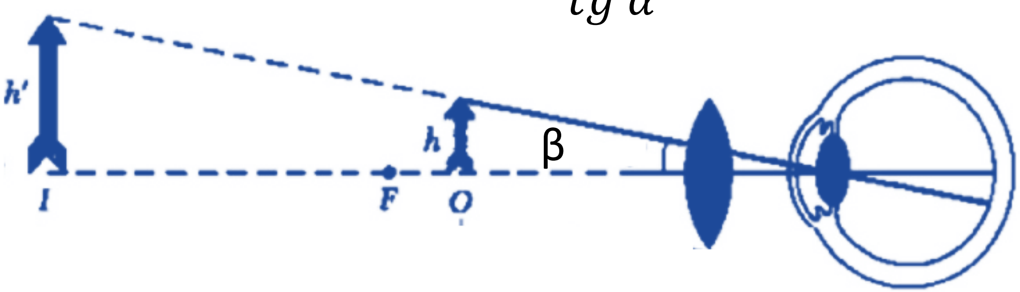
converging lens as a simple magnifier

The virtual image is viewed at a greater angle than the original object from the near point of the eye.

angular magnification



$$N_{angular} = \frac{tg\ \beta}{tg\ \alpha}$$



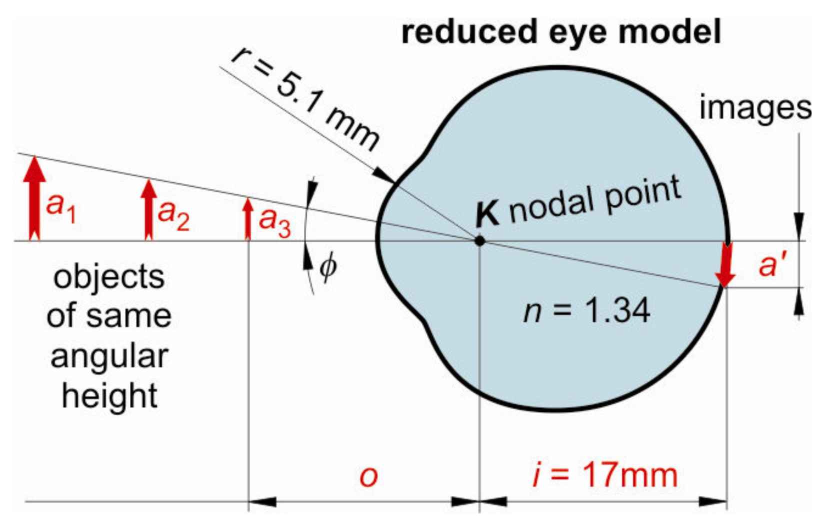
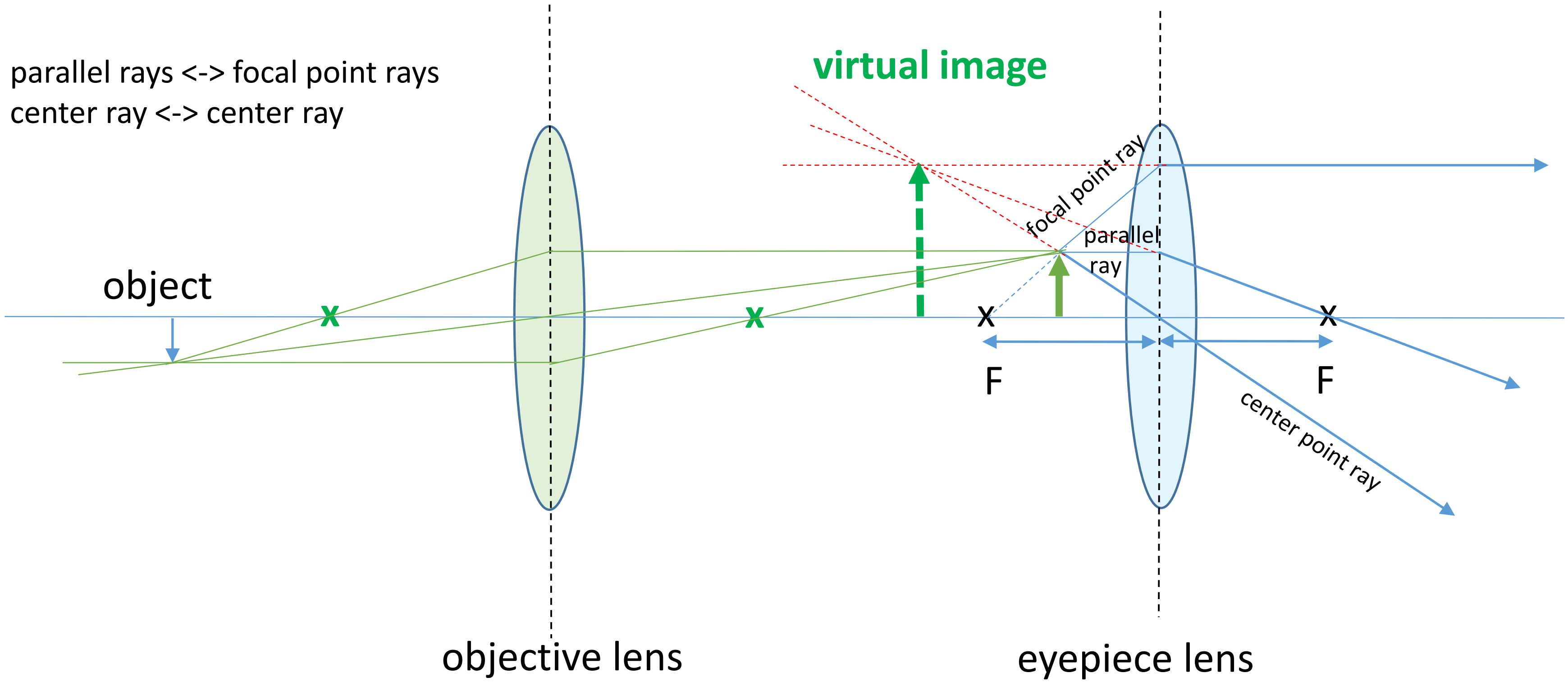


image formation in the microscope

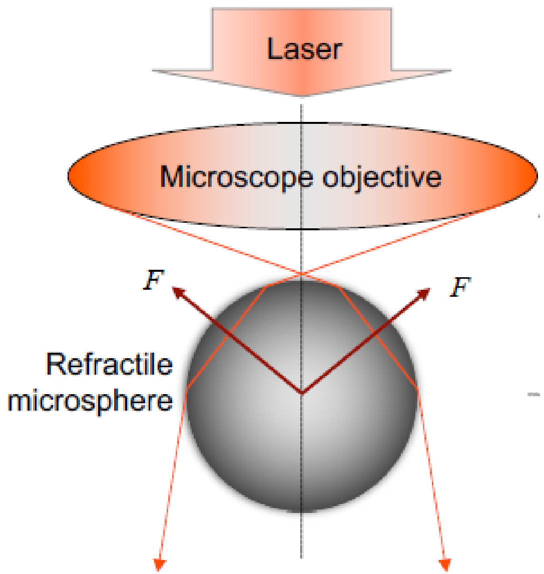


The microscope can be set to see the virtual image at the reading distance of 25 cm, but also to accommodate to infinity (like looking at the sky). The magnification will be different. Either the linear magnification or the angular magnification can be calculated.

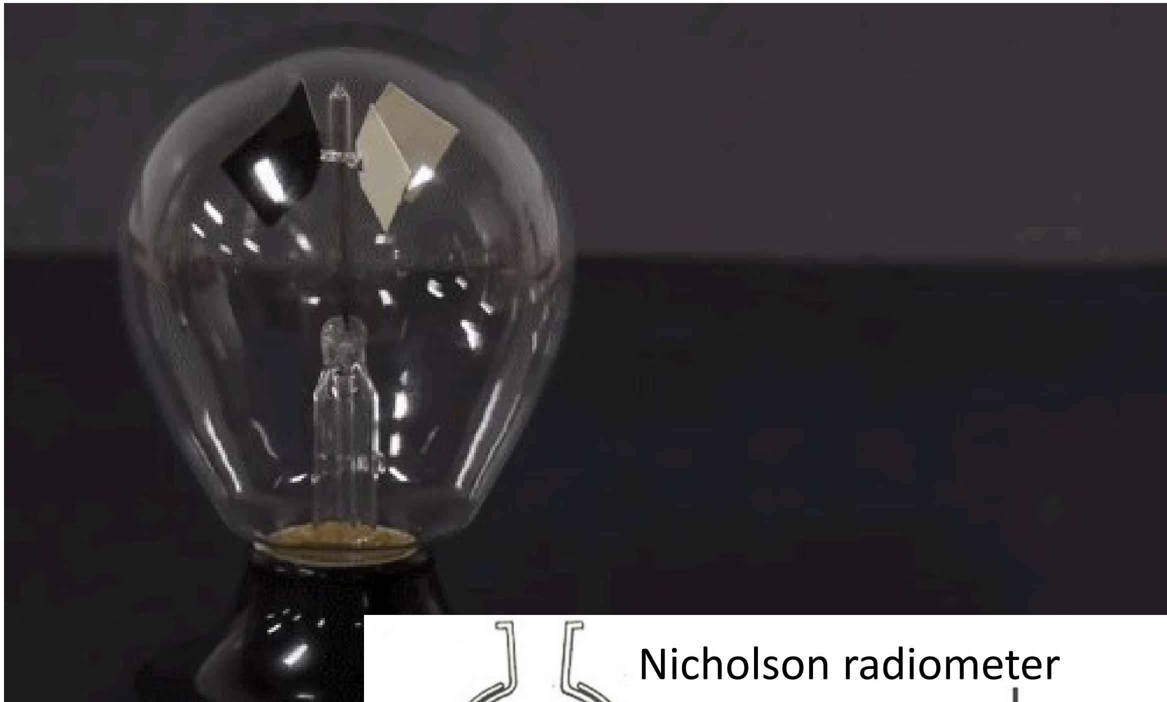
light can exert a force (photons have momentum)

optical „tweezer”

Refractile particles may be ***captured*** *with photonic forces:*

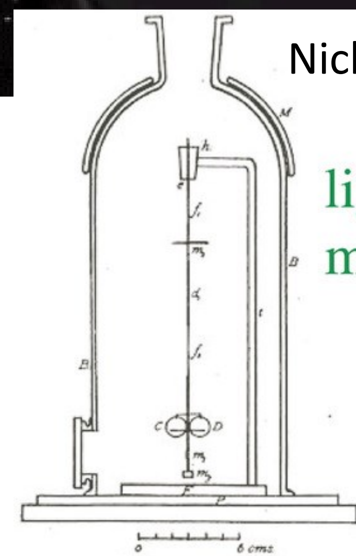


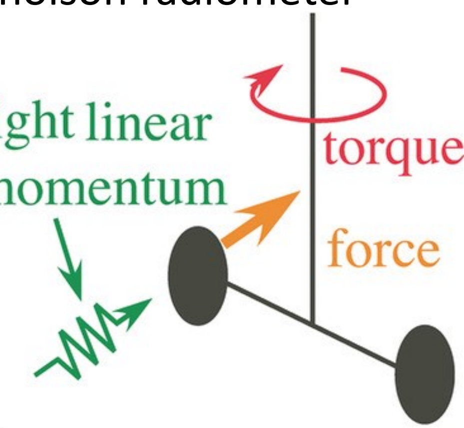
Crookes light mill



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

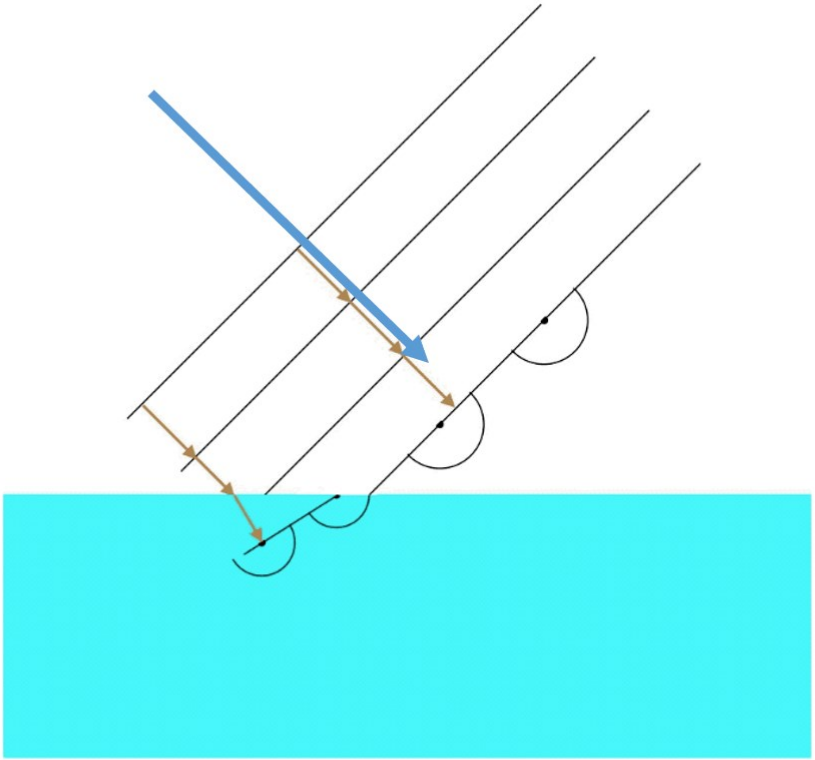
END of lecture slides

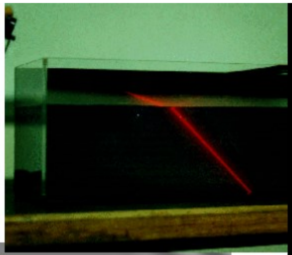
The next slides are EXTENSION material

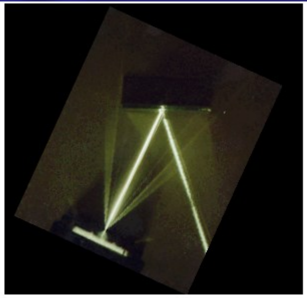
they can be used as learning aids, but are not part of the shortened 45 min lecture.

some screenshots of the animations are also included.

EXT







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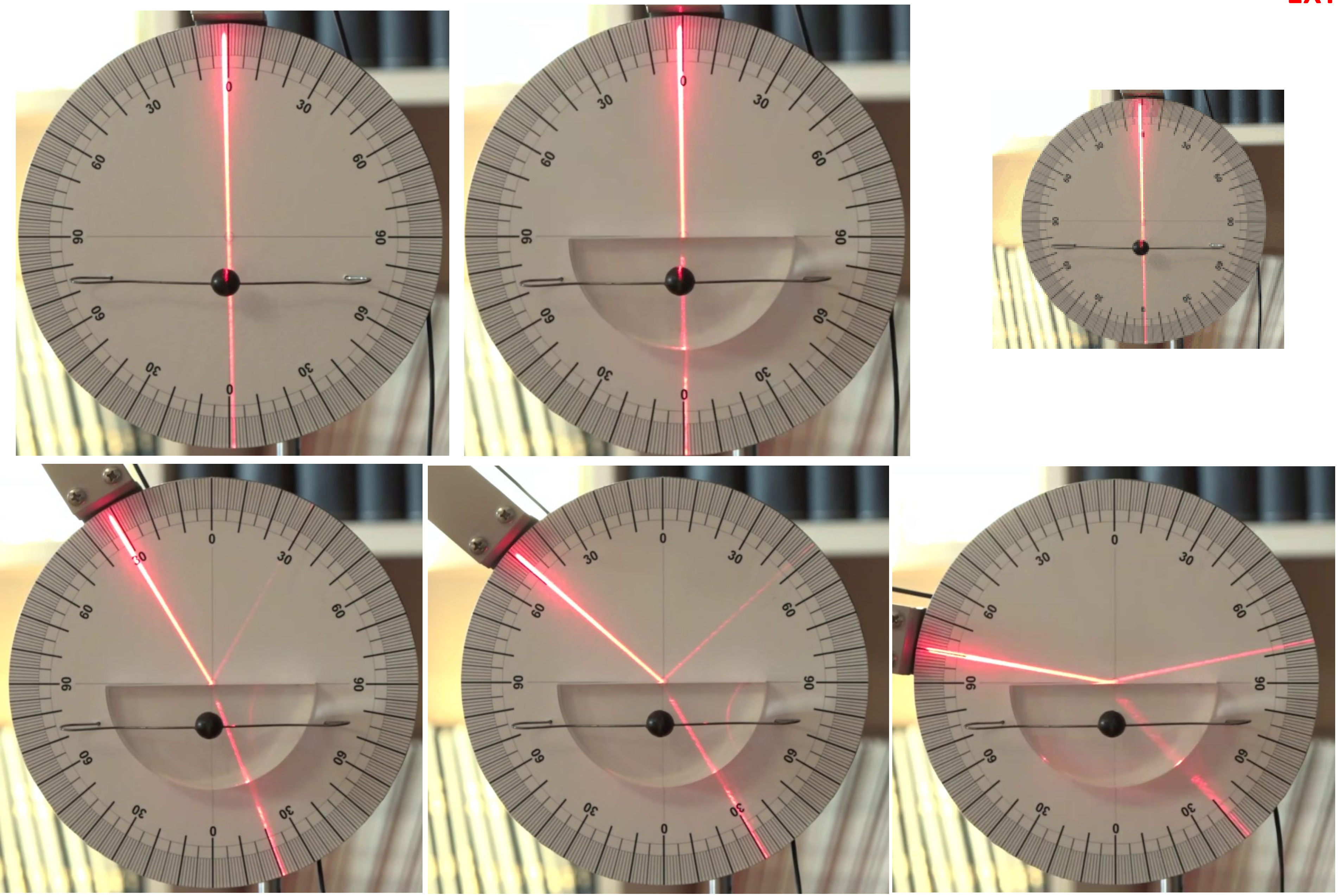
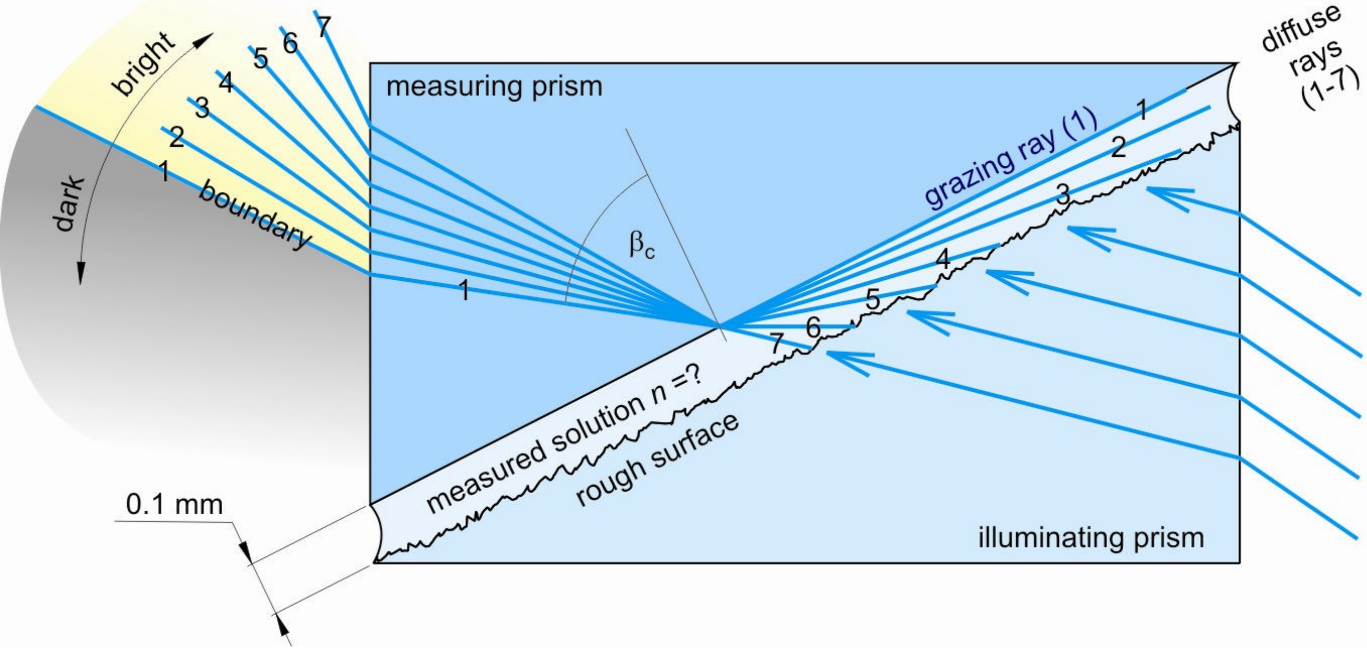
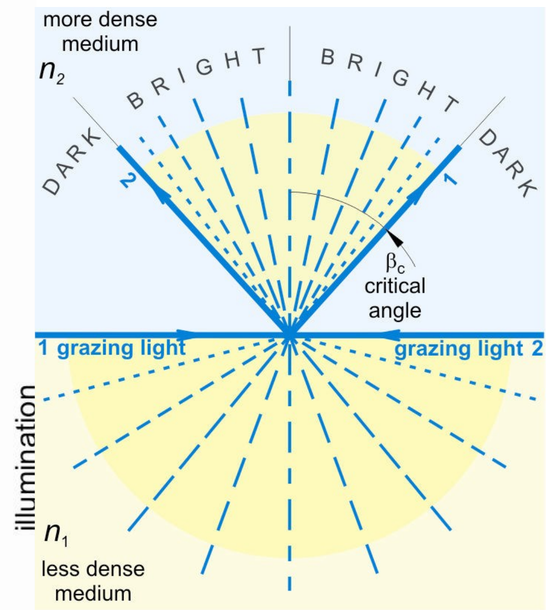
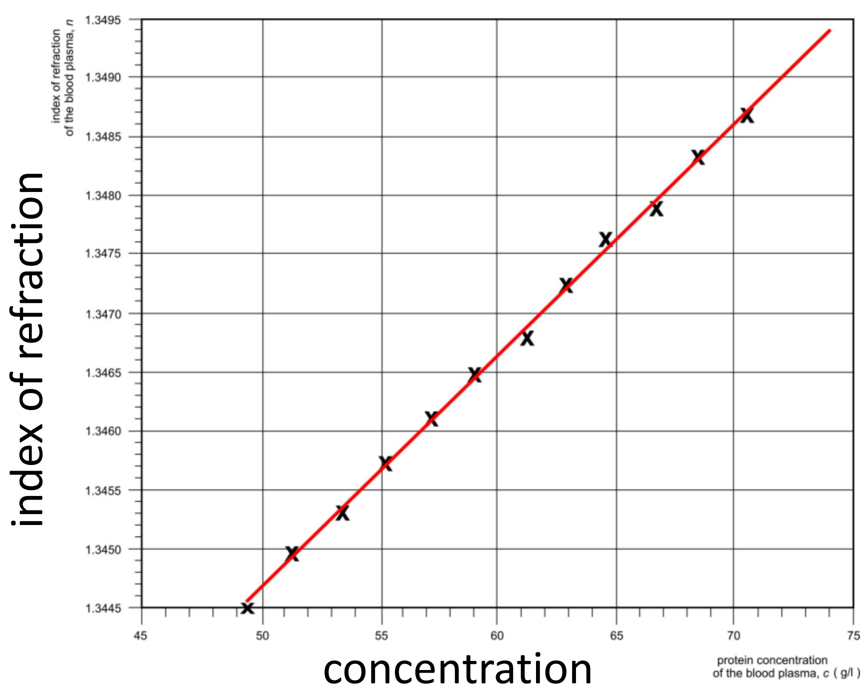


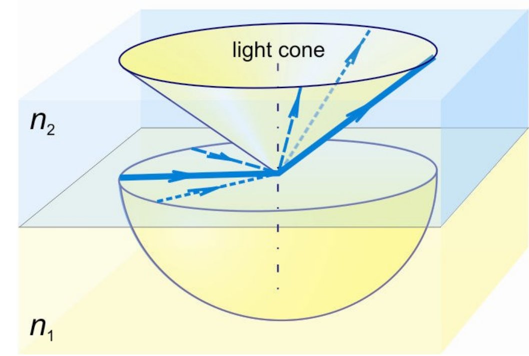
refractometry

EXT









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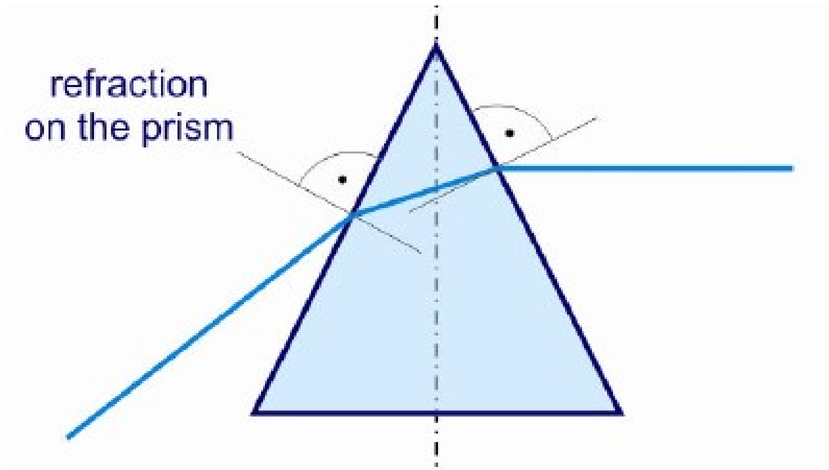
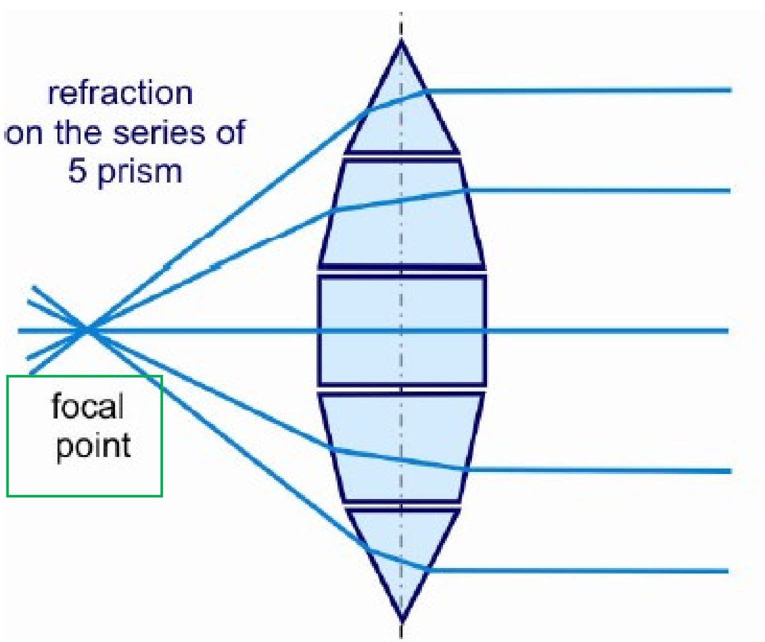


We have to apply SD twice
(and additionally *a LOT of geometrical calculations*, to get the angles and the normals)

-> ***geometrical*** optics



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

EXT

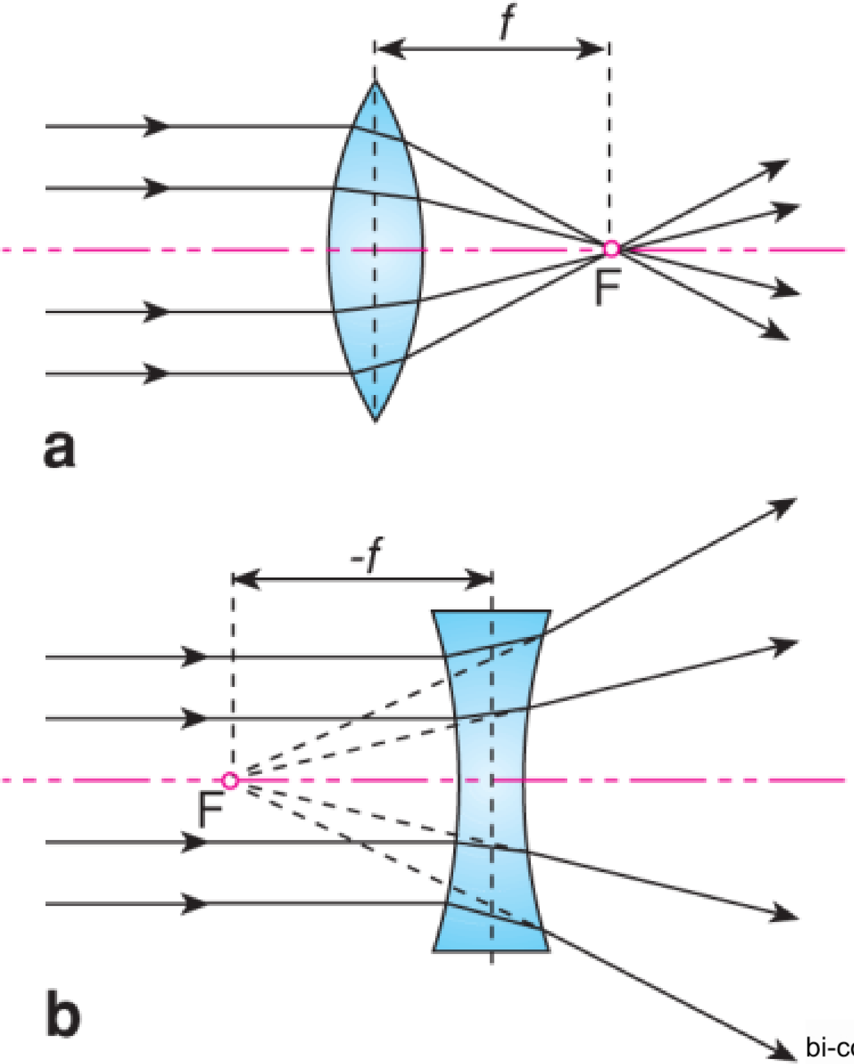
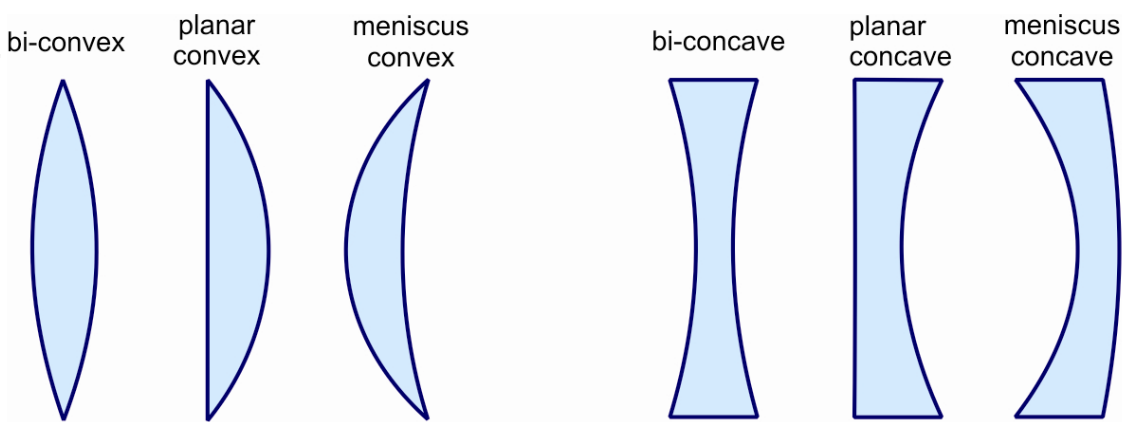
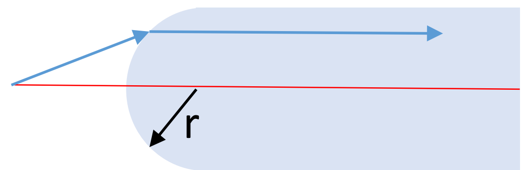


image formation of the diverging lens



one curved surface



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