Geometric optics

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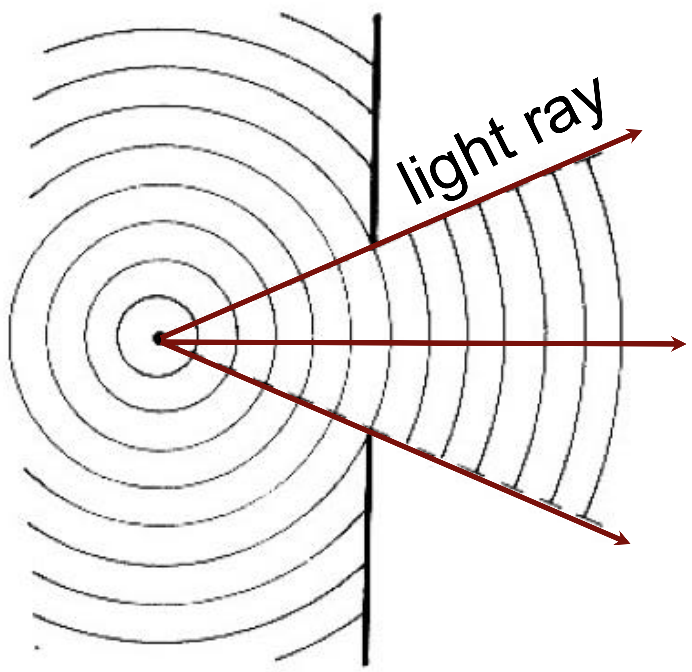
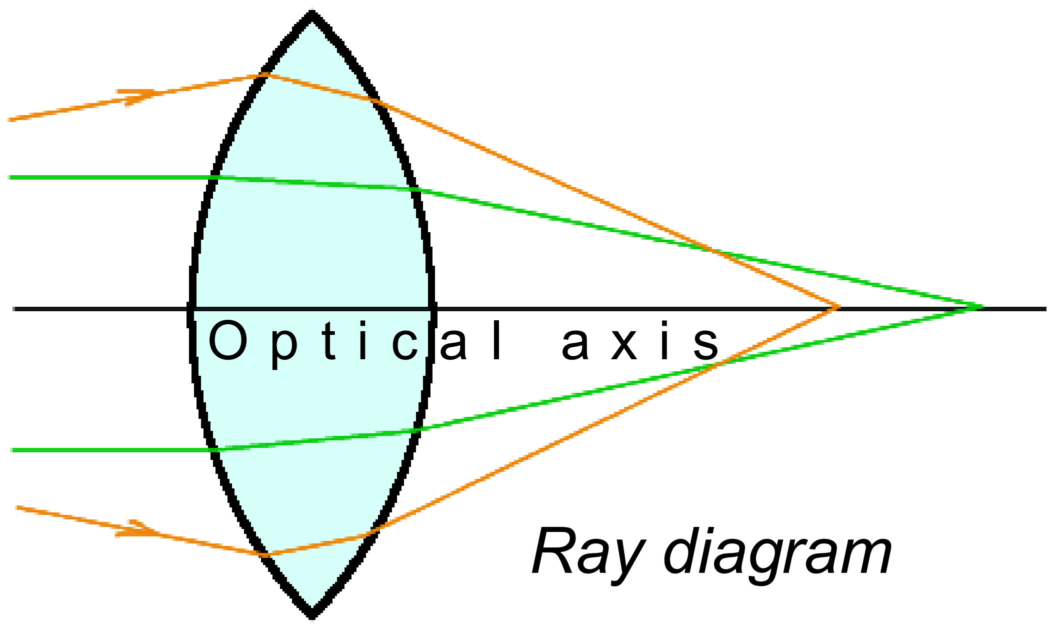
Geometric optics

If light propagates through a slit much larger than its wavelength, then the spreading of the wavefront (phase) may be simplified into a line (“light ray”).

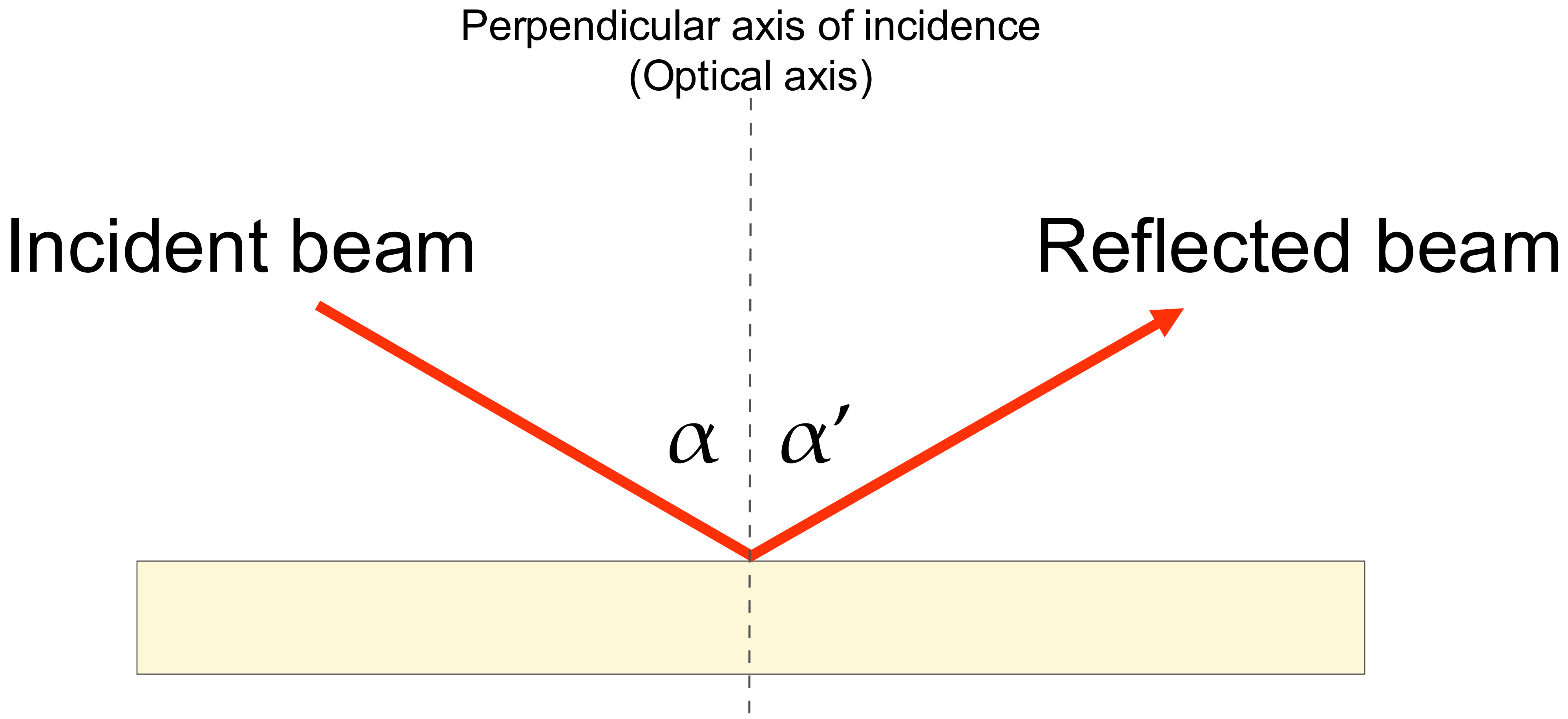




Ray diagram

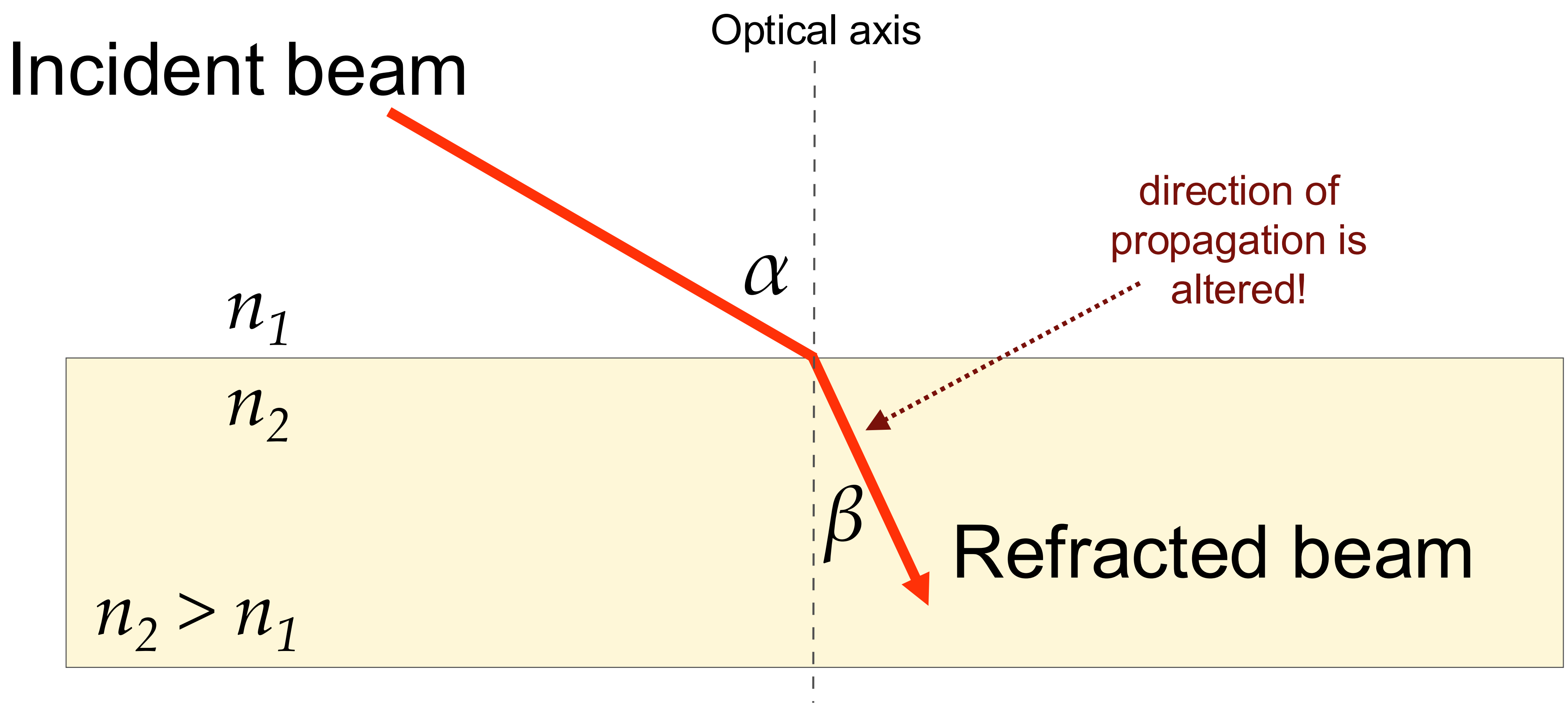
- Optical (light) ray (“light beam”): abstraction, mathematical line.
- Arrows represent the direction of energy propagation.
- Optical axis: line connecting the midpoint of optical components (e.g., lenses).
- Principle of reversibility: the direction of energy propagation (arrows) may be reversed.

Reflection



- α = angle of incidence; α' = angle of reflection.
- Incident beam, reflected beam and optical axis are in the same plane.
- Incident and reflected angles are identical ($\alpha=\alpha'$).

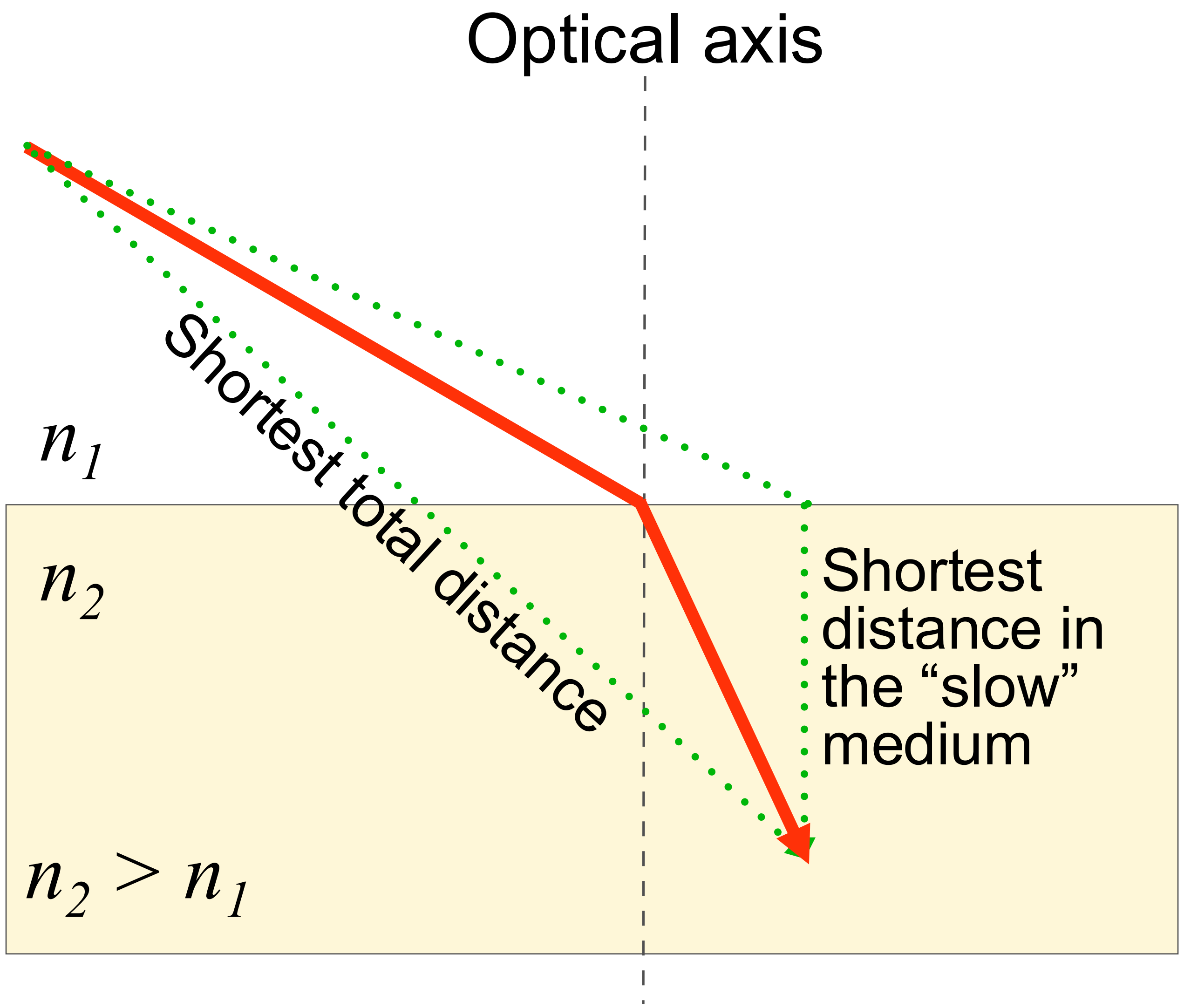
Refraction



- α = angle of incidence; β = angle of refraction.
- Incident and refracted beams and axis of incidence are in the same plane.
- Snell's law:

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

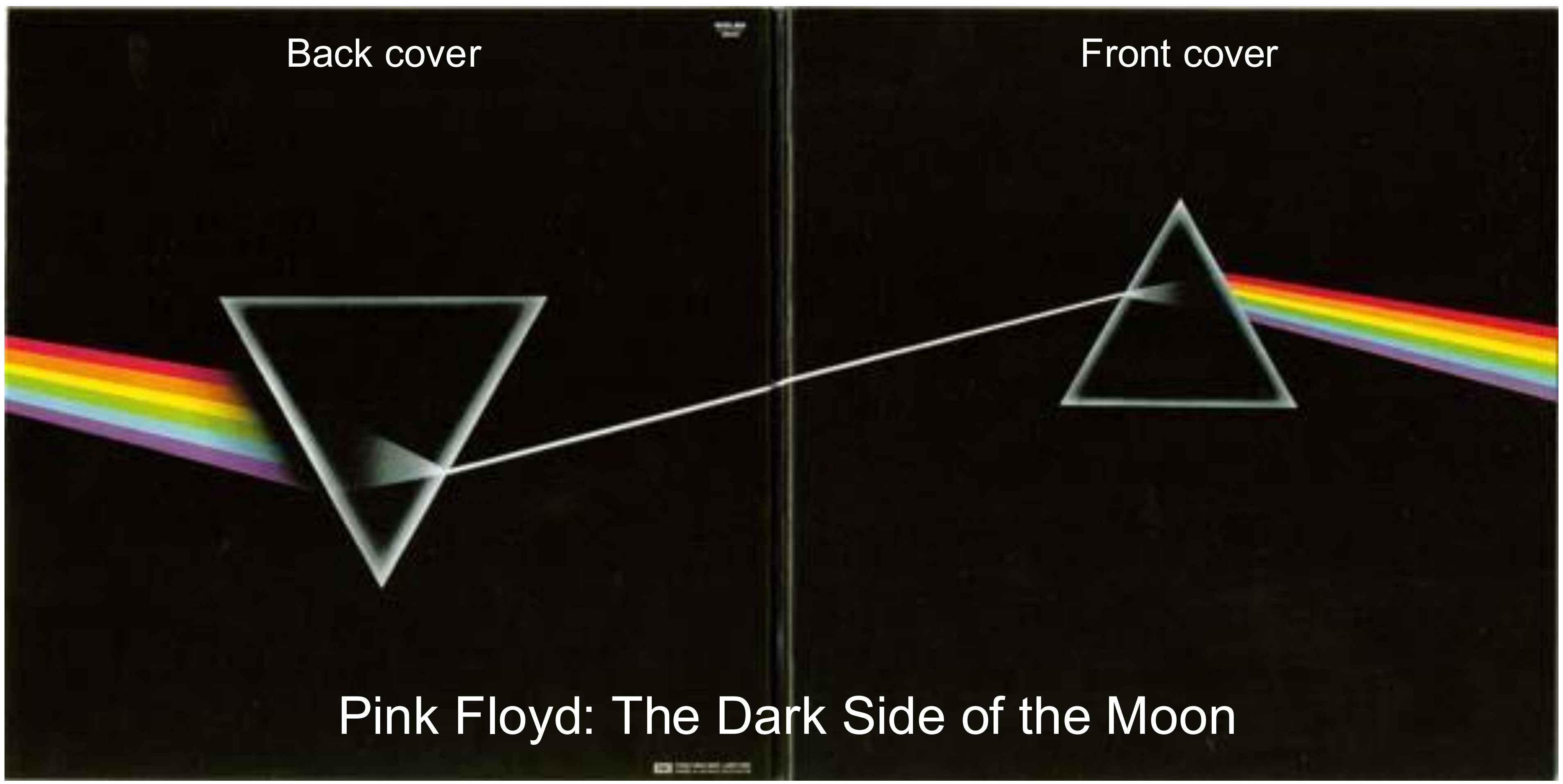
Explanation of refraction:
Fermat's principle of least times



Light "chooses" the path that can be covered in the least time (i.e., fastest).

Dispersion

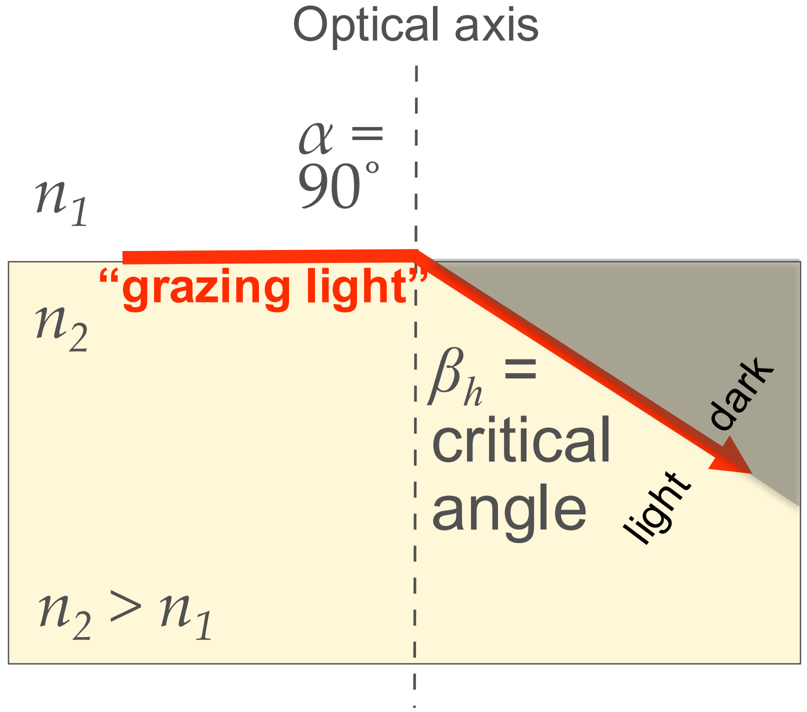
Index of refraction depends on frequency!



- The greater the frequency of light - the greater the refractive index.
- A prism decomposes white light according to frequency (physical color).

Analytical application of refraction: Refractometry

Boundary condition of refraction



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

$$n_1 = n_2 \sin \beta_h$$

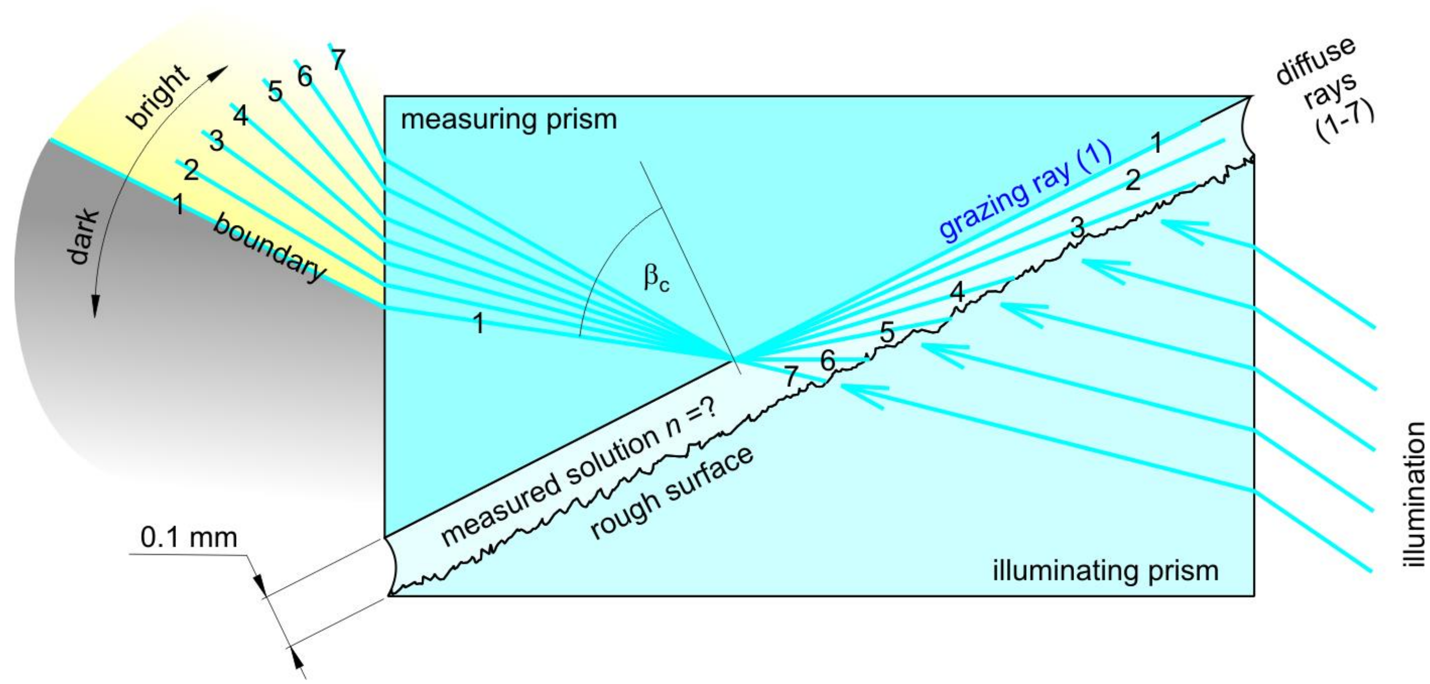
Thus, in case we know n_2, by measuring β_h the refractive index of the incident medium (n_1) may be obtained.

Refractometry

Refractive index of dilute solutions (n_1) depends on solute concentration (c):

$$n_1 = n_0 + k \cdot c$$

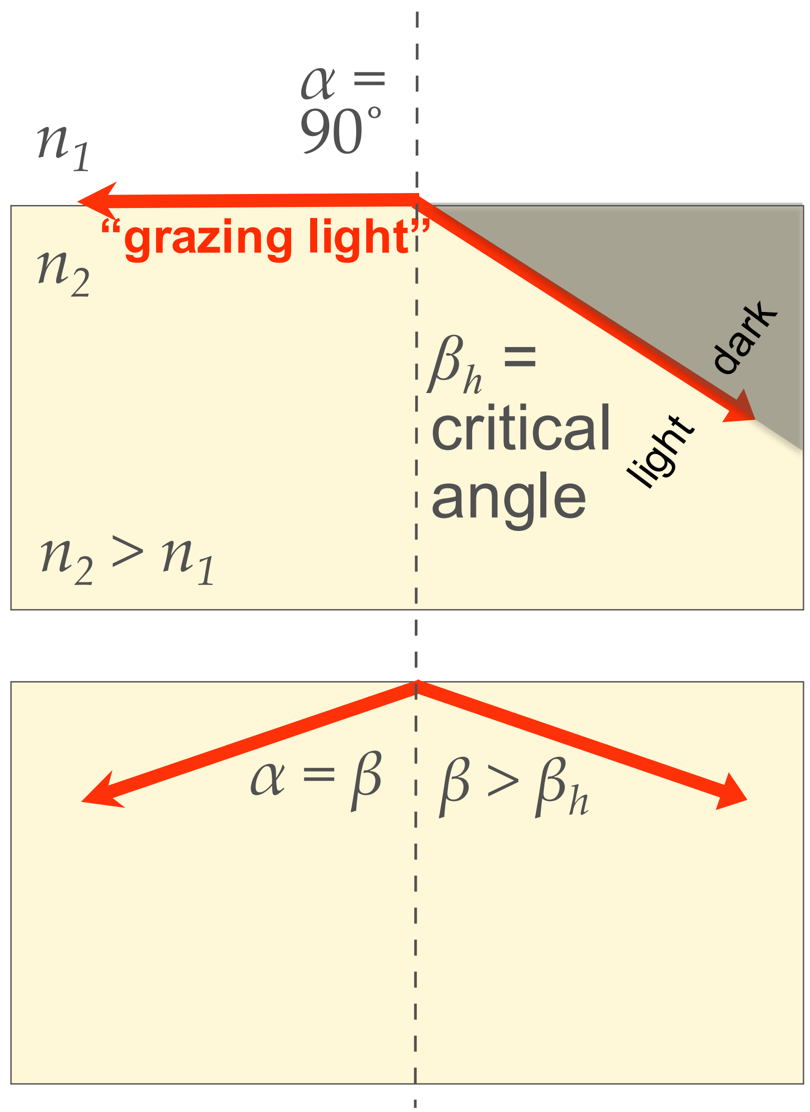
n_0 = refractive index of solvent, k = constant



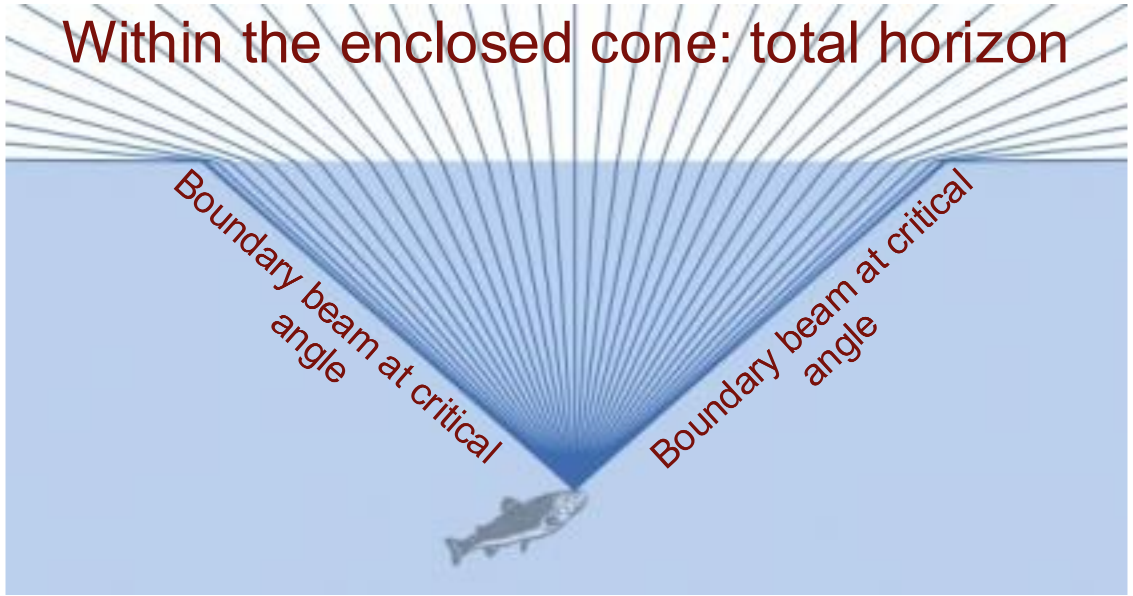
Conditions of applicability:

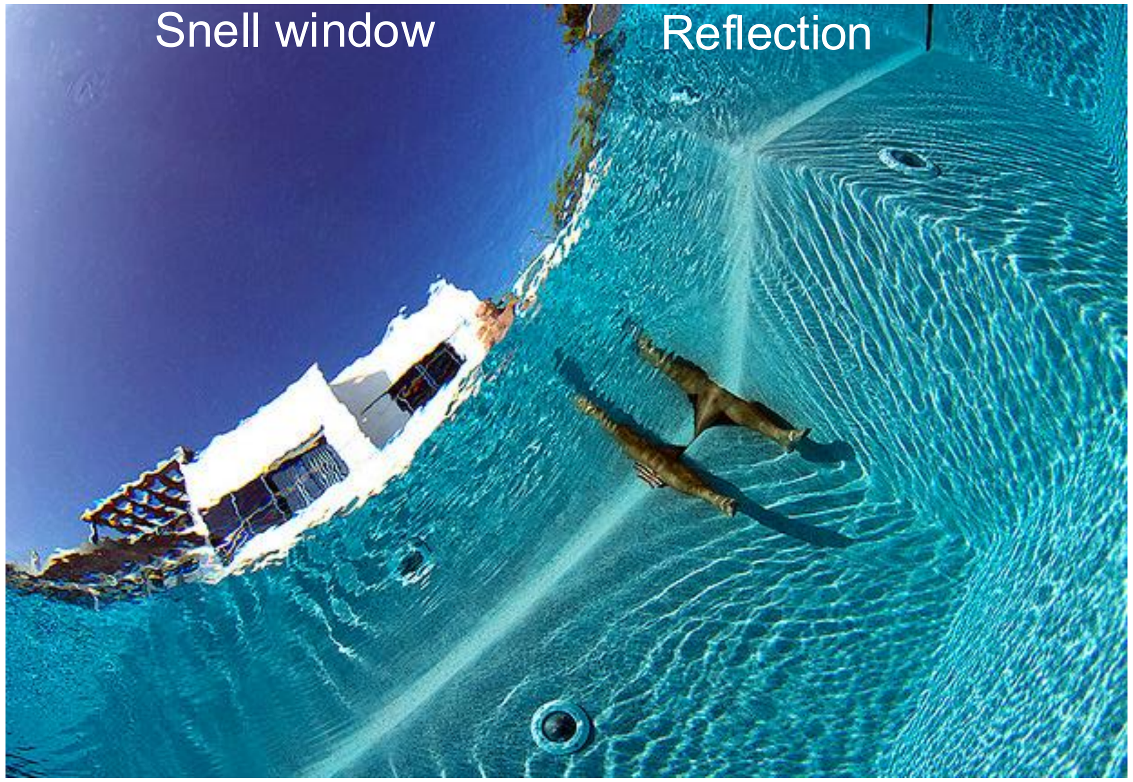
- Liquid sample
- Sample is transparent
- Refractive index of sample is smaller than that of the measuring prism.

Total internal reflection



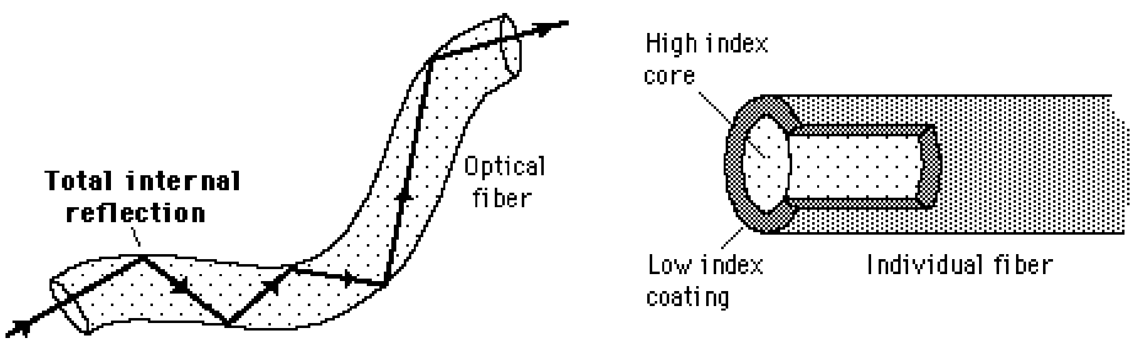
Total reflection within the optical medium of greater refractive index ("total ***internal*** reflection", TIR)



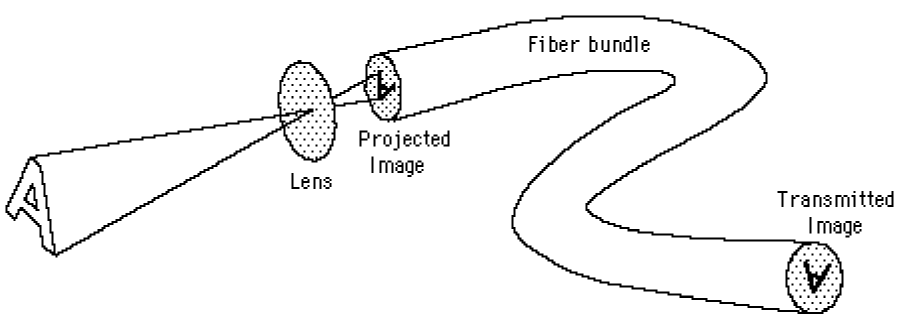


Biomedical Application of TIR: optical fibers

Single fiber



Highly ordered fiber bundle



If the arrangement of fibers is maintained within the bundle, then the image is faithfully transmitted.

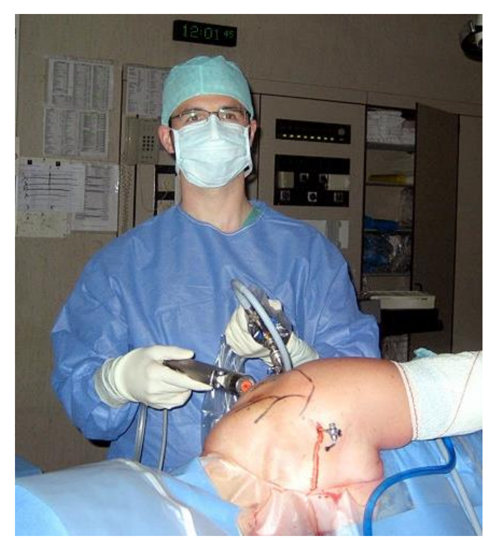
Endoscopy

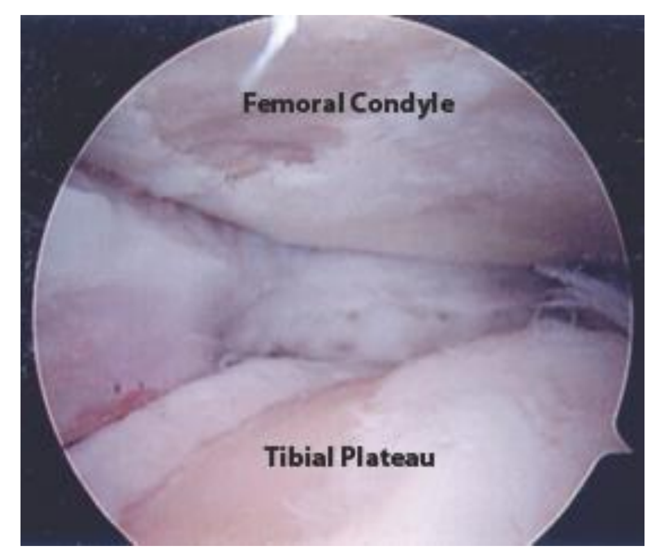
OBJECTIVES

1. Diagnostics: visual inspection, biopsy, contrast agent delivery
2. Therapy: surgery, cauterization, removal of foreign objects

TYPES

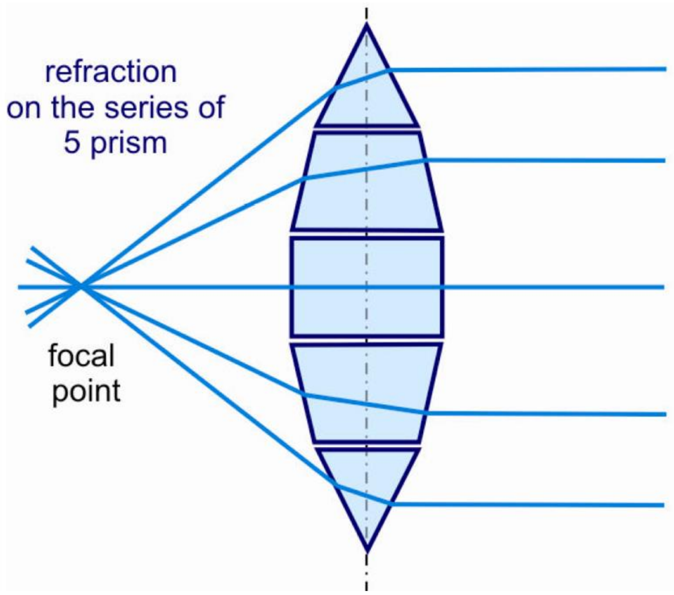
Arthroscopy (joints); *Bronchoscopy* (trachea and bronchi); *Colonoscopy* (colon); *Colposcopy* (vagina and cervix); *Cystoscopy* (urinary bladder, urethra uterus, prostate via urethra); *ERCP* (endoscopic retrograde cholangio-pancreatography, delivery of X-ray contrast agent into biliary tract and pancreatic duct) ; *EGD* (Esophago-gastroduodenoscopy, upper GI tract); *Laparoscopy* (stomach, liver, female gonads via abdominal wall); *Laryngoscopy* (larynx); *Proctoscopy* (rectum, sigmoidal colon); *Thoracoscopy* (pleura, mediastinum and pericardium via chest wall)

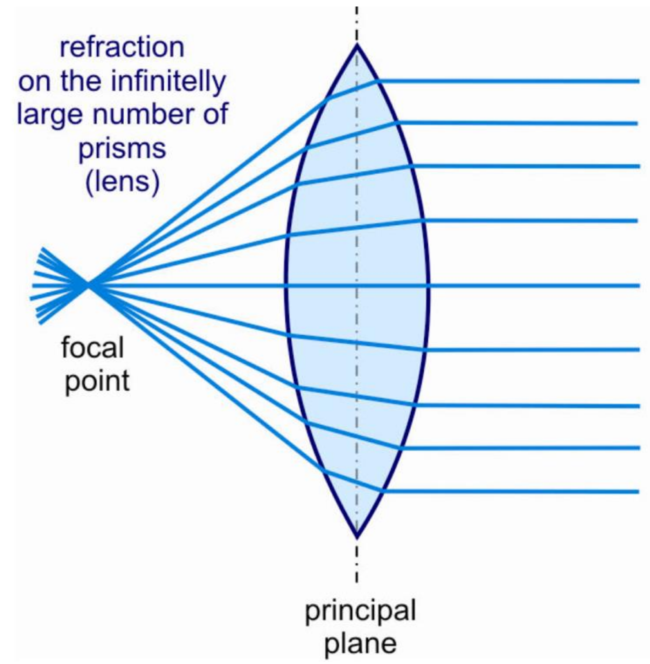


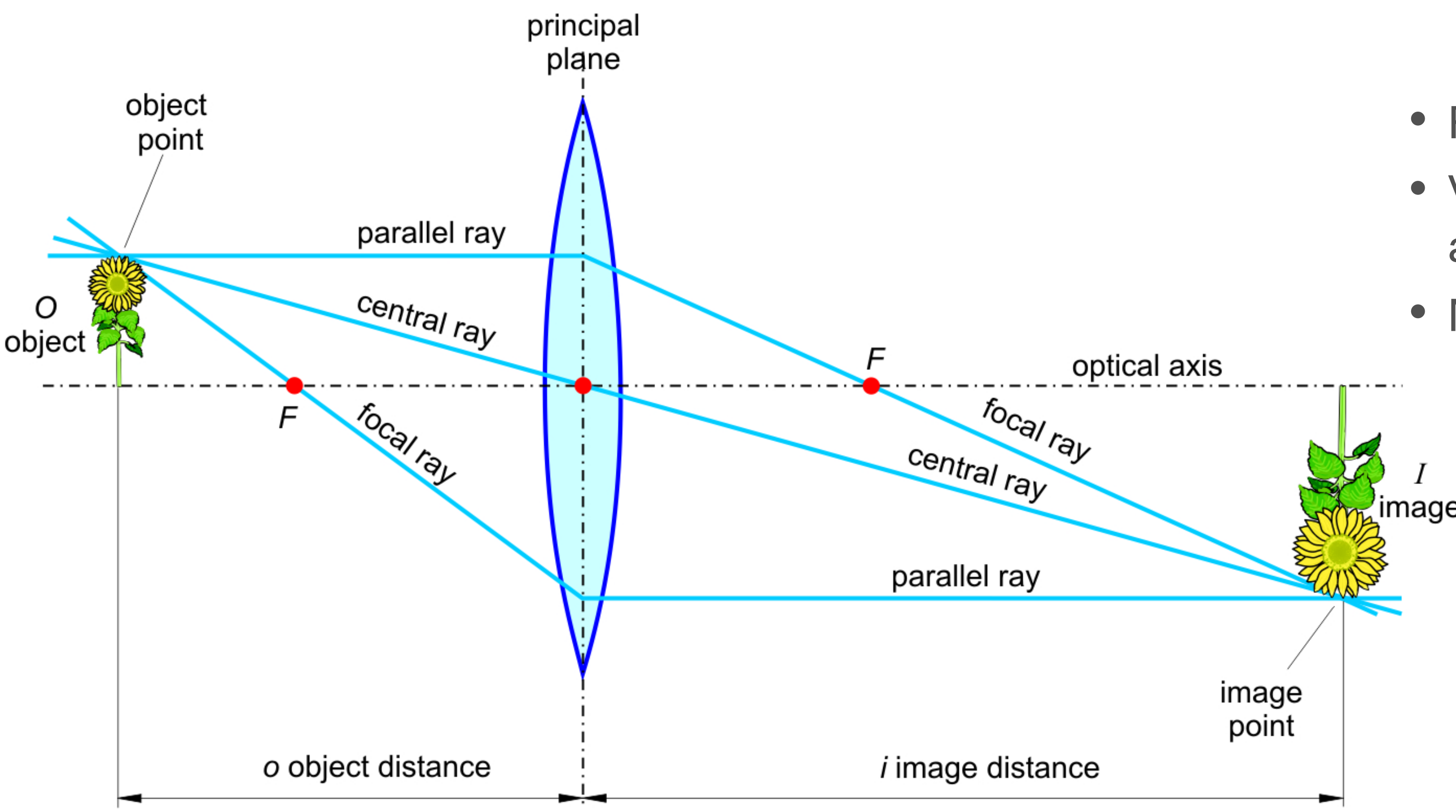


Arthroscopic surgery

Refraction on curved surface







- Real image: may be projected onto a surface
- Virtual image: may be mapped by using an accessory lens
- Magnification > 1, if the object is within $2f$ distance:

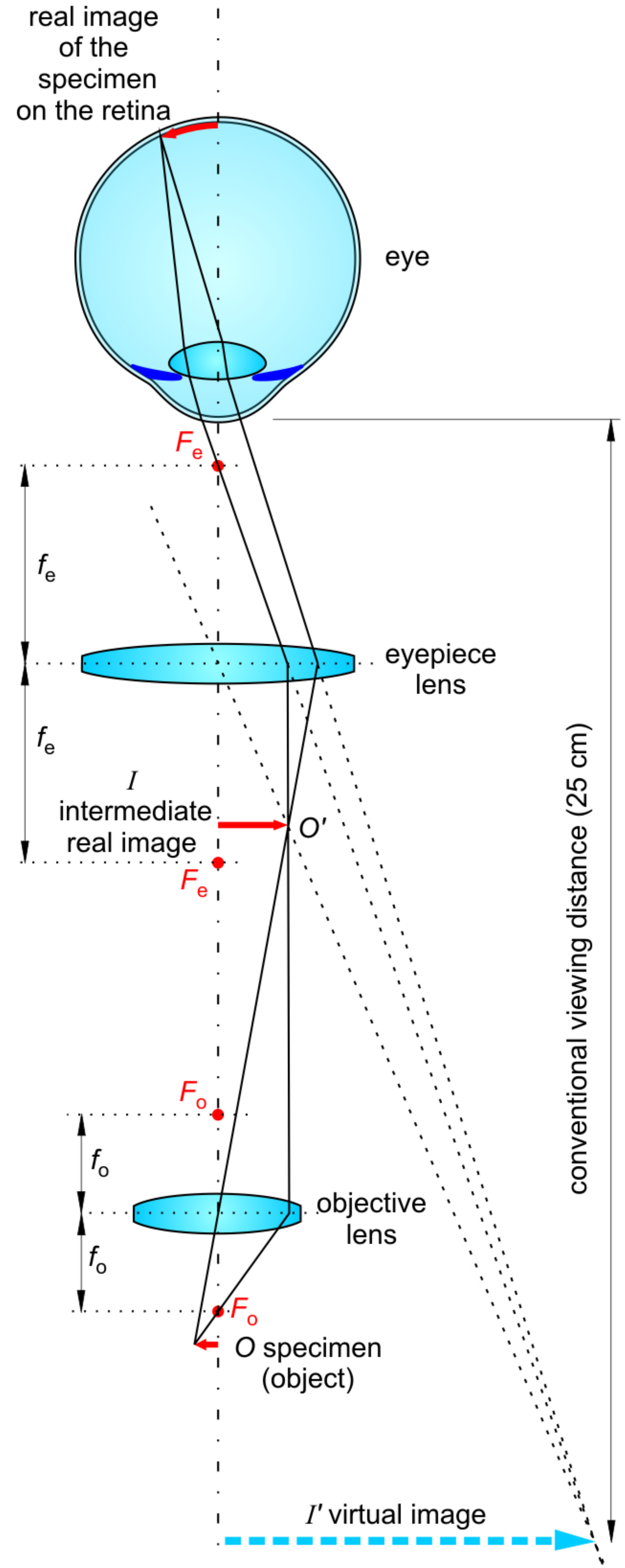
$$N = \frac{K}{T} = \frac{k}{t}$$

Lens equation: $$D = \frac{1}{f} = \frac{1}{t} + \frac{1}{k}$$

D=optical power (diopter, m^{-1})

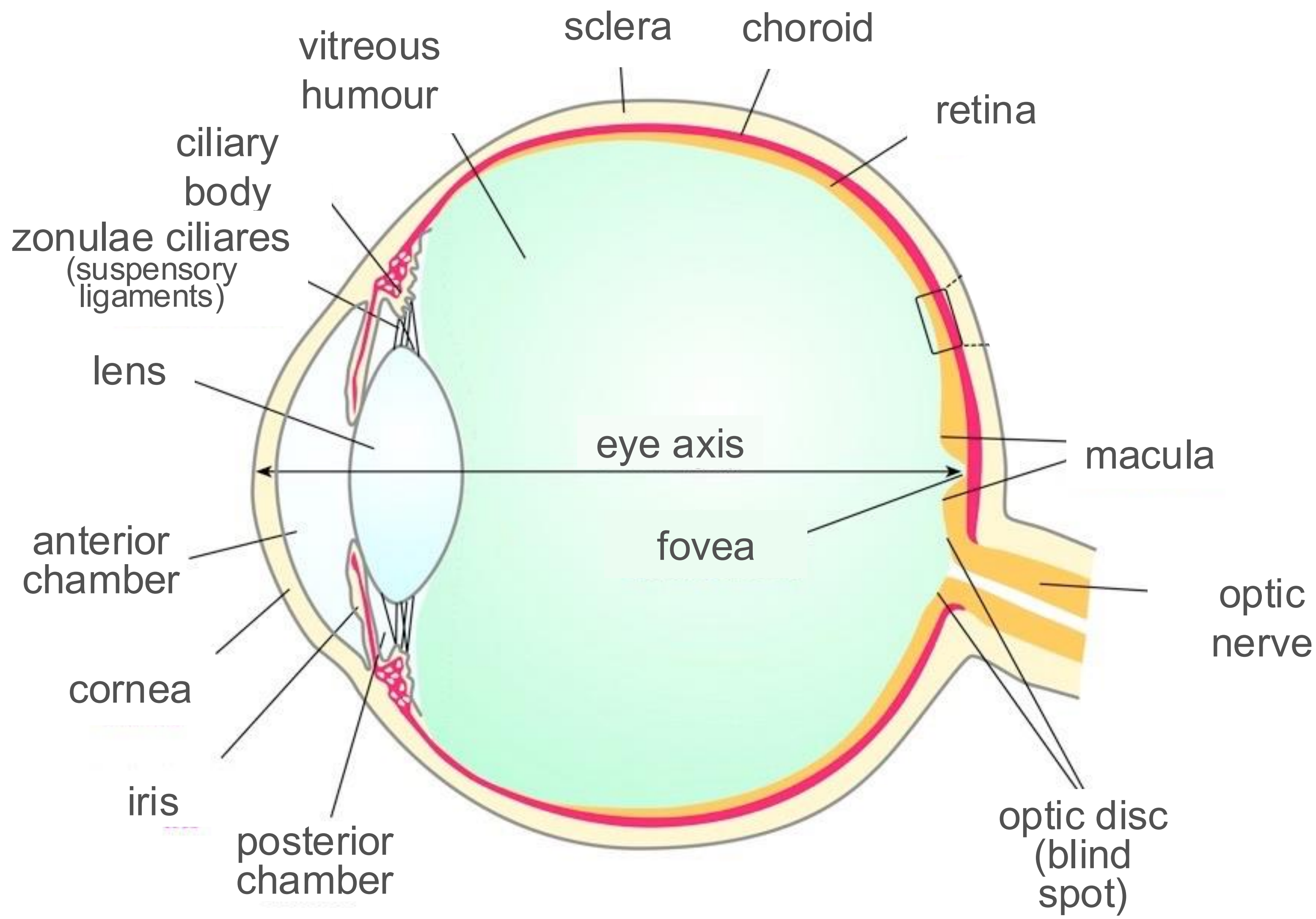
Image formation in the compound microscope

- Magnified, up-side-down, virtual image
- Condition of the formation of projected image: an accessory lens (eye lens) needs to be positioned in the optical path.
- Projection screen: retina



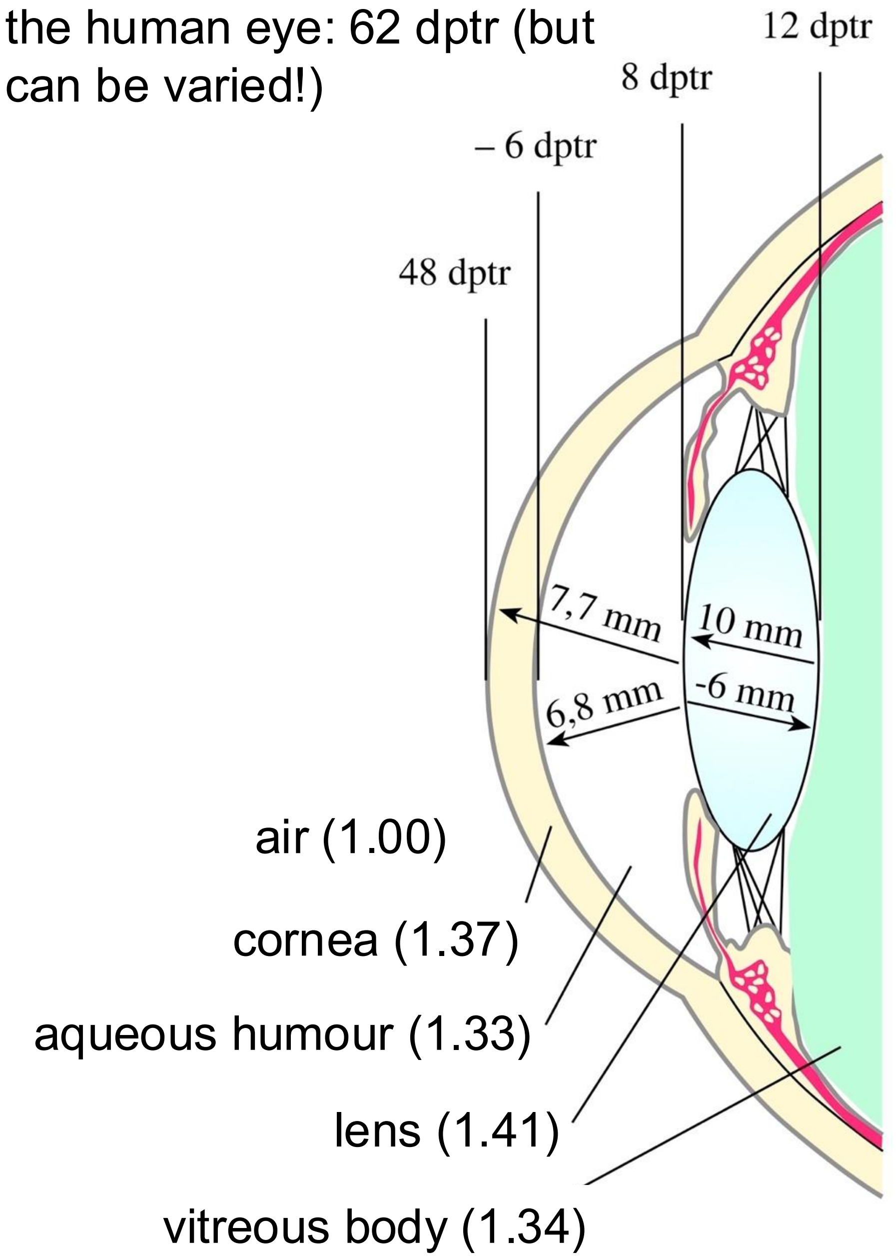
Optics of the human eye

Demagnified, up-side-down, real image is formed on the retina.



Horizontal section of the human eye

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



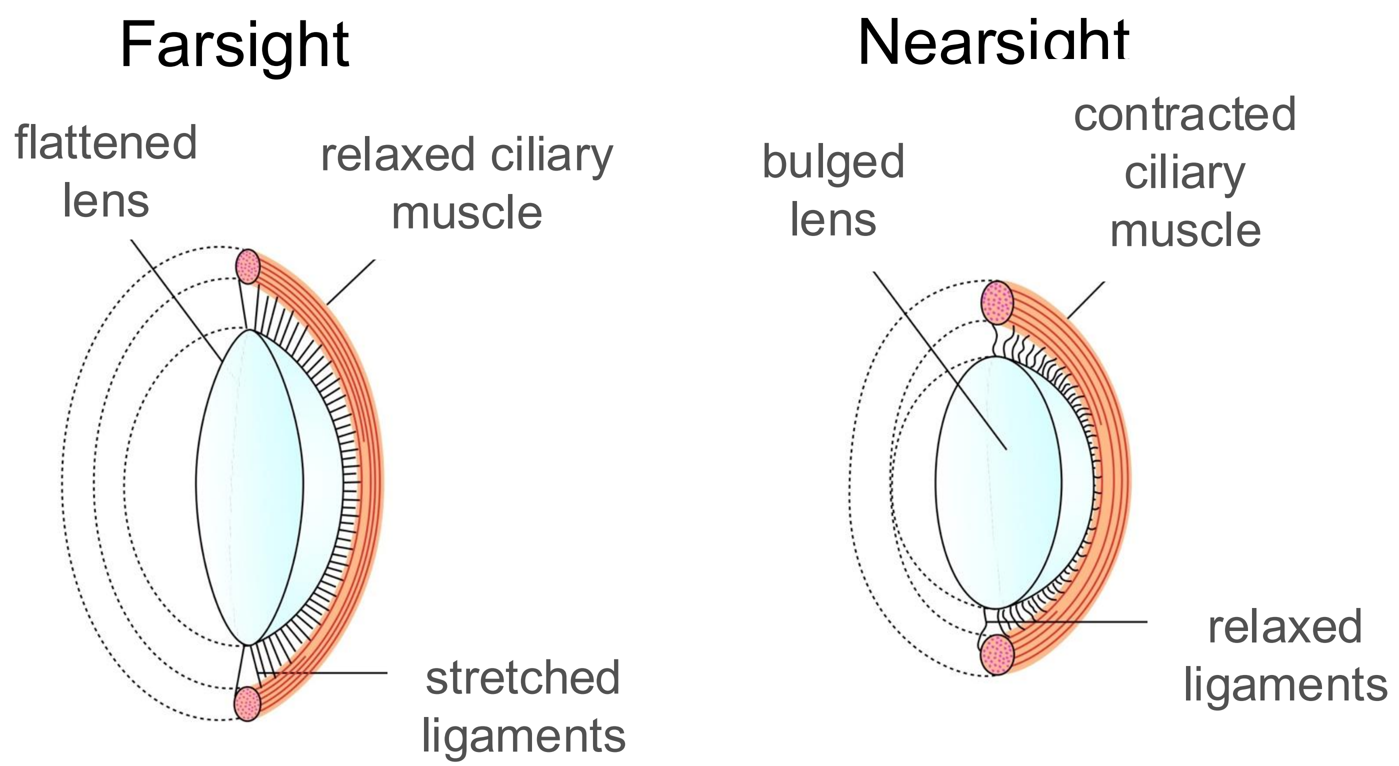
$$D = \frac{n - n'}{r}$$

n-n' = refractive index difference of bounding media (air, cornea, etc.)
r = radius of curvature of refractive surface

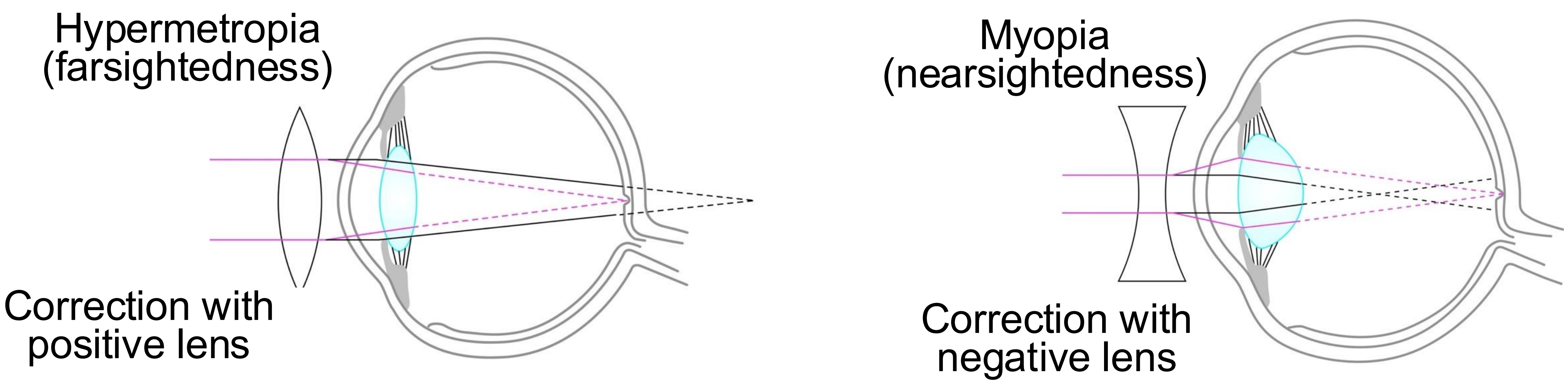
N.B.: 1) n-n' is greatest at the air-cornea surface.
2) There are two possible mechanisms for controlling refractive power (variation of n' or r)!

Accomodation

- Adaptation of the eye's refractive power to the object distance.
- Mechanism: radius of curvature of the lens is modified.
- Accomodation power: difference, in diopter, between the far and near points of the eye.

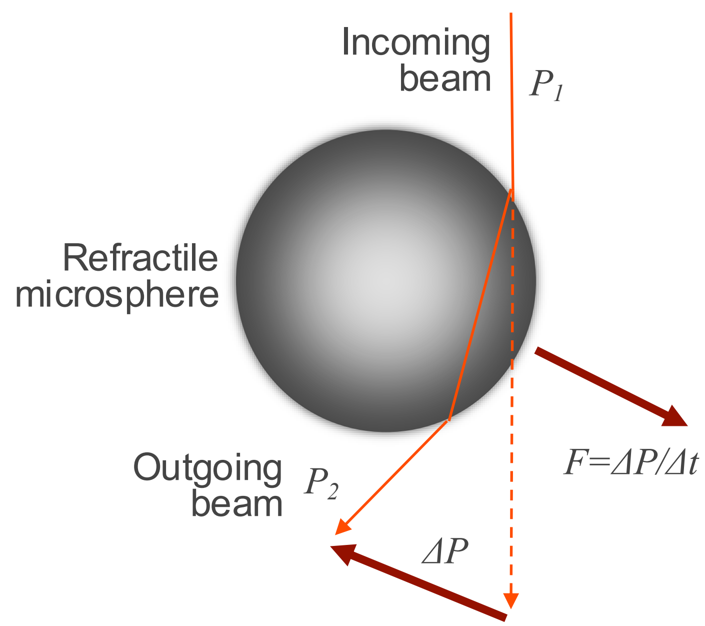


Refraction problems

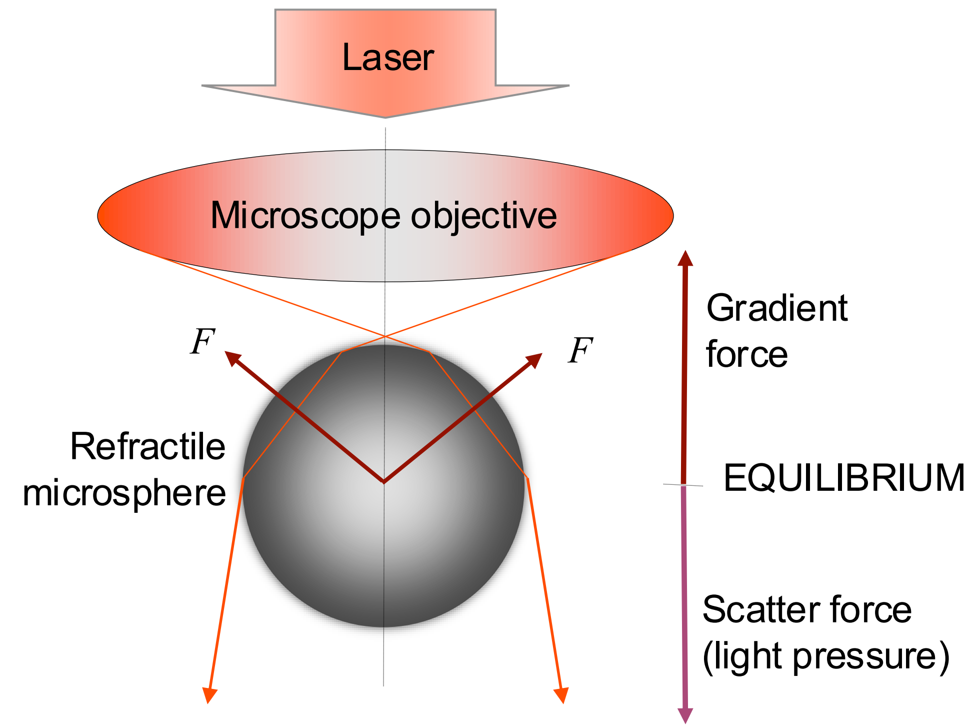


Manipulating objects with refraction

Refraction is accompanied by photonic momentum change (ΔP) (Theory later):

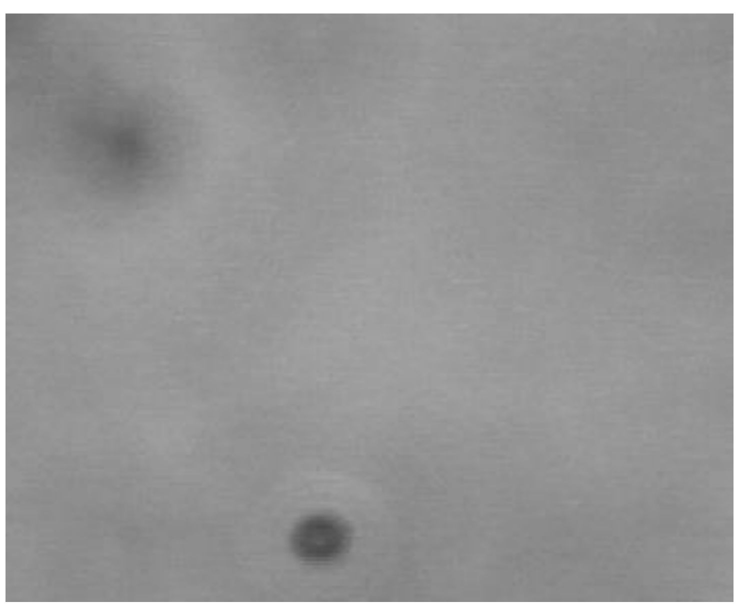


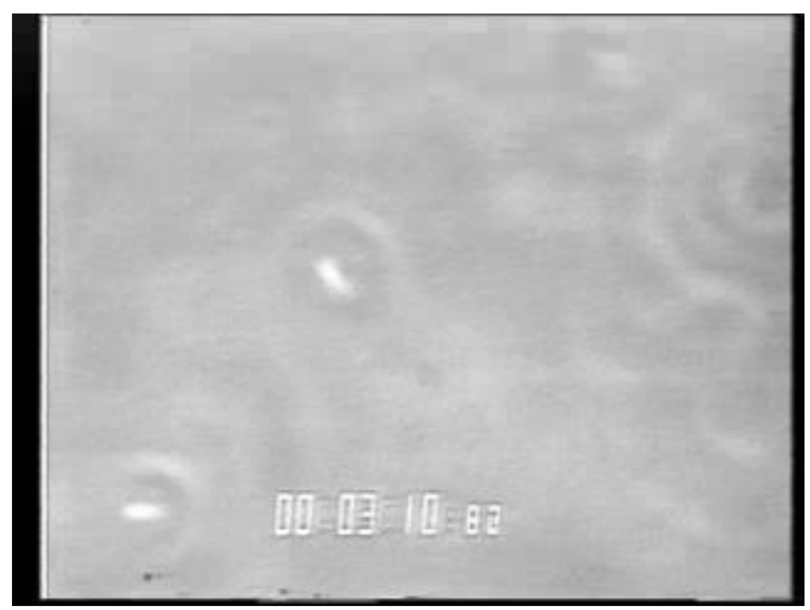
*Refractile particles may be **captured** with photonic forces:*



*In the **optical trap** a momentum change occurs between the photons and the trapped particle:*

3 μm latex (polystyrene) microspheres in the optical trap





Optical trapping of bacterial (E.coli) cells

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