

MEDICAL BIOPHYSICS

INTRODUCTION
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Objectives and methods of medical biophysics

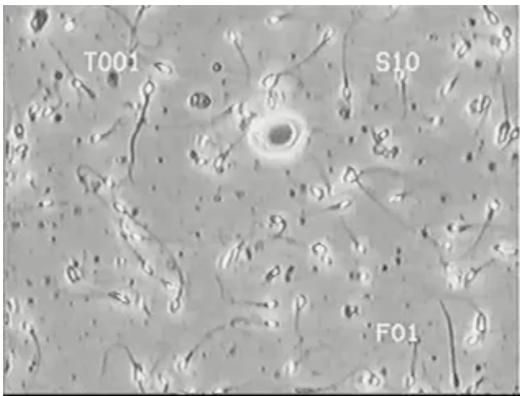
Objectives:

1. Provide a *physical* “description” of biomedical phenomena
2. Discuss and understand *physics*-based medical techniques

Methods:

- Biomedical phenomena and processes are
1. quantified
 2. simplified

I) Physical description of a biological phenomenon



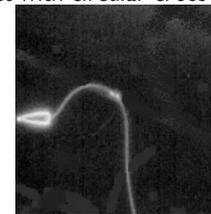
Questions we might ask:

1. How much force (F) is necessary for a spermatoocyte to travel with a given velocity (v)?
2. How does it happen (what is the exact mechanism)? Can we build a predictive model?

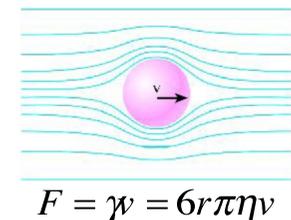
Drag coefficient of the spermatoocyte

How much force (F) is necessary for a spermatoocyte to travel with a given velocity (v)?

Simplified spermatoocyte model:
object with circular cross-section



Stokes' Law:

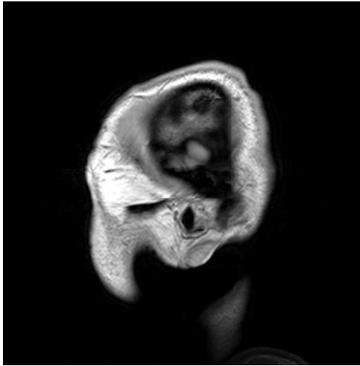


Friction coefficient: $\gamma = 6r\pi\eta = 6 \cdot 1.6 \times 10^{-6} (m) \cdot \pi \cdot 10^{-3} (Pas) = 3 \times 10^{-8} Ns/m$

Force: $F = \gamma = 3 \times 10^{-8} Ns/m \cdot 5 \times 10^{-5} m/s = 1.5 \times 10^{-12} N = 1.5 pN$

2) Understanding a physics-based medical technique

How does the MRI work?



Questions we might ask:

1. What is this? (Magnetic Resonance Imaging)
2. What physical phenomena are utilized? (magnetism, radiations, absorption, emission)
3. What can MRI reveal about the human body? (structure, function, tissue composition)

GEOMETRIC OPTICS

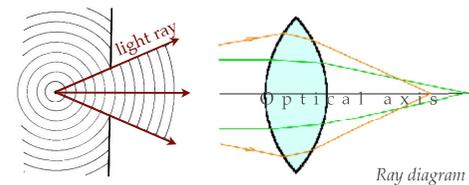
GEOMETRIC OPTICS

- Reflection, refraction, refractometry
- Total internal reflection, endoscopy
- Refraction on curved surfaces, optical imaging, lens equation
- Light microscope
- Optics of the human eye
- Manipulating objects with refraction

GEOMETRIC OPTICS

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").



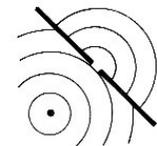
- Optical (light) ray ("light beam"): abstraction, mathematical line.
- Arrows represent the direction of energy propagation.
- Optical axis: line connecting the midpoint of optical components (e.g., lenses).
- Principle of reversibility: the direction of energy propagation (arrows) may be reversed.

Speed of propagation of light in *vacuum*: $c=2,99792458 \times 10^8 \text{ ms}^{-1}$
In *optically denser media* the speed of propagation is reduced (c_1).
This may be expressed with the *absolute refractive index* (n_1):

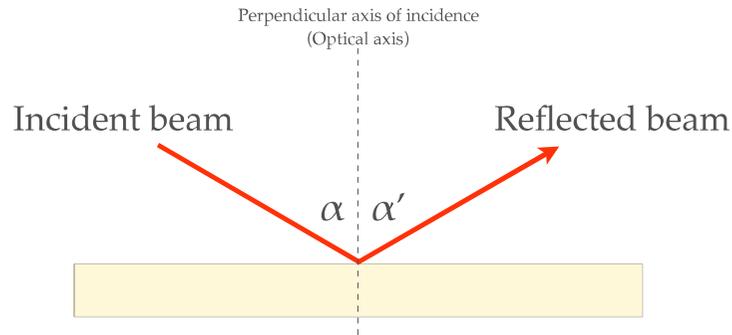
$$n_1 = \frac{c}{c_1}$$

(by comparison:
wave optics - next week)

If light propagates through a slit comparable or smaller than its wavelength, then its wave properties must be taken into account.

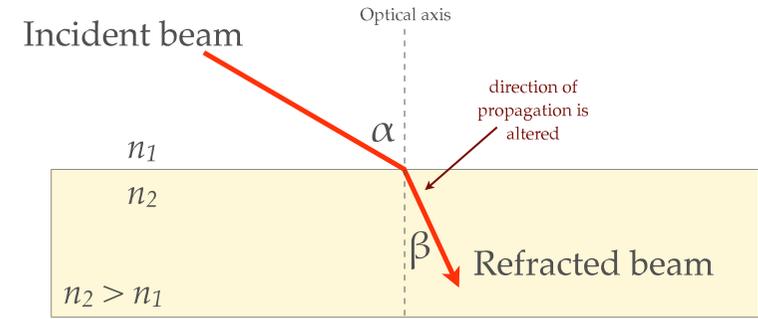


REFLECTION



- 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 ($\alpha = \alpha'$).

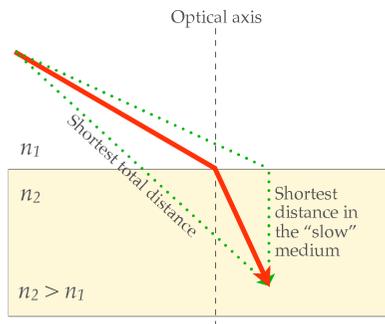
REFRACTION



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

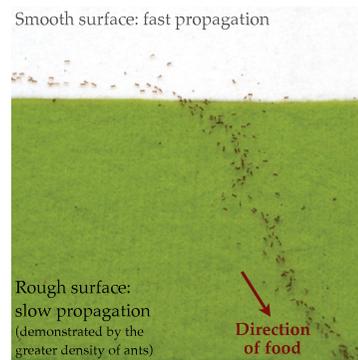
$$\frac{\sin \alpha}{\sin \beta} = \frac{c_1}{c_2} = \frac{n_2}{n_1}$$

EXPLANATION OF REFRACTION: FERMAT'S PRINCIPLE OF LEAST TIMES



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

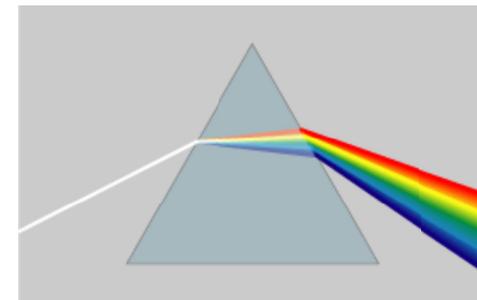
Fermat's principle is at work in other places, too!



Path "selection" by ants (*Wasmannia auropunctata*) at the boundary of media with different "resistances".

DISPERSION

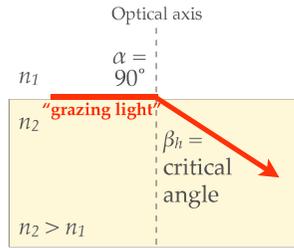
Index of refraction depends on frequency!



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

ANALYTICAL APPLICATION OF REFRACTION: REFRACTOMETRY

Boundary condition of refraction



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

$$n_1 = n_2 \sin \beta_h$$

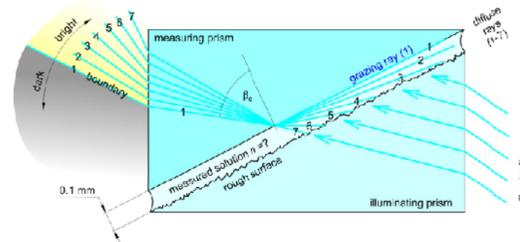
Thus, in case we know n_2 , by measuring β_h the refractive index of the incident medium (n_1) may be obtained.

Refractometry

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

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

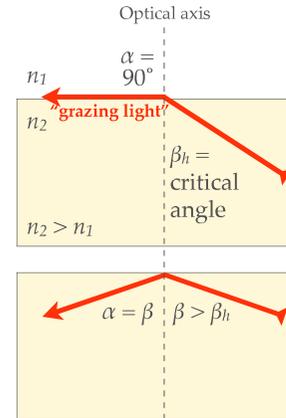
n_0 = refractive index of solvent, k = constant



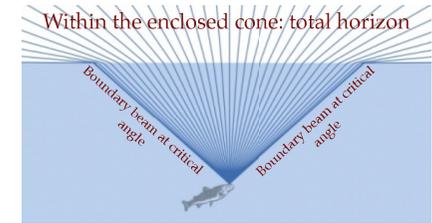
Conditions of applicability:

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

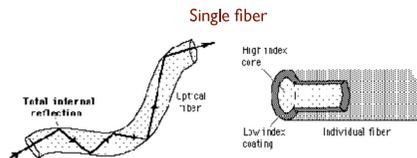
TOTAL INTERNAL REFLECTION



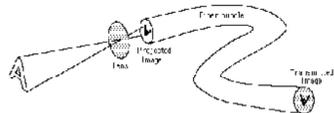
Total reflection within the optical medium of greater refractive index ("total internal reflection", TIR)



BIOMEDICAL APPLICATION OF TIR: OPTICAL FIBERS



Highly ordered fiber bundle



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

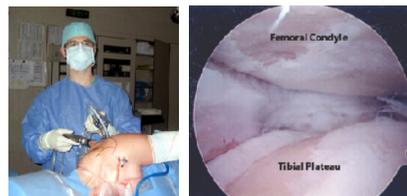
Endoscopy

OBJECTIVES

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

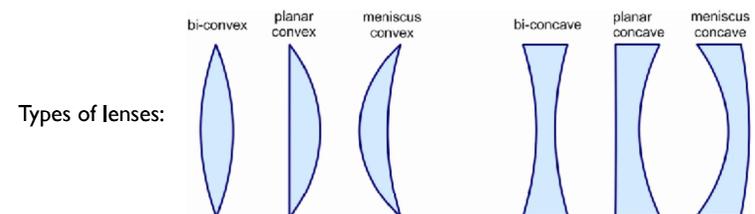
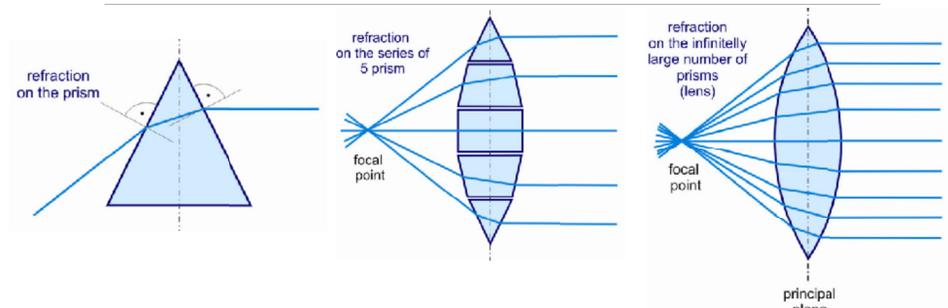
TYPES

Arthroscopy (joints); **Bronchoscopy** (trachea and bronchi); **Colonoscopy** (colon); **Colposcopy** (agina 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

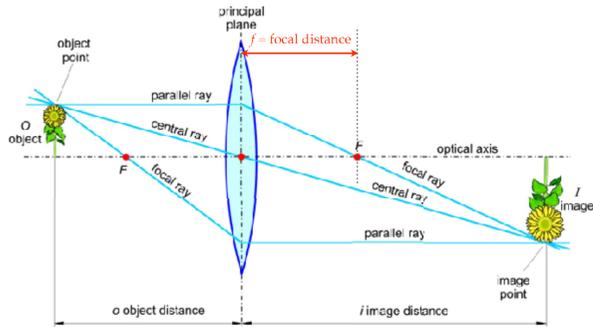
REFRACTION ON CURVED SURFACE



Types of lenses:

OPTICAL IMAGING

Image formation may be achieved by using a curved refractile 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

Magnification

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

Lens equation

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

D=optical power (diopter, m⁻¹)

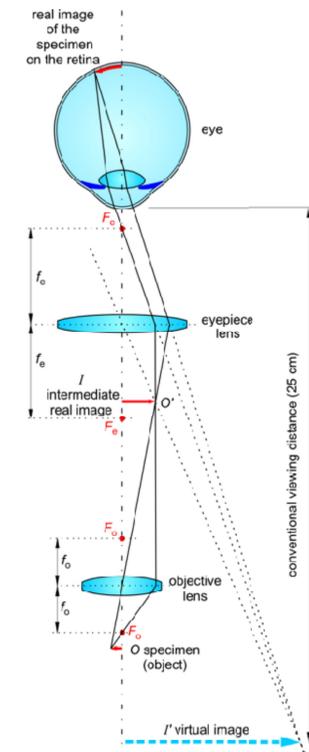
Optical power of refractile surface

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

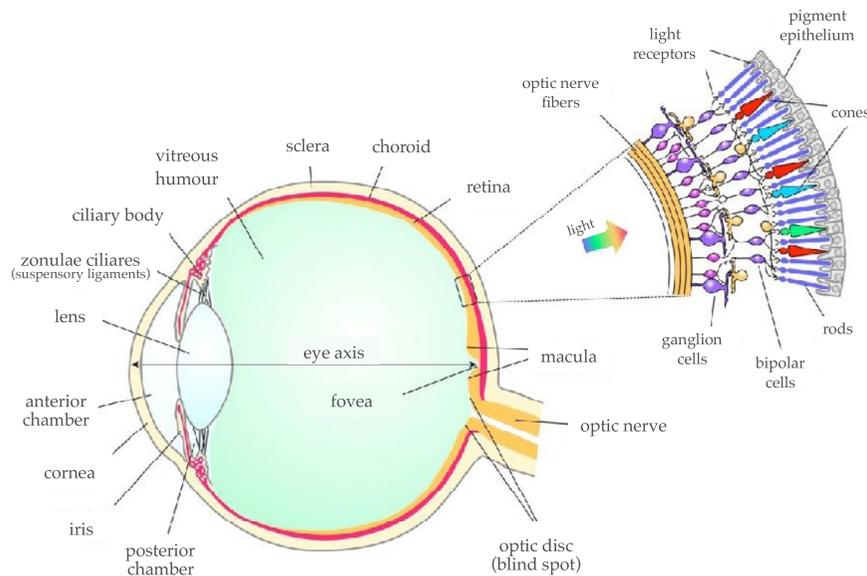
n-n' = difference between the refractive indices of optical media
r = radius of curvature of refractile surface

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



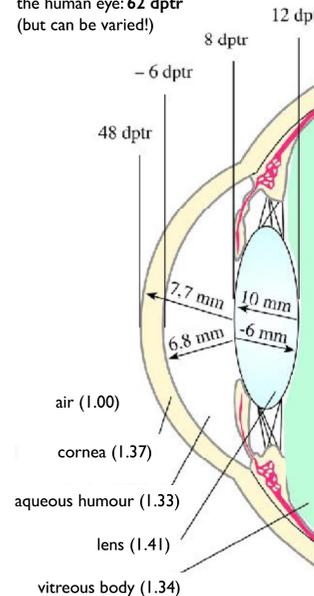
Optics of the human eye



Horizontal section of the human eye

Optics of the human eye

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



Optical power entering the eye (P):

$$P = J\pi \left(\frac{d}{2}\right)^2$$

J=intensity (W/m²)
d=pupil diameter

Power depends on pupil diameter:

$$\frac{P_{\max}}{P_{\min}} = \left(\frac{d_{\max}}{d_{\min}}\right)^2 = 16$$

d_{max}=8 mm
d_{min}=2 mm

Refractive power of surfaces (D, dptr):

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

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

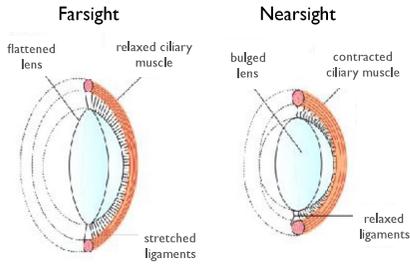
N.B.:

- 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)!

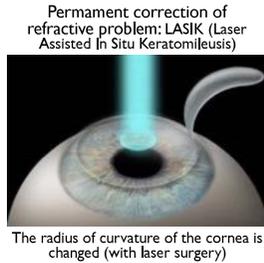
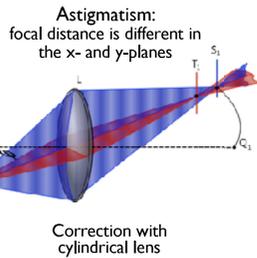
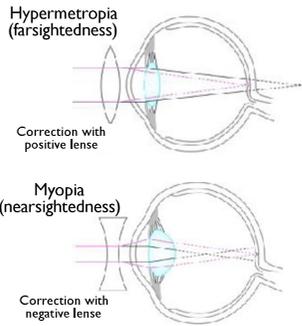
Accommodation and refraction problems

Accommodation:

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

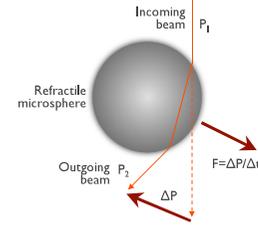


- Presbyopia:**
- Accommodation power decreases.
 - Manifests with age (>45 years).
 - Nearsight worsens.

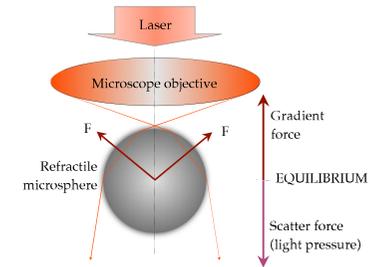


Manipulating objects with refraction

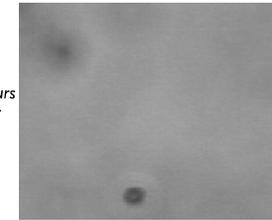
Refraction is accompanied by photonic momentum change (ΔP) (Theory later):



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

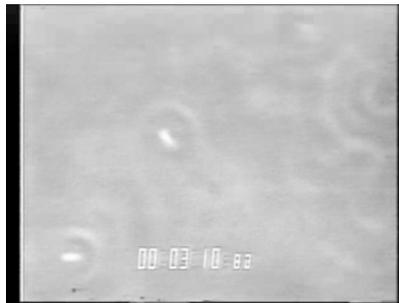


In the **optical trap** a momentum change occurs between the photons and the trapped particle:



3 μm latex (polystyrene) microspheres in the optical trap

Even cells can be captured with the optical trap



Trapping of bacterial cells

Tying a knot on a molecular filament by using optical trap

Actin filament

DNA



Phase contrast image

Fluorescence image

