PHYSICAL BASIS OF OPTICS

OPTICS

Optics – is a part of physics which studies optical radiation (the light), its propagation and effects of light & matter interaction.

Geometrical optics studies the geometry of light rays, their propagation & the laws of reflection, refraction in mediums with different optical properties.

Light ray – is a geometrical line along which the electromagnetic radiation propagates.

Light ray – is a geometrical value. In some cases its better to replace physical value "light wave " with geometrical value - "light ray". Thanks to this value the direction of light energy propagation can be found.

Wave optics – is a part of optics which considers light to be an electromagnetic wave. Wave optics studies events that show the wave properties of light (transverse electromagnetic wave).

LAWS OF GEOMETRICAL OPTICS

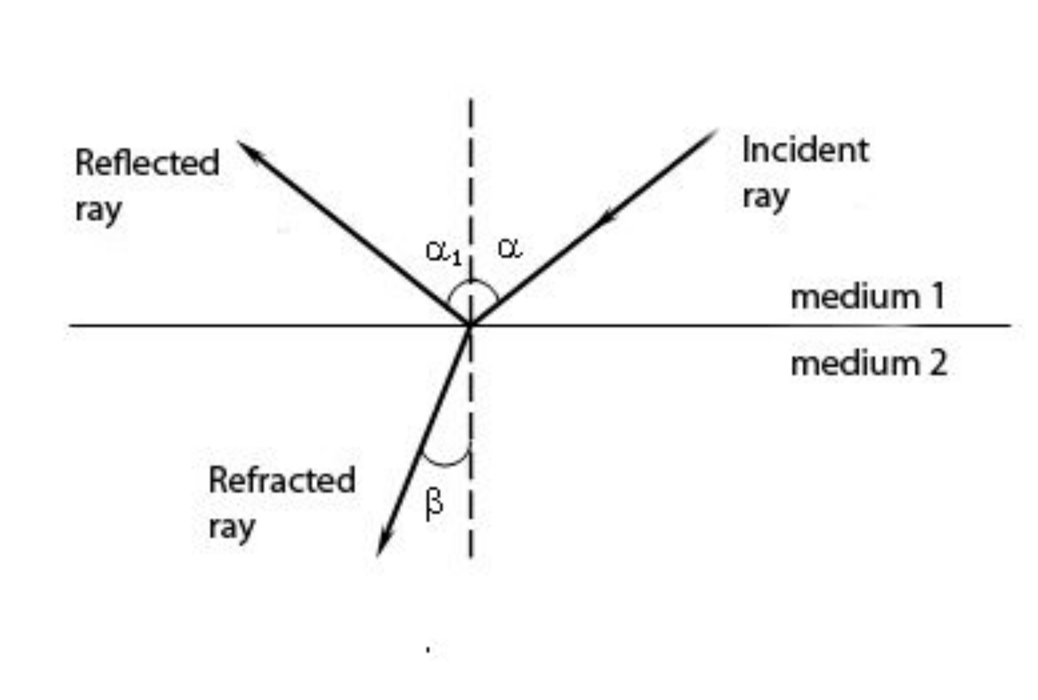
Law of reflection : incident ray, reflected ray & perpendicular (normal) to the two mediums border in the point of ray incidence lie in one plane. Angle of incidence я β is equal to angle of reflection α.

Law of refraction: incident ray, refracted ray & perpendicular (normal) to the two mediums border in the point of ray incidence lie in one plane. Relation between incident ray sine α to the refraction angle sine β is a constant value for two mediums:

$$\sin\alpha/\sin\beta = n_{2\text{-}1} = const$$

Constant value $n_{2\text{-}1}$ is called relative refraction index of one medium to another. Refraction index of a medium relatively to vacuum is called absolute refraction index. Relative refraction index of two mediums is equal to relation of their absolute refraction indexes:

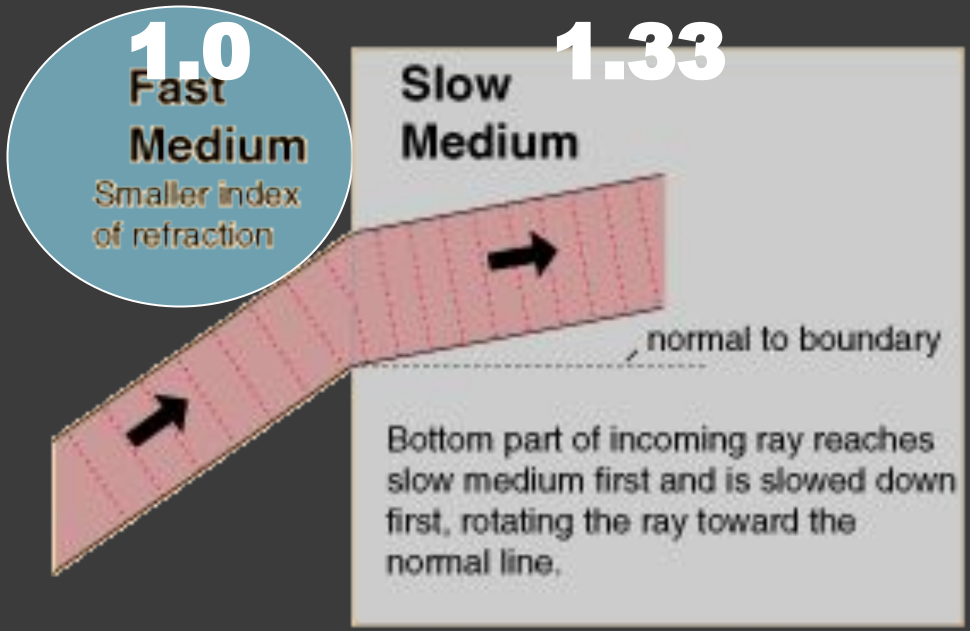
$$n_{2\text{-}1} = n_2/n_1$$



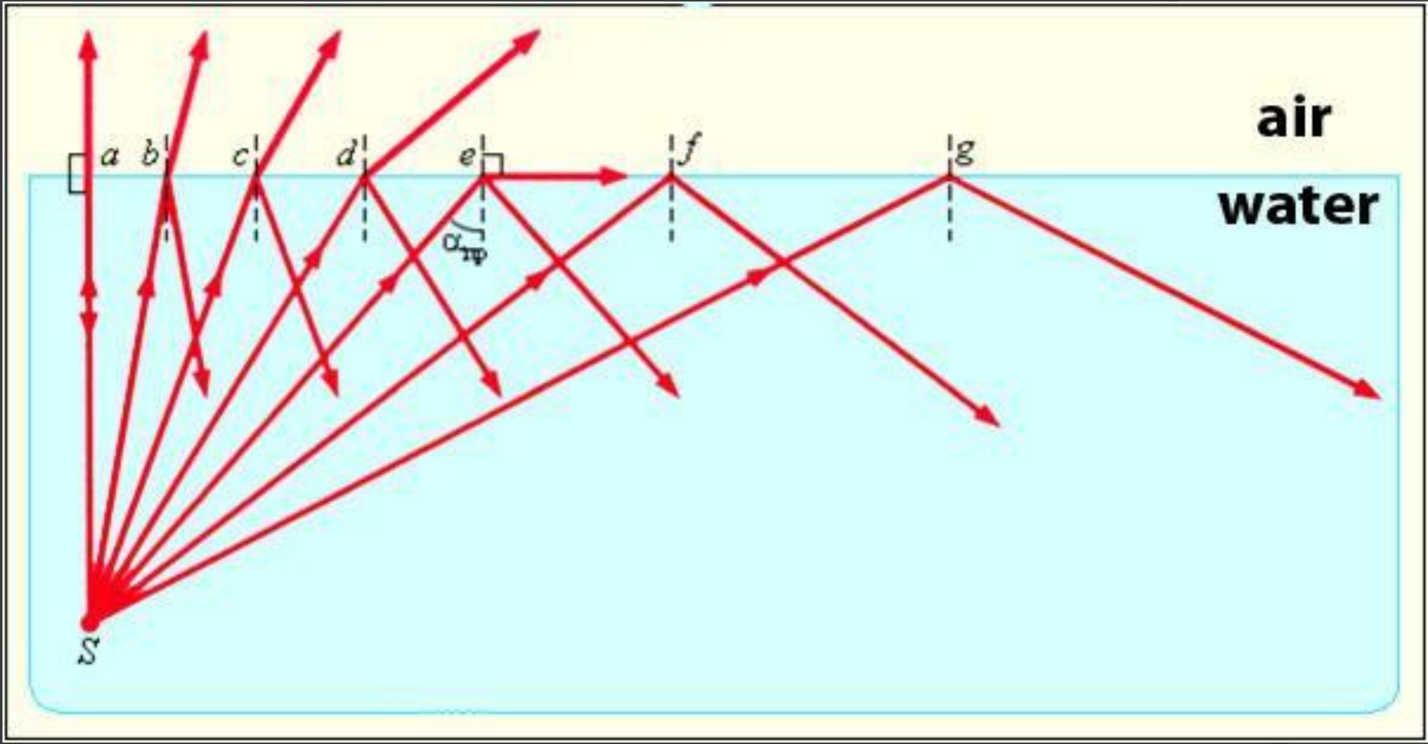
REFLECTION & REFRACTION

Air: 1.0

Water: 1.33

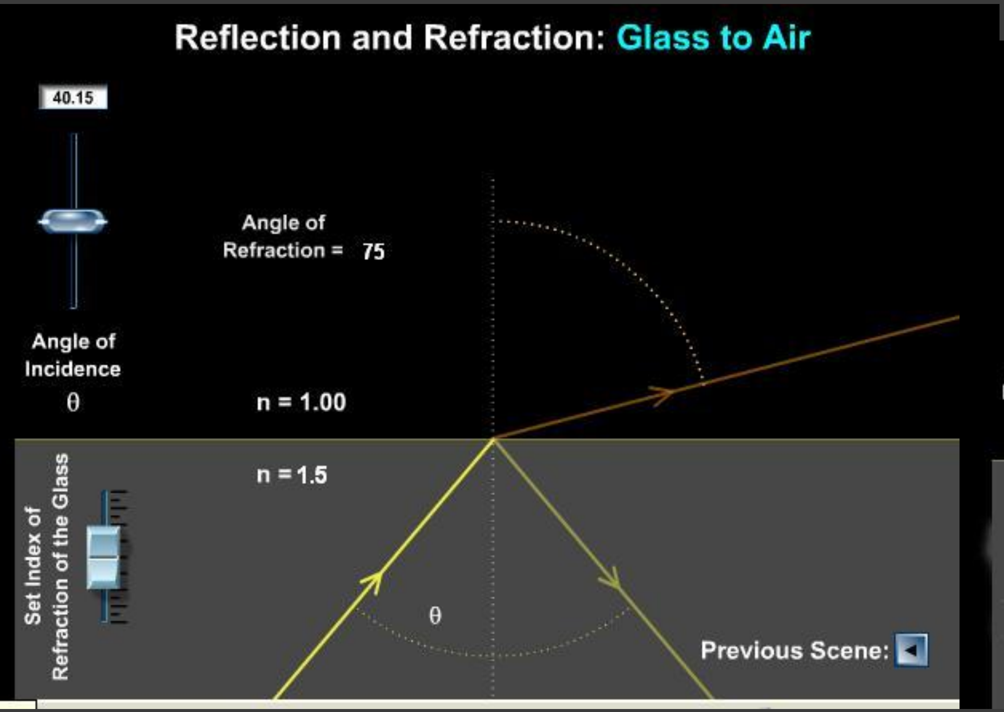


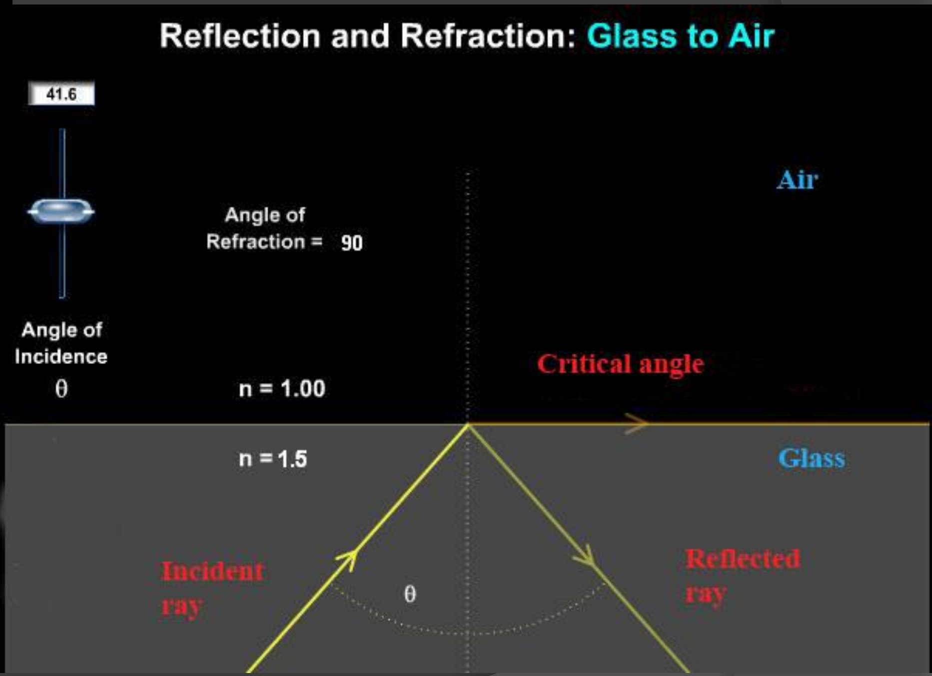
EFFECT OF TOTAL INTERNAL REFLECTION



Effect of total internal reflection can be seen as the light goes from medium with higher optical density to medium with lower optical density $\mathbf{n_2 < n_1}$ (e.g. from water or glass to the air or vacuum). The incident angle in this case should be greater than some total internal reflection critical angle. For glass-air boundary the critical angle is equal 42°, for water-air boundary - 48,7°.

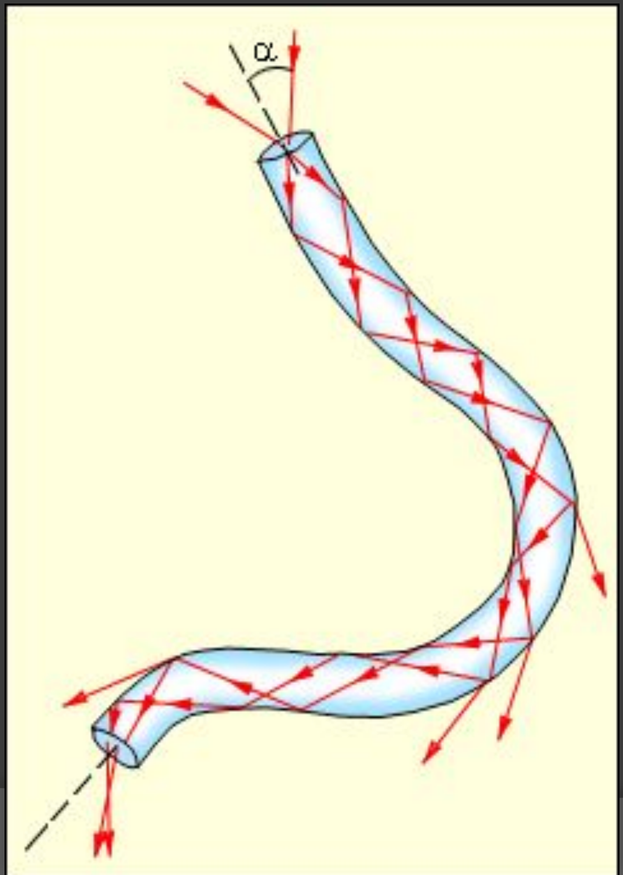
EFFECT OF TOTAL INTERNAL REFLECTION

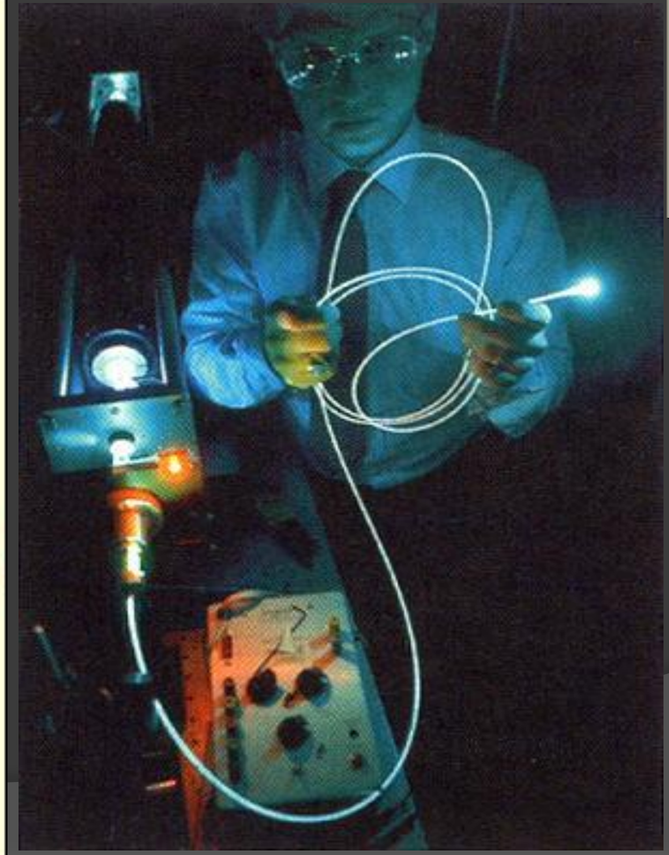


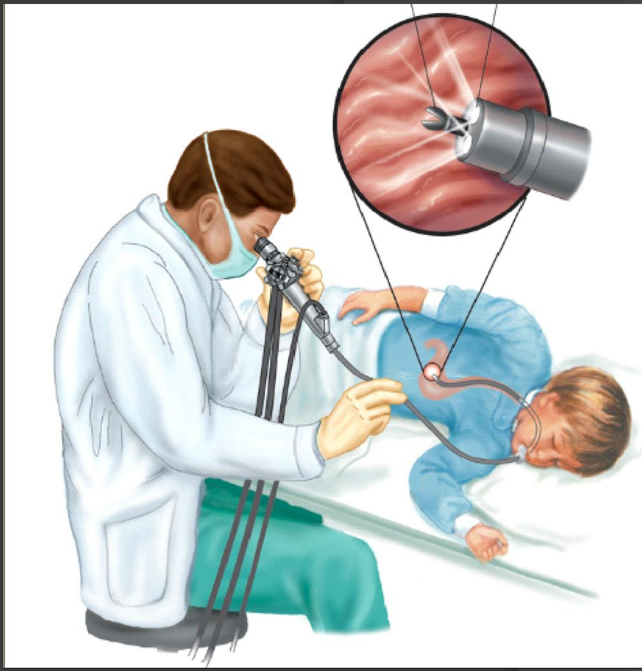


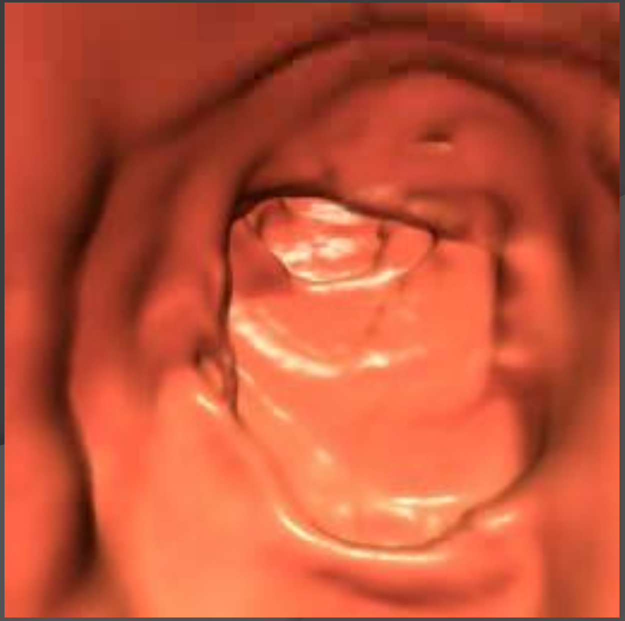
FIBER OPTICS

Total internal reflection effect is used in optic fibers which are thin strings made of optically clear material (glass, quartz etc.). Light which gets on the edge of optic fiber can propagate along this fiber on large distance because of total internal reflection effect. In medicine this effect is used in endoscopic technique.



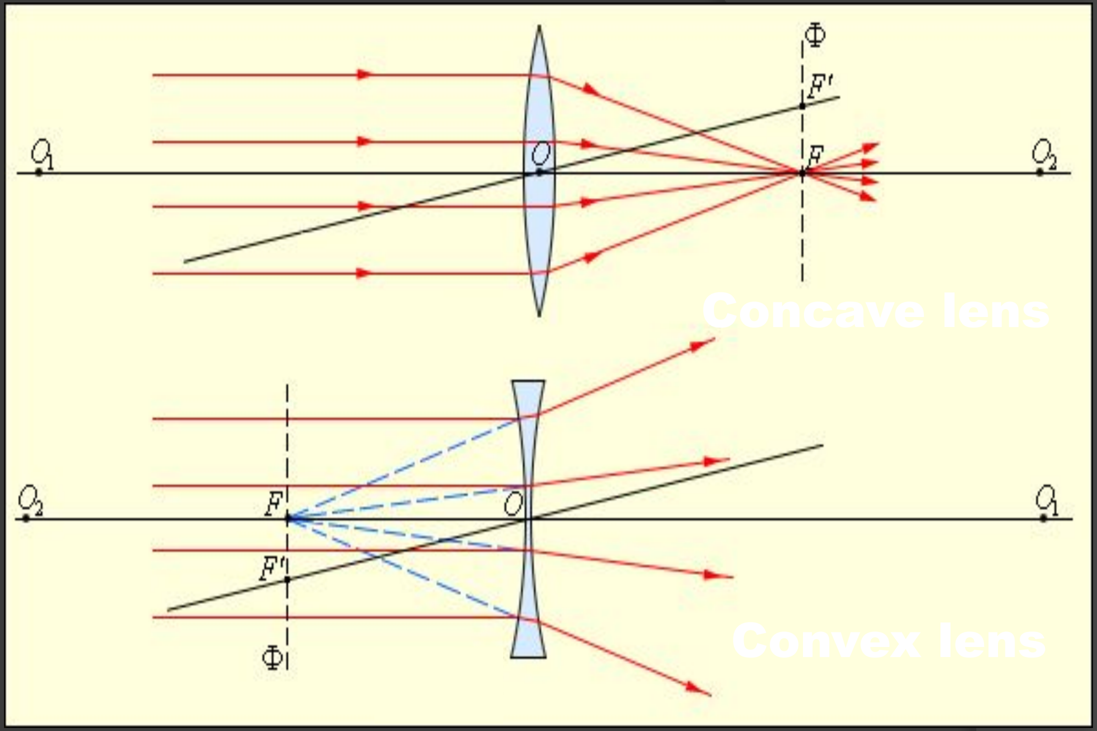






LENSES

Lens is a clear body, limited with two spherical surfaces.



Main optical axis of lens – is a line which goes through the centers of spherical surfaces curvature.

There are convex lens & concave lens.
If the beam of light rays parallel to main optical axis goes through the lens they will be gathered in one point after the lens called main focus of lens F.
Convex lens has real focuses. Concave lens has virtual focuses.
Distance from optical centre of lens and its main focus is called focal length F.

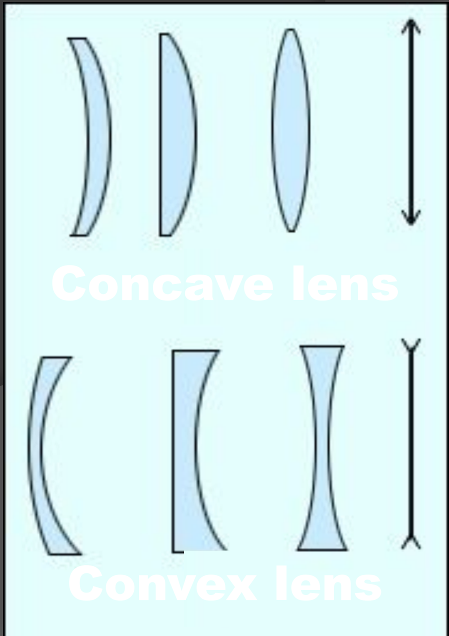
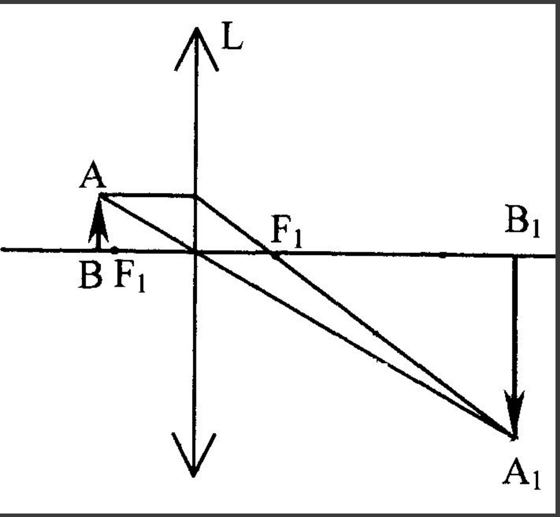


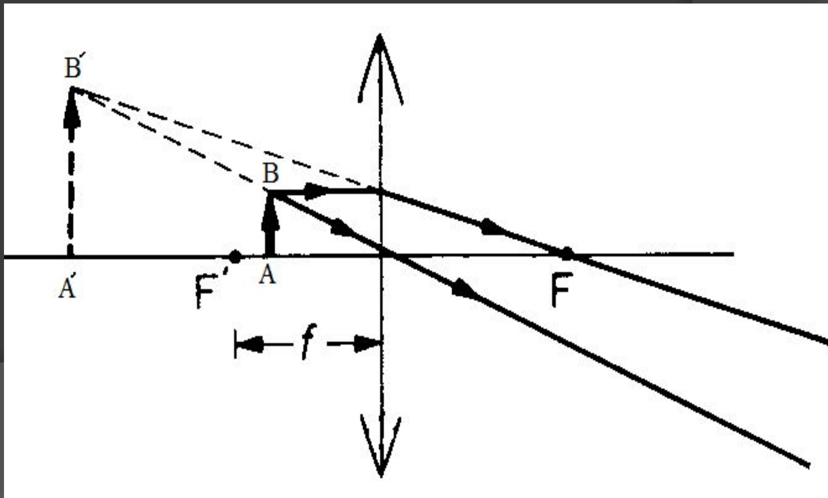
IMAGE CONSTRUCTION IN LENSES

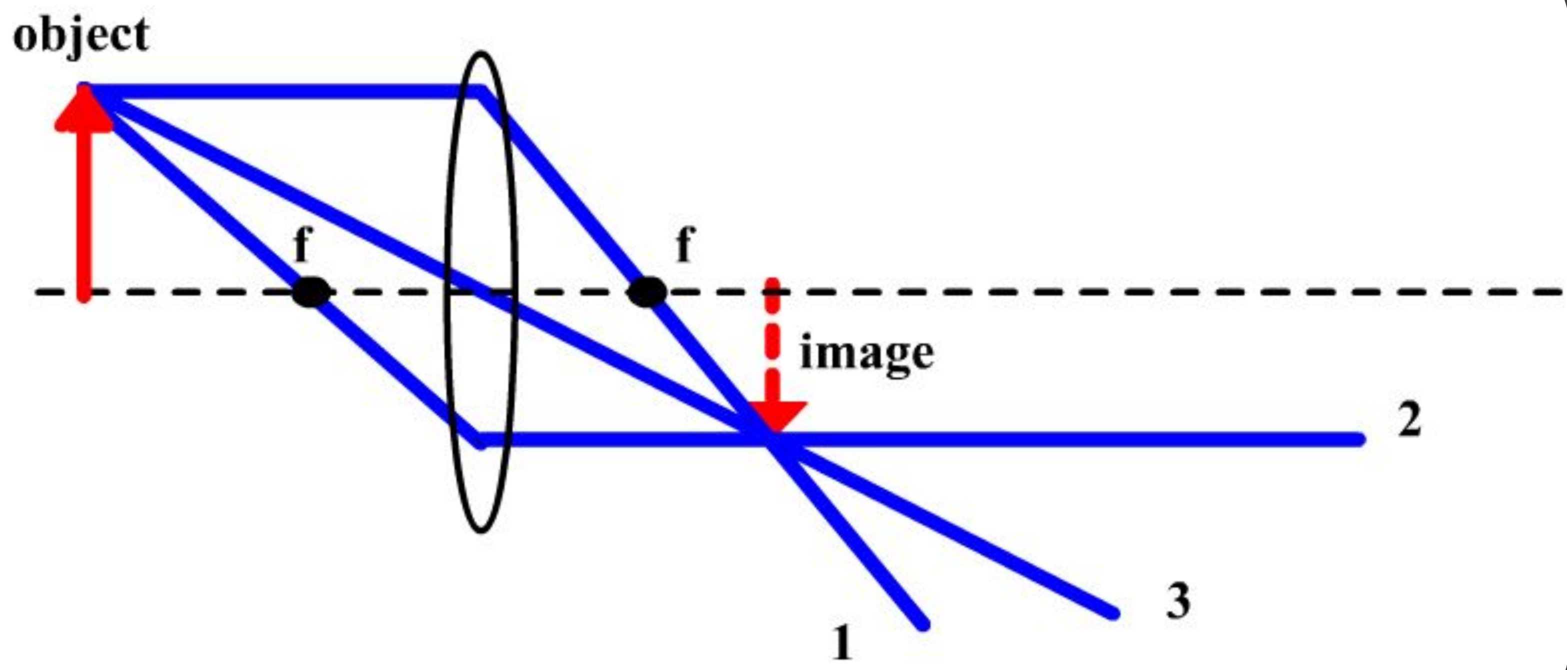
Lenses are used to change light rays direction in optics. Main property of lenses is an ability to give the image of the objects. These images can be: straight, reversed (inverted), real, virtual, enlarged, decreased. Position and characteristics of lens image can be defined with the help of geometrical constructions. In this case the properties of some light rays with determined ray paths are used. These are the rays that go through the optical centre or through one of the focuses of the lens & rays which paths are parallel to main or secondary optical axis.

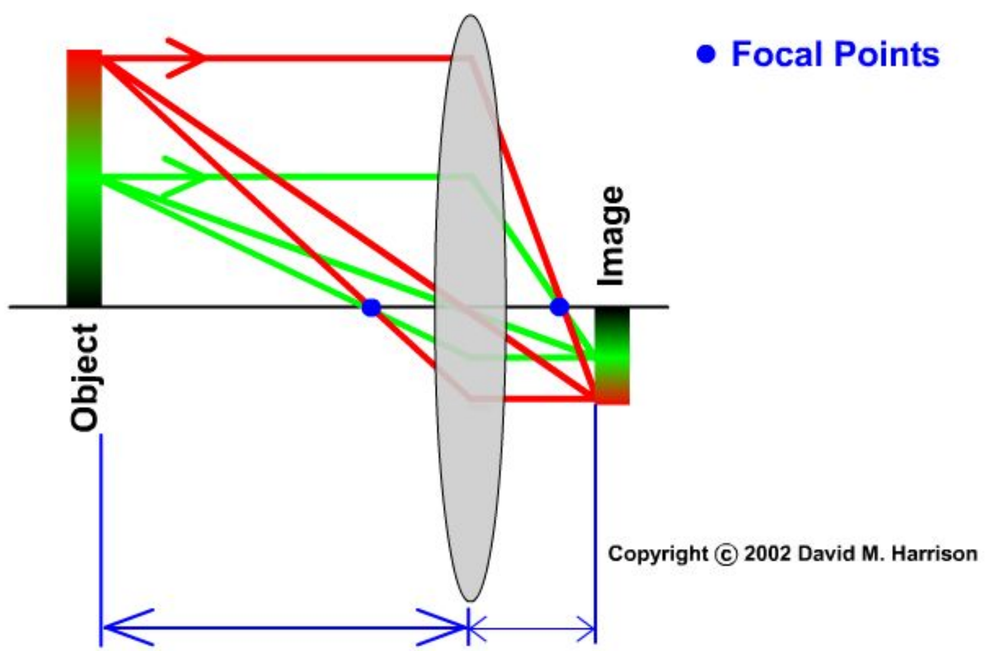


Object behind the focus
A-B - object
F – focal length
L – lens
A1-B1 – image (inverted, real, enlarged)

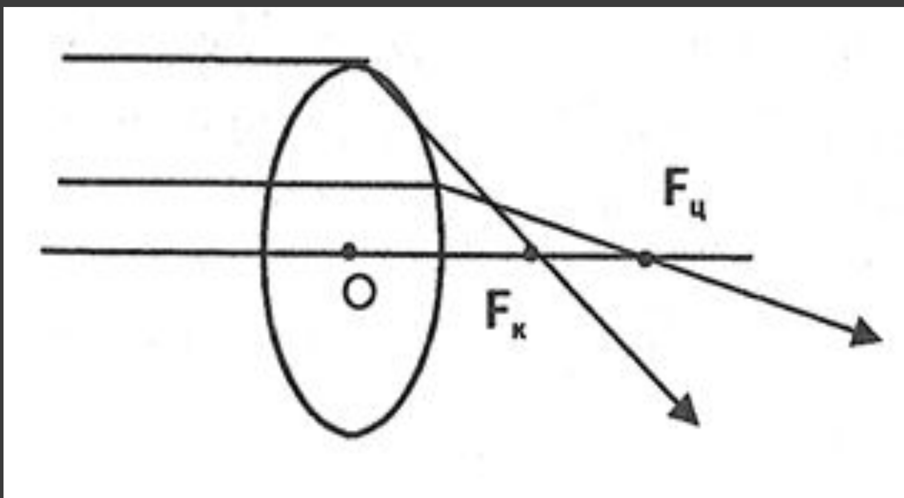
Object after focus
A-B - object
F – focal length
A'-B' – image (straight, virtual, enlarged)



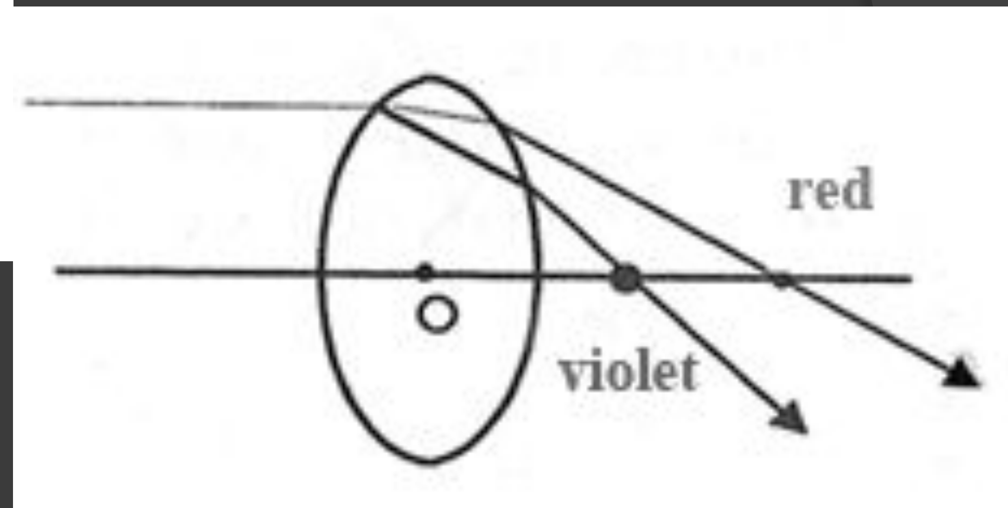

object
f
f
image
2
3
1


Focal Points
Image
Object
Copyright © 2002 David M. Harrison

LENSE ABERRATIONS



Spherical aberration

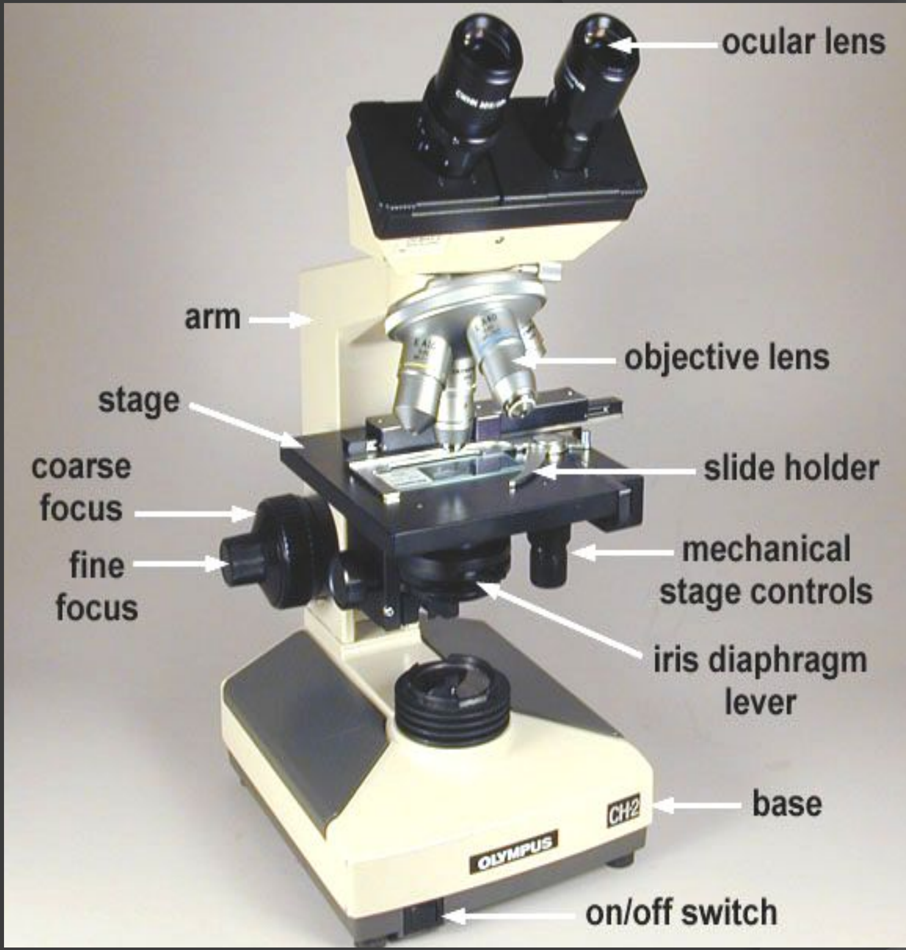


Chromatical aberration

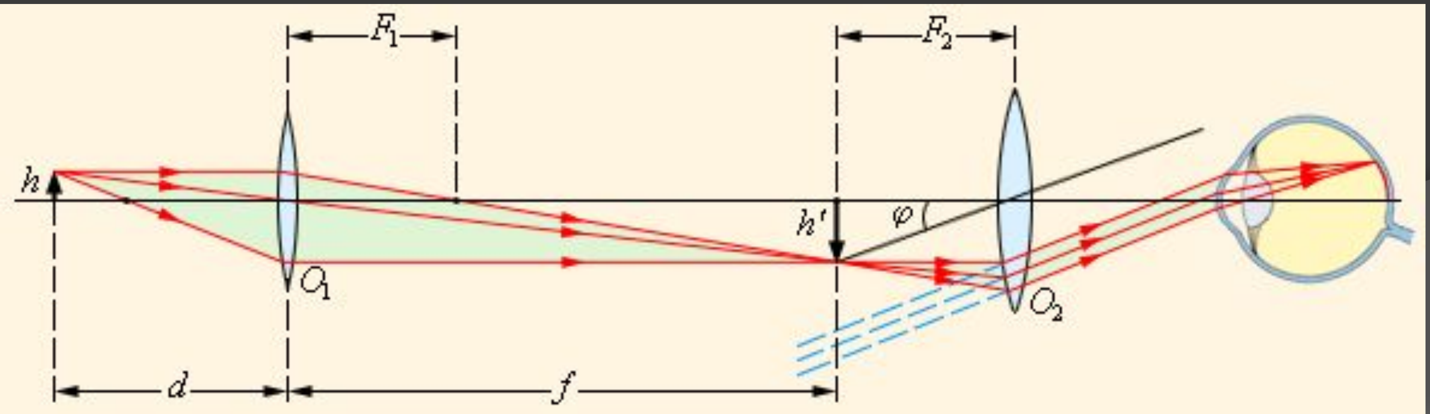
OPTICAL MICROSCOPE

Microscope is used to get the enlarged images of small objects. Enlarged image is received with microscope optical system. The optical system of optical microscope contains two short-focused lenses - objective & ocular. Objective gives real, reversed, enlarged image of the object.

Ocular plays the role of magnifying glass for the first image, built by objective.

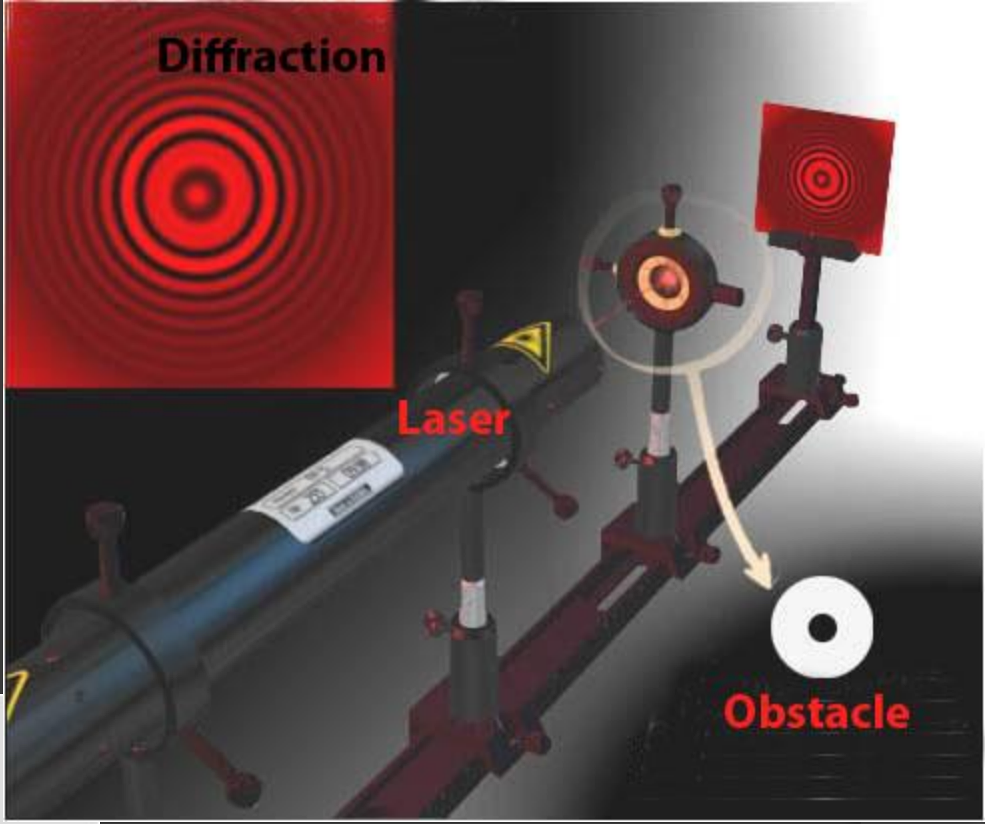


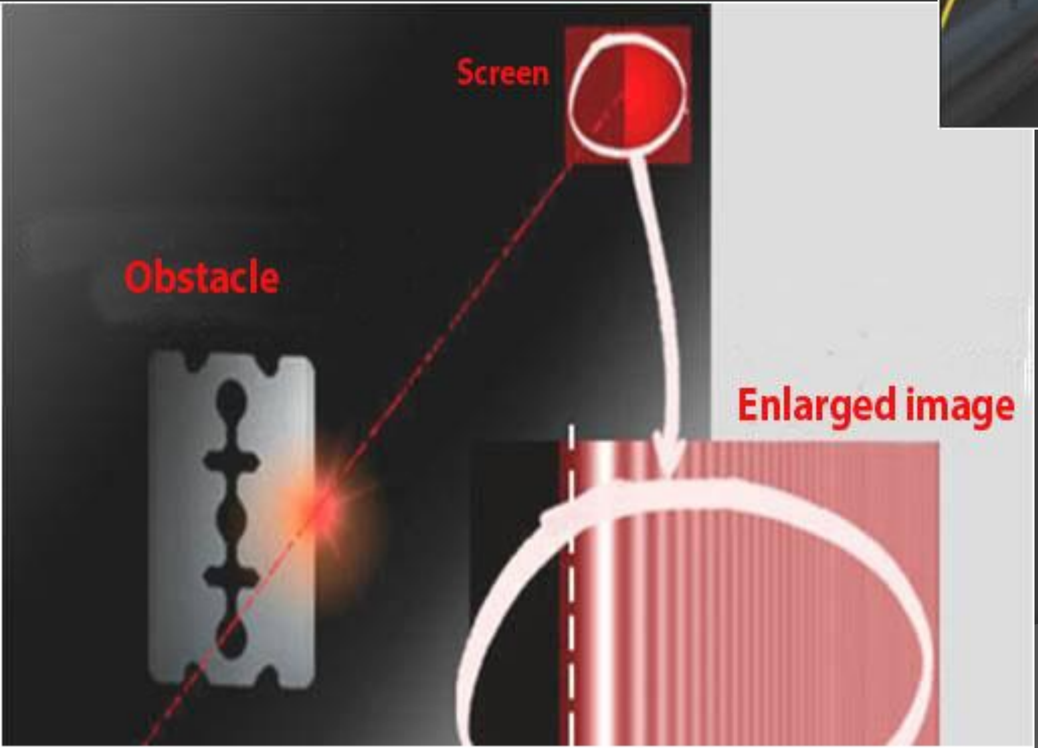
RAYS PATHS IN MICROSCOPE

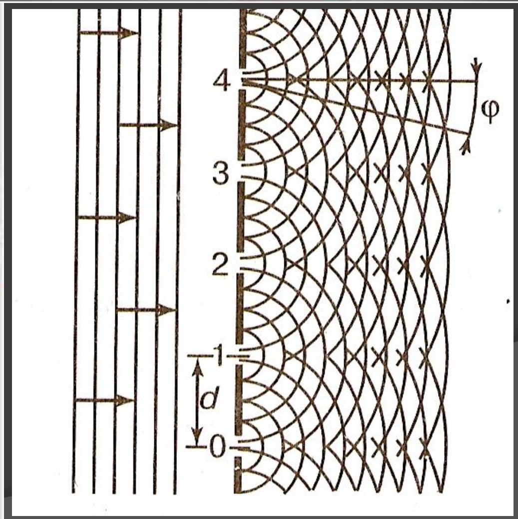


DIFFRACTION

Diffraction – is the effect of waves rounding of the obstacle. This effect can be observed for all kinds of waves: electromagnetic (light), elastic (sound), waves on the surface of water. The most clear this effect can be observed when the size of obstacle is almost equal to the wavelength.

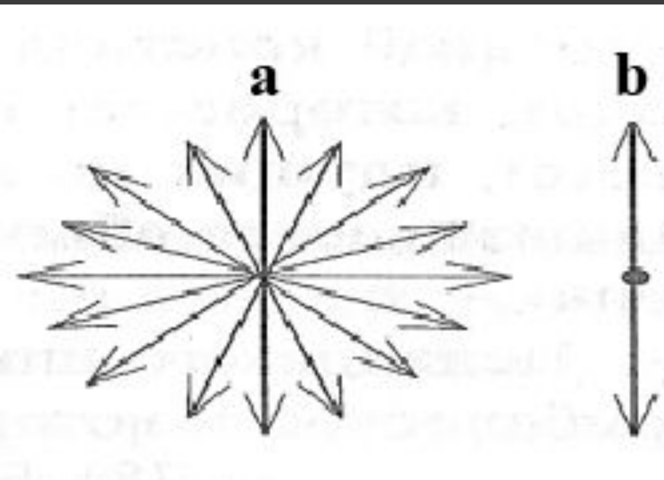






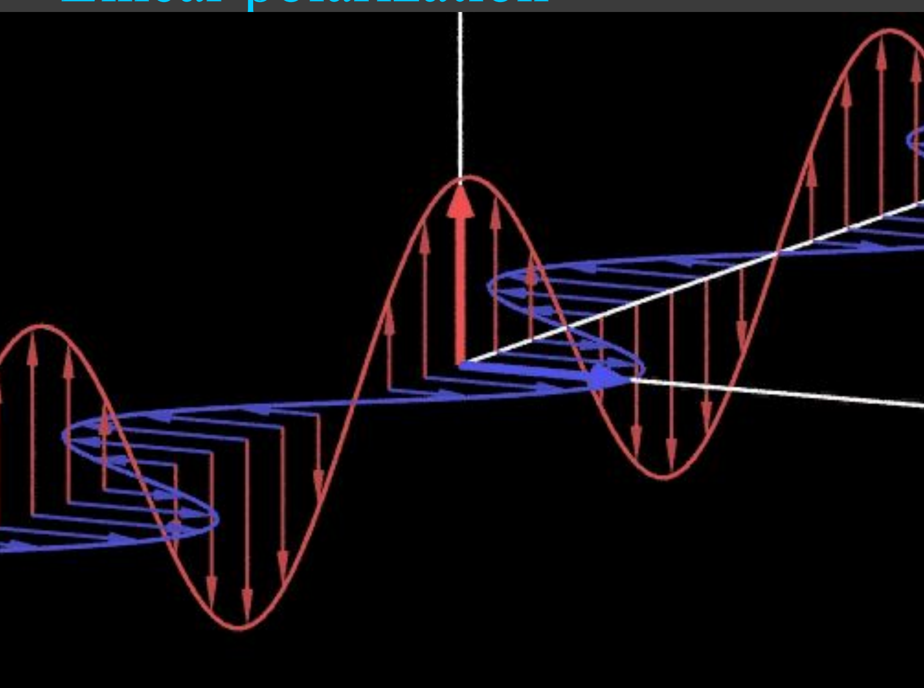
Scheme of diffraction grate

POLARIZATION

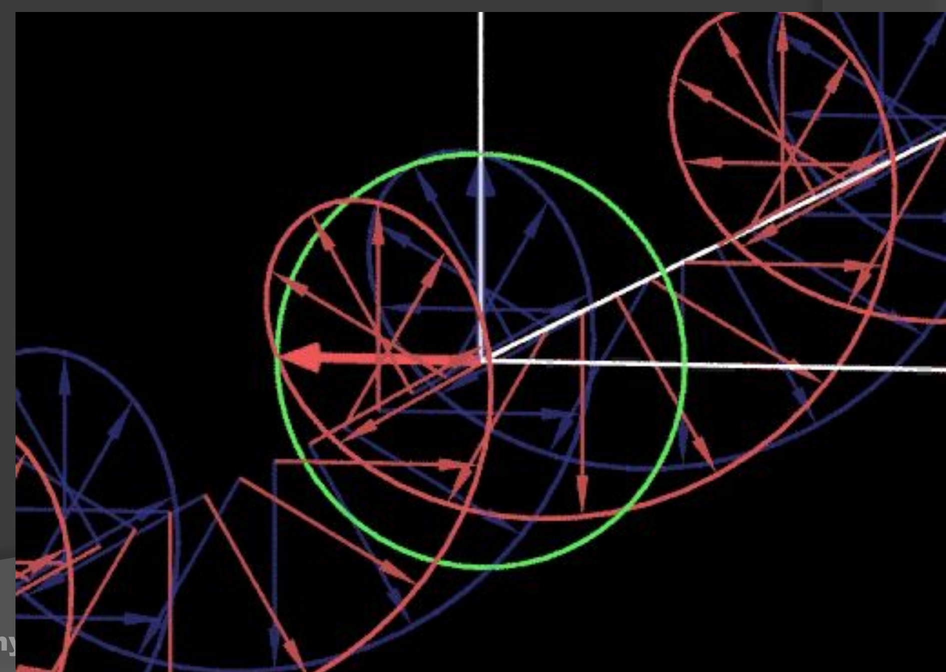


a – unpolarized light
b – polarized light

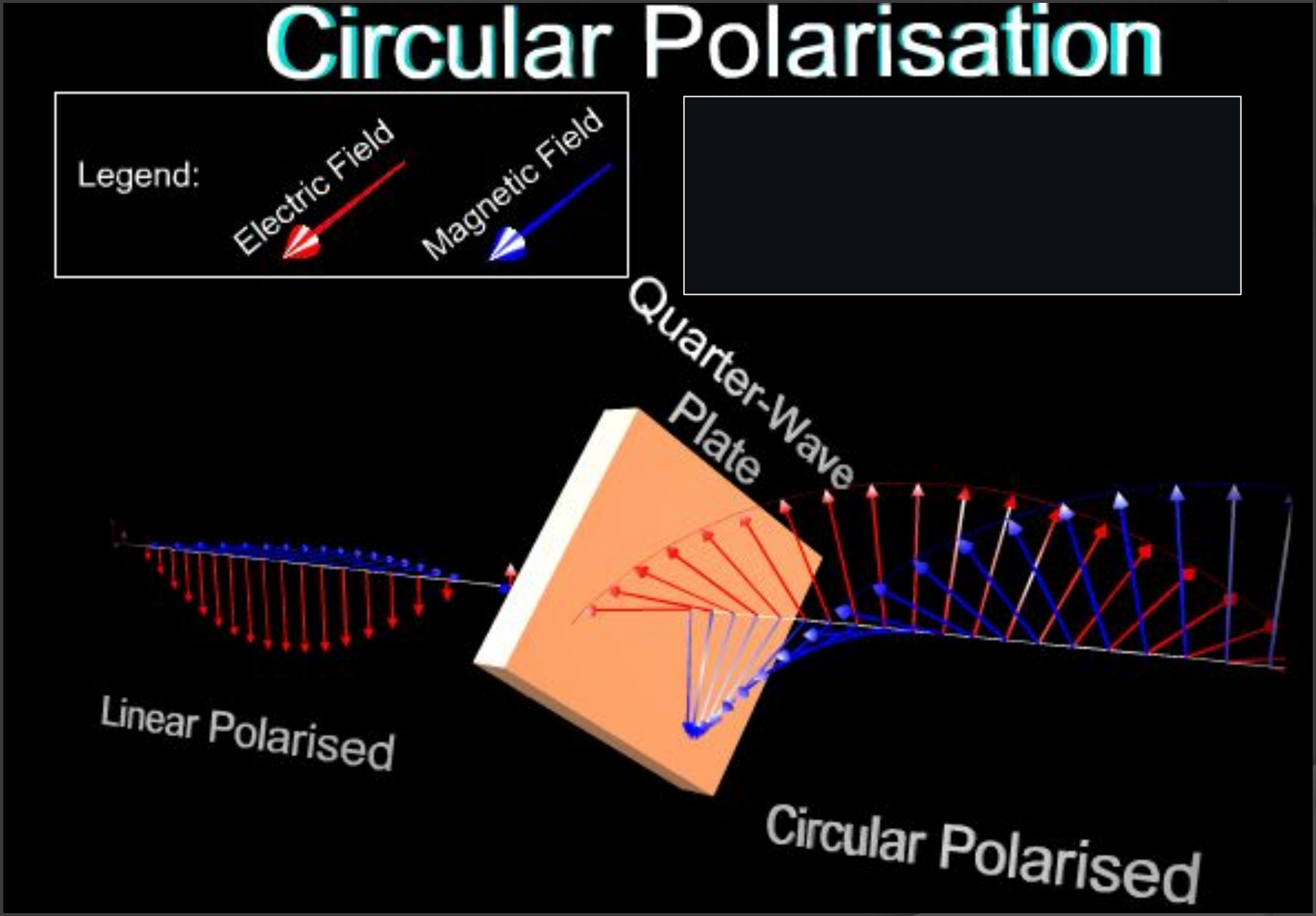
Linear polarization



Circular polarization



POLARIZATION

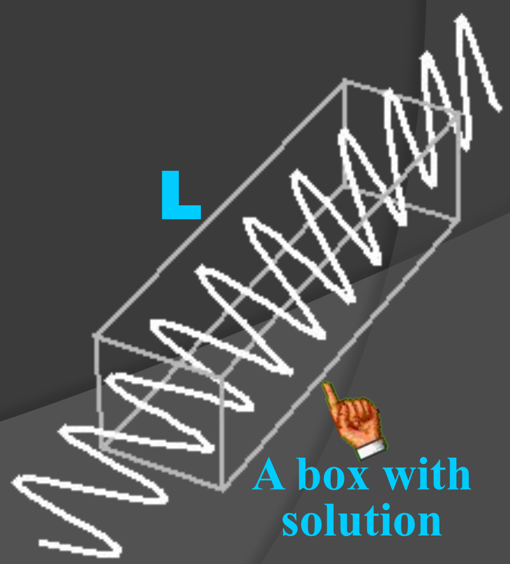


Polarimetry

As plane-polarized light goes through some substances their plane of polarization spatial orientation changes (turns on some angle). Such substances are called optically active substances. Some crystals (quartz, vermilion, etc.), pure liquids (turpentine, nicotine, etc.), solutions of some substances (sugar, vinic acid, etc.), some gases (camphor vapor) – are optically active substances. All important biological molecules (proteins, nucleic acids, vitamins, polysaccharids, etc.) are optically active. The law of plane of polarization turn was stated for solutions. Plane of polarization turning angle φ depends on optically active substance concentration in solution **C** & light path length in solution **L:** $\varphi = aCL$,

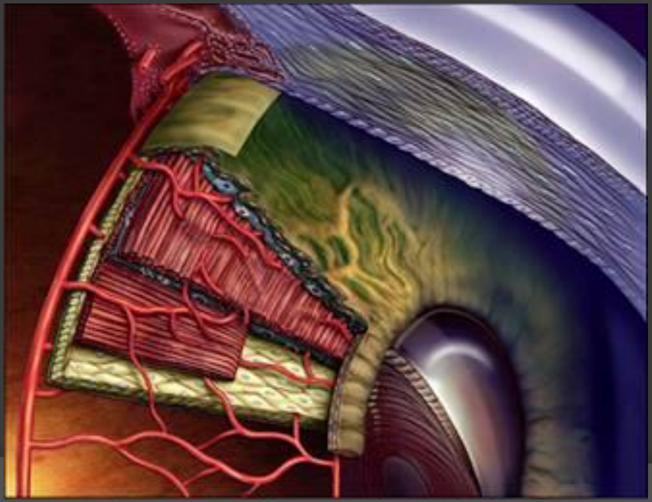
a – is called specific turning coefficient.

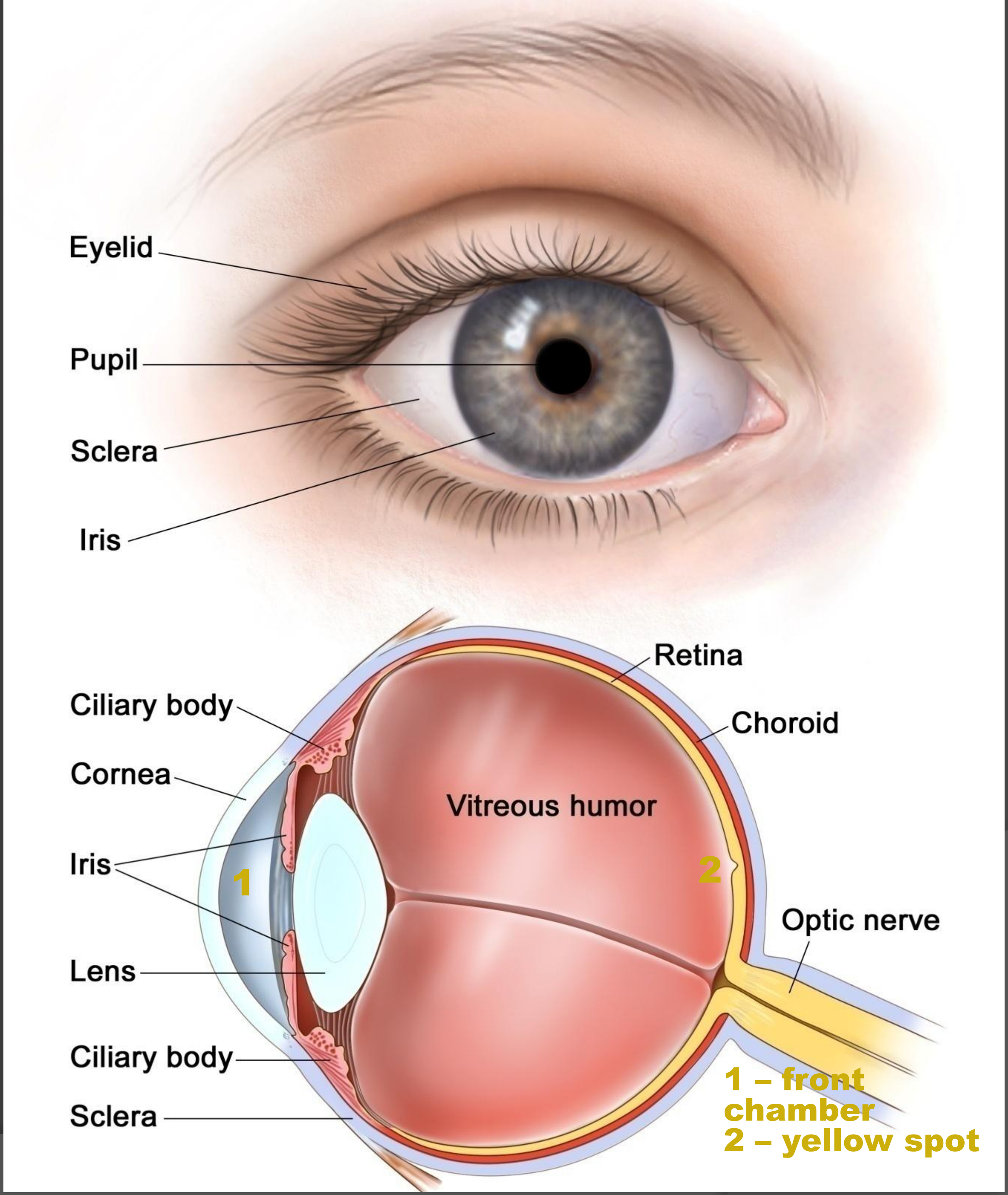
This equation is the base of Polarimetry– the method of solution examination. Thanks to this method the concentration of substances in solution can be defined. Polarimetry is also used in molecular biophysics for molecular structure transformation research. One of the most important examples of polarized light using is polarimetry microscope. Some tissues (i.e. muscle, bone and nerve tissues) are optically active and only they can be seen in polarization microscope during examination. During examination on polarization microscope only objects which turn plate of polarization can be seen.



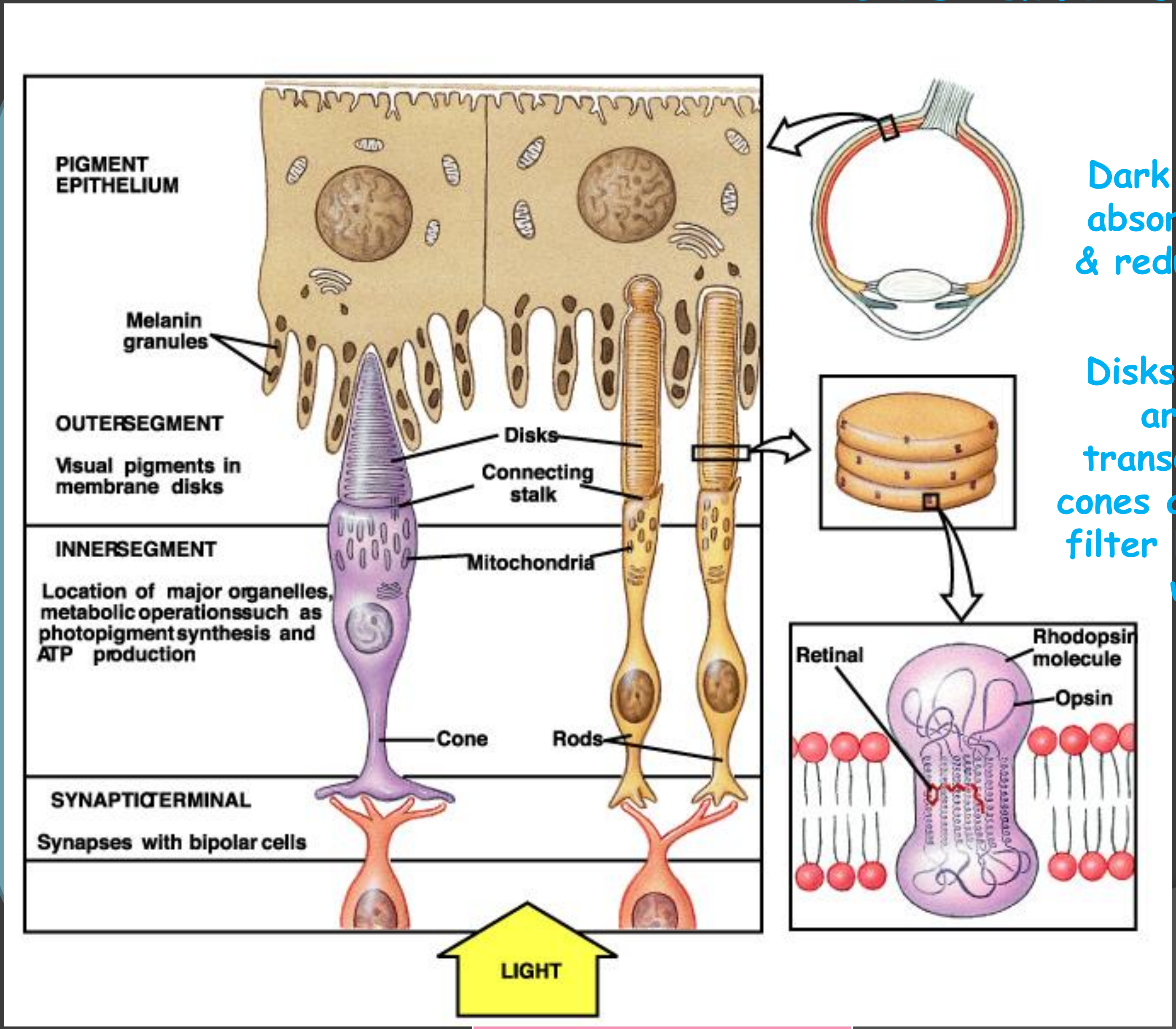
EYE STRUCTURE

An eye has almost round form. Diameter of an eye is about 2,5 cm. It is covered with white protecting cover - **sclera**. The front clear part of sclera is called **cornea**. After the cornea on some distance goes **iris, colored with pigment.** The aperture in iris is called **pupil**. Area between cornea & iris is called **front chamber** – it is filled with liquid. Behind the pupil the **crystalline lens is situated**. Crystalline lens – is an elastic lens-like body. The rest part of the is an elastic lens-like body. The rest part of the eye is filled with **vitreous humor**. Back part of an eye – the eyeground. The eyeground is covered with **retina,** which is a complex branching of visual nerve with nerve endings – **rods & cones,** which are lightsensitive elements of an eye.





Rods and cones..



Dark pigment layer absorbs stray light & reduces reflection

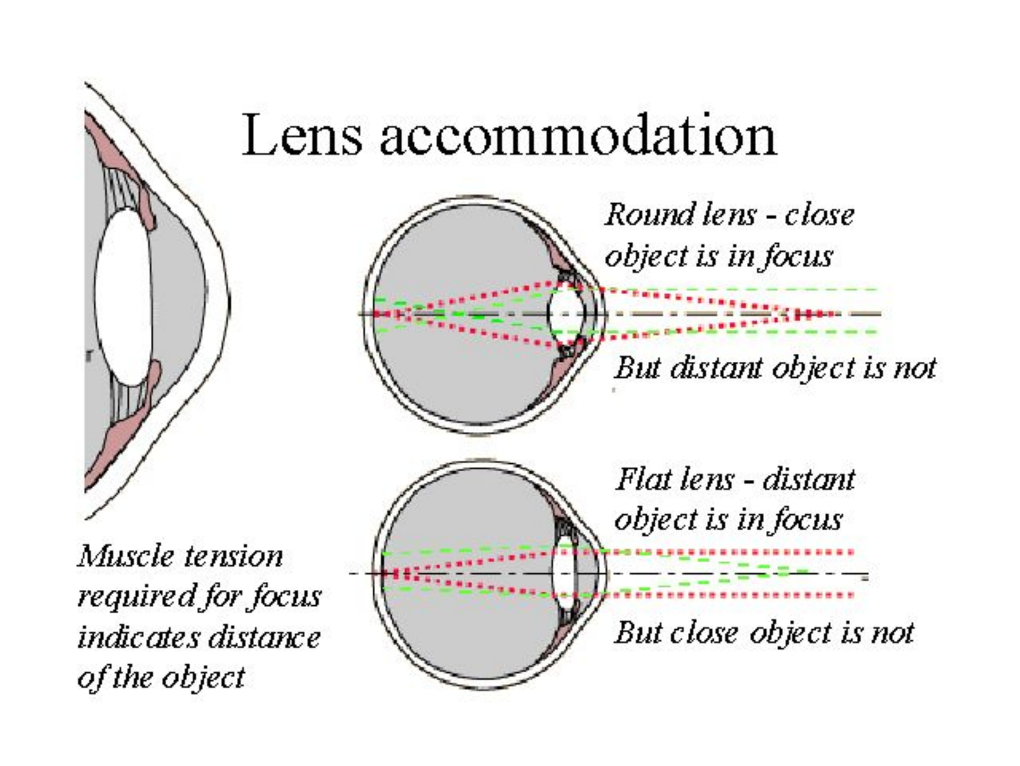
Disks in rods & cones are the site of transduction. Disks in cones are pigmented and filter light at different wavelengths

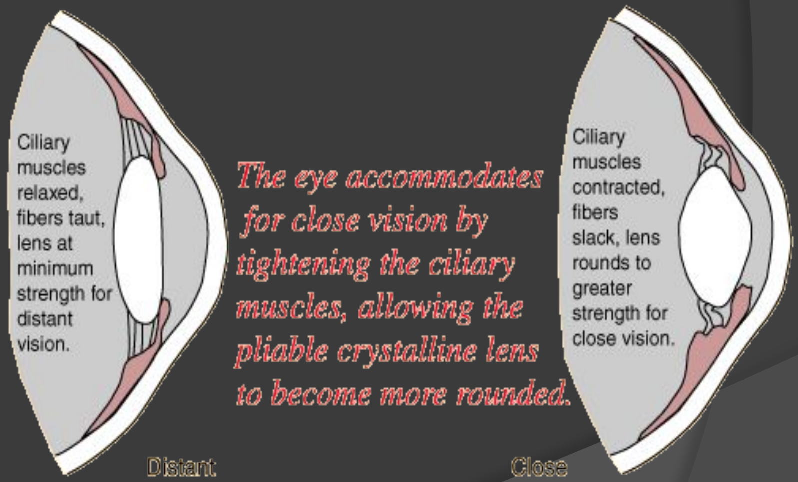
Transduction process mediated by pigments in the disks ..example is rod

...are selective light transducers

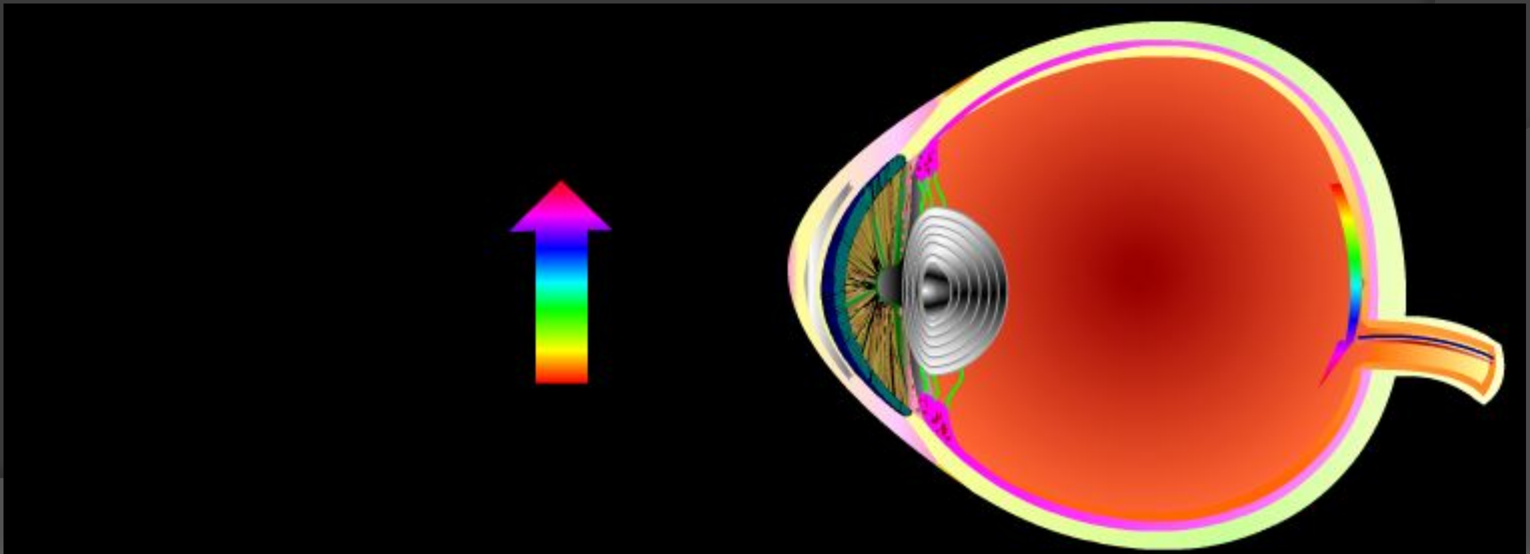
Eye accommodation

The cornea, clear liquid of front chamber, crystalline lens & vitreous humor are the optic system of an eye. The optic centre of this system is situated on a distance of about 5mm from the cornea. When the eye muscle is relaxed the optic power of an eye is equal to 59dptr, when the muscle is in maximal contraction – 70dptr. Main peculiarity of an eye as the optical system is it ability to change reflectory its optical power. This depends on what position the object the eye is focusing on is situated. Such adaptation of eye optical system to see objects on diferent distances is called **accommodation**. Accommodation goes by the mean of crystalline lens curvature change by ciliary muscles.





ACOMMODATION MECHANISM

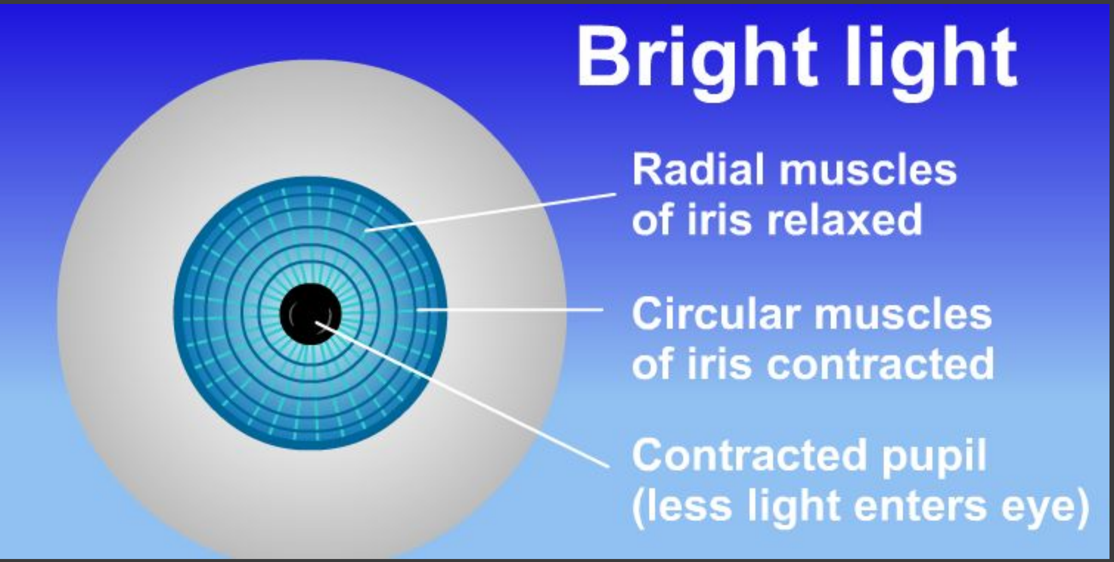


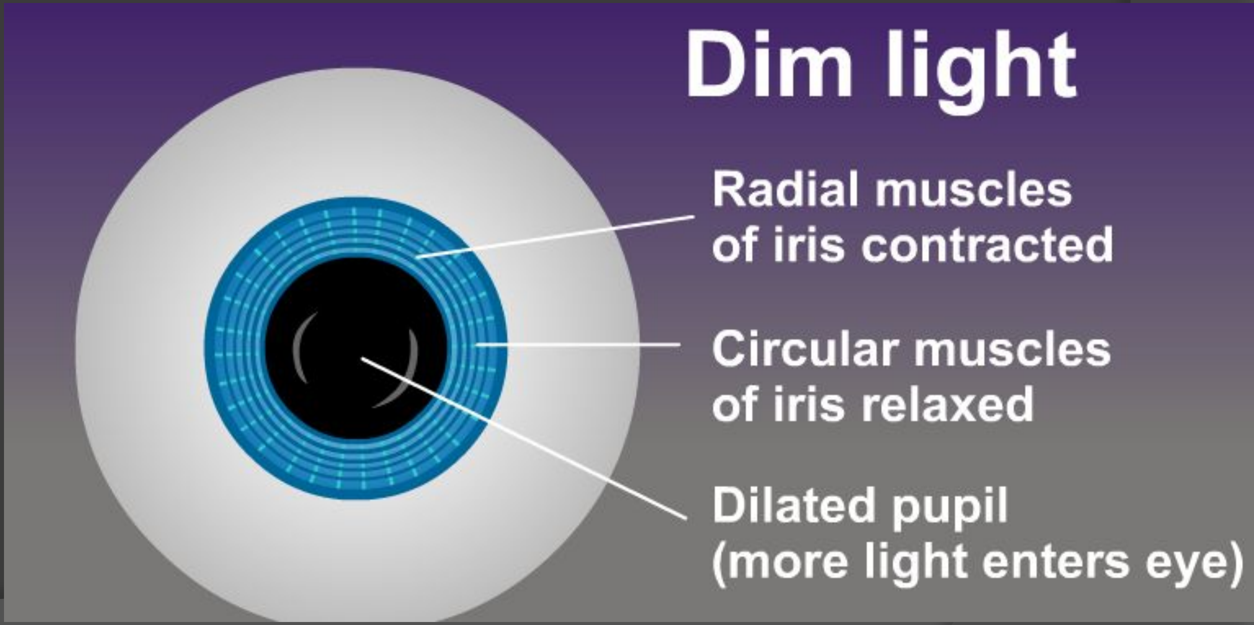
EYE ADAPTATION TO LIGHT & DARKNESS

Eye adaptation – is an eye adjustment to the lighting conditions. When an eye first was in a bright lighted conditions then it was placed in the dark, such adaptation is called **dark adaptation.** If an eye was in the dark then it was put in the bright lighting conditions such adaptation is called **light adaptation.**

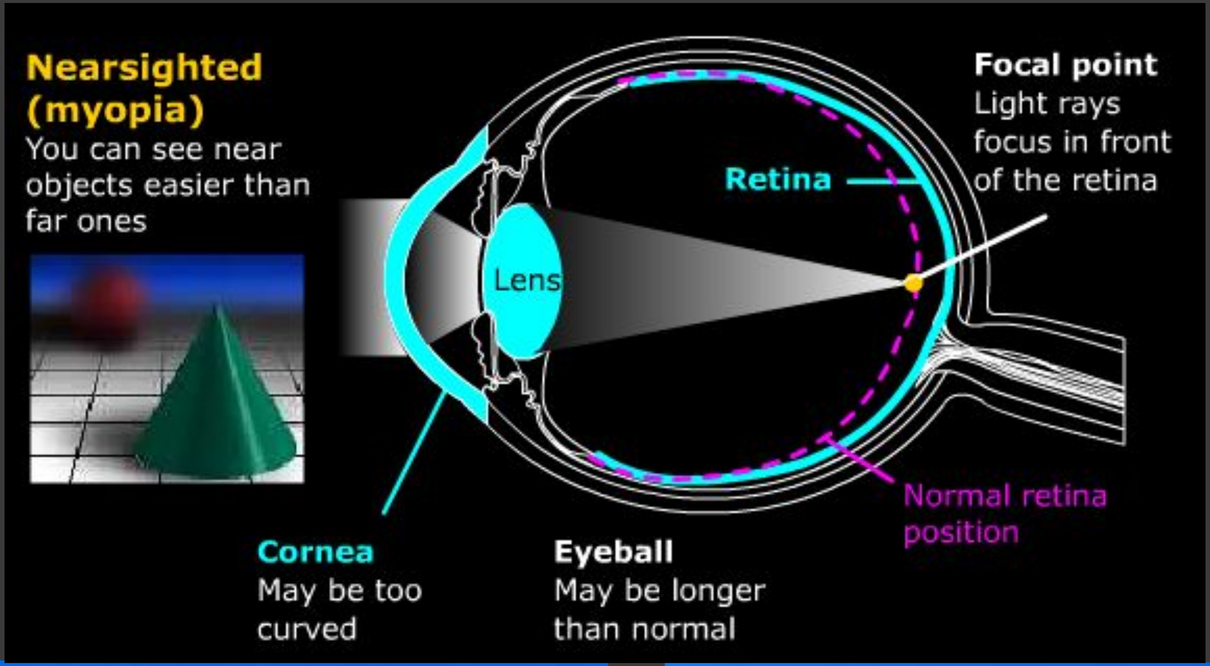
During dark adaptation the sensitivity of an eye increases first very fast then more slowly. This process lasts several hours, but in the end of the first hour the sensitivity of an eye increases in many times. During light adaptation the sensitivity of an eye in the light increases more fast. Light adaptation takes 1-3 minutes in the average brightness of light.

EYE ADAPTATION TO LIGHT & DARKNESS

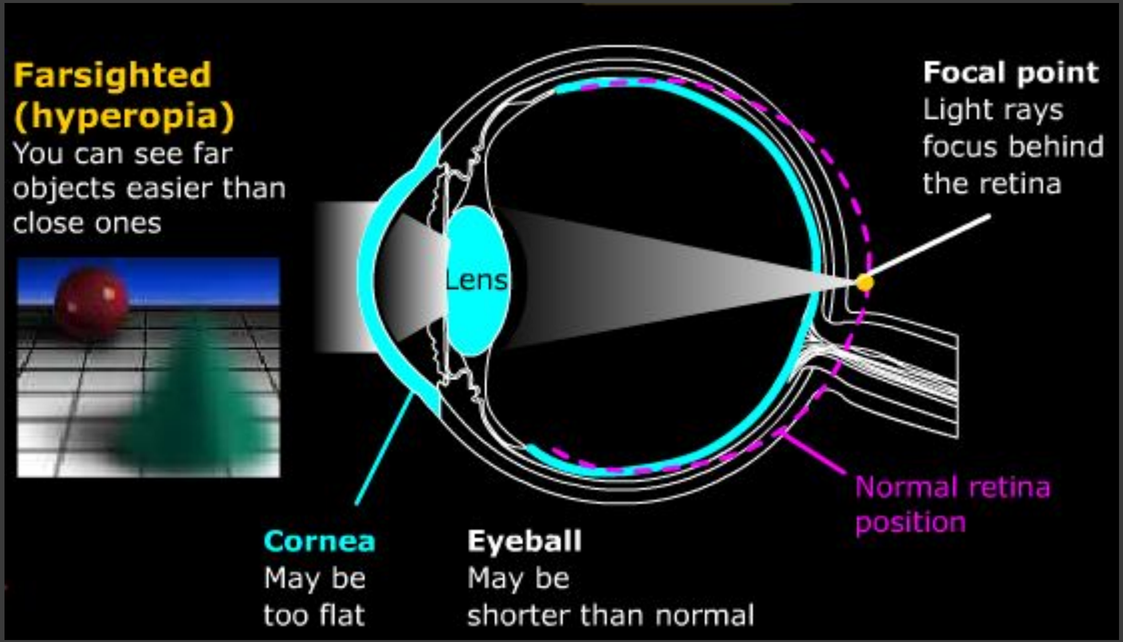




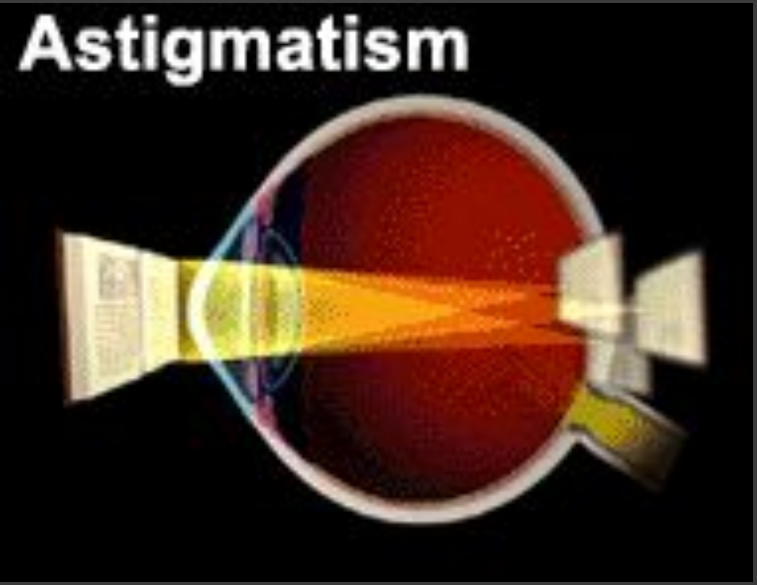
Myopia (nearsightedness)

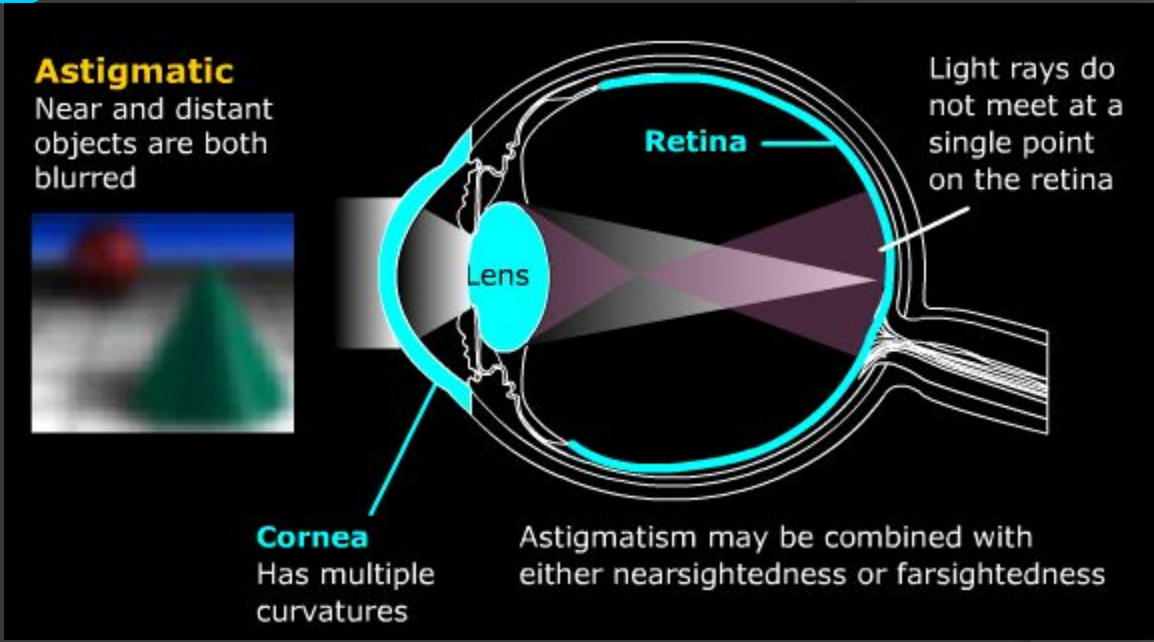


Hyperopia (farsightedness)



Astigmatism





LASER CORRECTION