Optical Physics

By

Prepared by

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Lecture 3

Lensing System Apertures

The aperture of a lens system is understood to be the relationship between the system focal length and the free diameter of the system. This is especially true of systems whose object or image back focus is infinite. This is usually true of photographic lenses where the object is at infinity and the image side back focus is very short.

The aperture number is given by:

$$F = \frac{f}{d} = \frac{1}{2n\,\sin(u)} \qquad 22$$

The included angle between the outermost ray and the optical axis is related to the aperture of a lens. One can easily see from Equation that d = 2 f n sin (u) (n.. index of refraction).

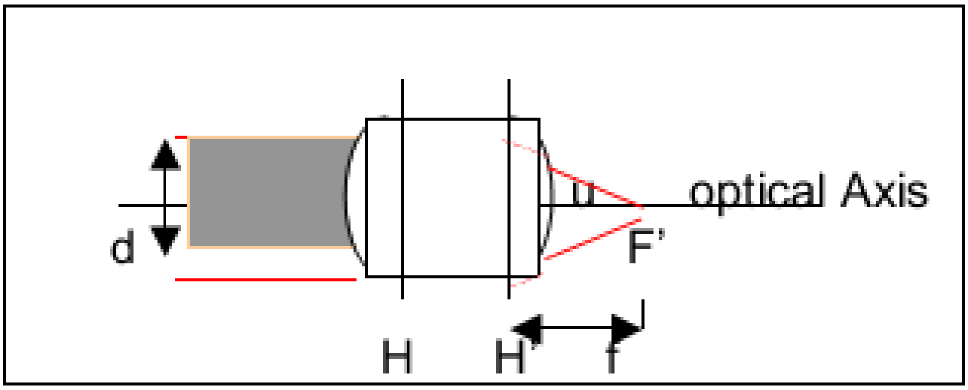


Figure: Lens aperture with focal length f and effective free diameter d. The image side, including angle sin (u), is defined by d/2f .

According to Equation (22), systems with large aperture have small aperture numbers. The aperture numbers of most lenses are assigned a number according to the diaphragm range. This range is defined such that a step in aperture number reflects a factor of 2 change in the light flux. The diaphragm range is as follows:

Aperture Number	F :	1	1.4	2	2.8	4	5.6	8	11	16
Light flux	Φ :	1	1/2	1/4	1/8	1/16	1/32	1/64	1/128	1/256

The relationship between relative light flux and aperture number is:

$\varphi \; U \frac{1}{F2}$ 23

Optical professionals sometimes refer to the **numerical aperture** of a lens system. This is defined as:

A= n sin(u) 24

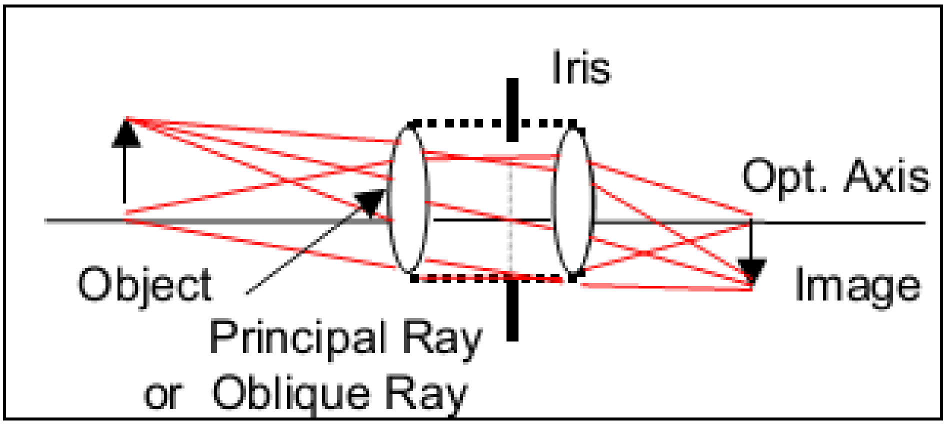
where the index of refraction is that of the medium where u appears. From Equation (22) the relationship between numerical aperture and aperture number can be readily seen. where the index of refraction is that of the medium where u appears. From Equation (22) the relationship between numerical aperture and aperture number can be readily seen.

$A=\frac{1}{2F}$ 25

Irises and Pupils

Optical systems are often designed with a fixed or variable iris. For single lens systems, the lens diameter can act as the iris at the principal plane. Irises, also called aperture stops, are precise mechanical apertures, which restrict light rays transmitted through a lens. This restricting is obviously related to the aperture number. The free diameter in Equation (22) can be replaced with the aperture diameter. The iris defines the amount of light flux transmitted by an optical system

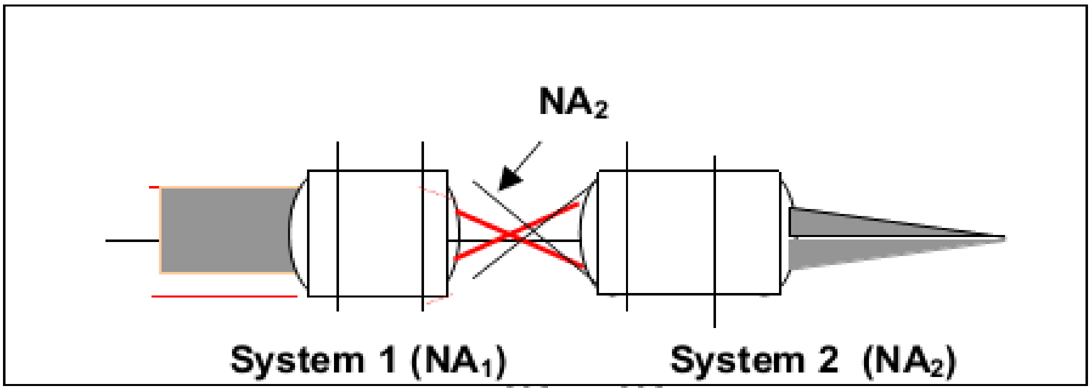
Figure schematically shows the rays transmitted through an optical system with an iris. Typically, the middle ray of a ray bundle (principle ray) intersects the optical axis at the iris plane. The corresponding peripheral ray is restricted by the iris.



Optical system with iris. The location of the principal ray is determined by the intersection of the iris plane and the optical axis.

Numerical Aperture Interface Requirements

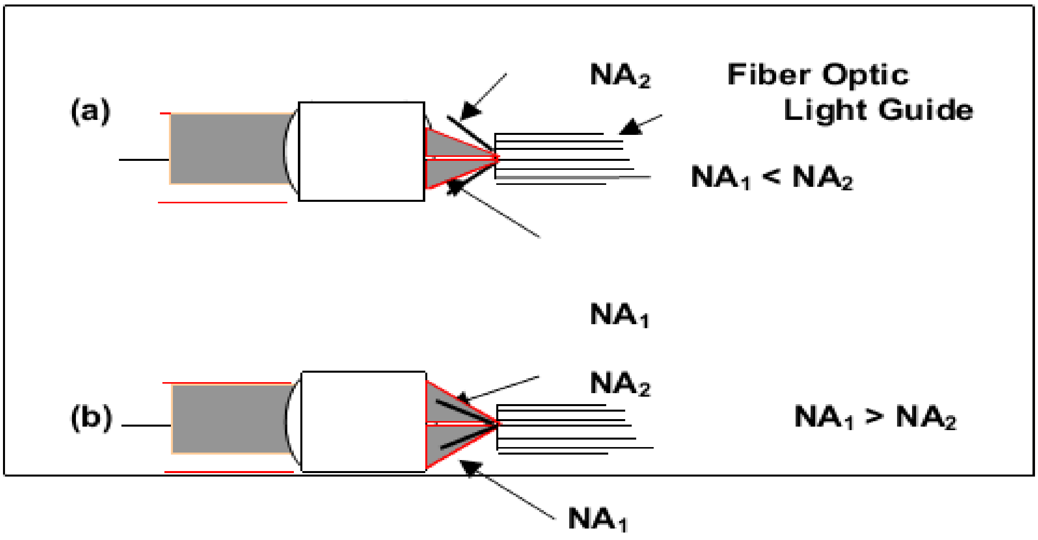
Should several optical systems be assembled in series, each individual apertures of each system must be paid attention to for optimal energy transmission. As a basic theoretical requirement, two optical systems must have matched numerical apertures at their point of coupling. $\mathbf{NA_i \leq NA_{i+1}}$



$NA_1 < NA_2$

Only if NA_2 is larger than or equal to NA_1, is it possible to couple the total energy flux through the entire system.

The same requirements hold for coupling light in and out of fiber optic light guides Several things can jeopardize light transport through fibers. If the coupling light has a smaller aperture than the fiber (Figure a), one would want to maintain the coupled luminous flux over the whole length of the fiber. The light transmission will remain more constant for applications where the fiber moves (varying bend radius) than with an impinging beam of larger aperture than that of the fiber (Figure b). An under-filled numerical aperture is therefore desired for measurement applications.



Optical lenses for coupling to glass fibers a) $NA_1 < NA_2$ and b) $NA_1 > NA_2$

Dispersion

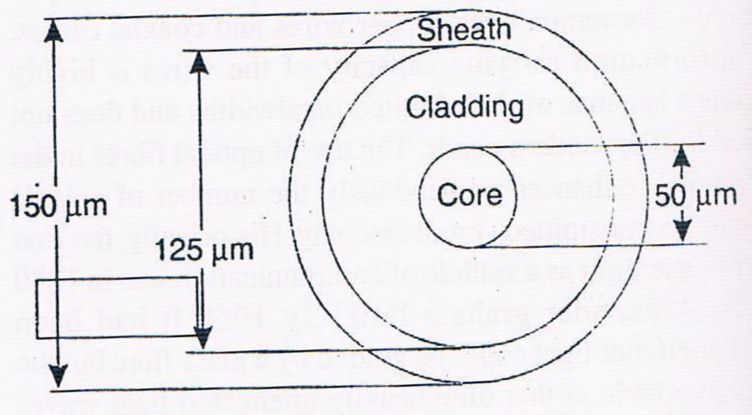
- The refractive index is a function of wavelength ,generaly it decreases as the wavelength increases
- Light passing through a material medium will be separated according to wavelength , this is known as chromatic dispersion
- When a ray of white light falls on glass prism it splits up into different colours , this display of colours is known as spectrum of the source of light
- This separation of composite beam into its constituent colours is called dispersion
- When colours travel through arefracting medium , their velocities are different , hence the refractive index of the material is different
- Out of the seven colours formed by the white light , violet colour suffers greater diviation than red

Fiber Optics

- Graham Bell(1960)established that light could be guided by a glass fiber and the invention of sold state lasers in 1970 made optical communications practicable
- An optical fiber is transparent conduit as thin as human hair , made of glass or clear plastic, designed to guide light waves along its length
- An optical fiber works on principle of total internal reflection

A practical optical fibre has in general three coaxial regions.

The inner most region is the light guided region known as the Core , it is surrounded by a coaxial middle region known as **Cladding** . The outermost region is called **Sheath.**



Cross-sectional view of an optical fibre.

- The refractive index of cladding always lower than that of the core .the purpose of the cladding is to make the light to be confined to the core . the sheath protects the cladding and the core from abrasions, contamination and the harmful influence of moisture. In addition, it increases the mechanical strength of the fibers.

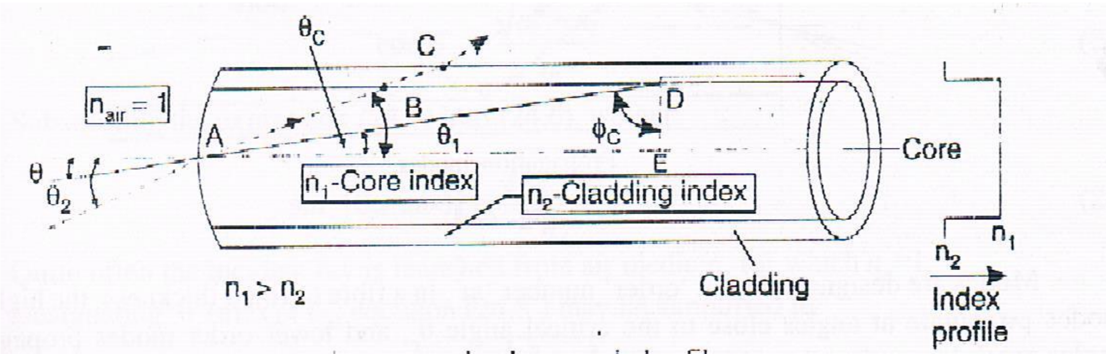
- The end at which light enters the fibre is called the **Launching end**.

We consider two rays entering the fibre at two deffernt angles of incidence as :

- 1-Ray shown by the broken solid line is incident at angle **θ2** with respect to the axis of the fiber , which undergoes refraction at point ***A*** , the ray refract into the fibre at an angle **θ1 (θ1<θ2)** .

- The ray reaches the core-cladding interface at point ***B*** , refraction takes place again and the ray travels in the cladding , at point ***C*** the ray refracts once again and emerges out of the fobre into the air , that the ray does not propagate through the fibre

- 2-Ray shown by the solid line is incident at an angle **θ** undergoes refraction at point ***A*** and propagates at an angle **θc** in the fibre , at point ***D*** the ray undergoes total internal reflection since **n1>n2**



Light propagation in a step-index fibre.

- Let us assume that the angle of incident at the core cladding interface is the critical angle **θc** , where **θc** is given by

$\theta_c = \sin^{-1}(n2/n1)$

- A ray incident with an angle larger than **θc** will be confined to the fibre and propagate in the fibre , a ray incident at the critical angle is called a critical ray , **θc** is called the critical propagation angle where **θc** is

θc $=\cos^{-1}(n2/n1)$

- When light is launched into optical fibre , waves having directions less than the critical angle **θc** will be trapped within the fibre due to the total internal reflection.

- Only certain ray directions are allowed to propagate the allowed directions corresponds to the modes of the fibre

In simple terms ***modes*** can be visualized as: (the Possible number of paths of light)

- The paths are all zigzag path excepting the axial direction.

- As a zigzag ray gets repeatedly reflected at the walls of the fibre, phase shift occurs , the wave travelling along certain zigzag will be in phase and intensified while the waves coursing along certain other paths will be out of phase and diminish due to destructive interference

- (The light ray paths along which the waves are in phase inside the fibre are known as **modes**)

- The number of modes that a fibre will support depends on the ratio ***(d/λ)*** where ***d*** is the diameter of the core and ***λ*** is the wavelength of the wave being transmitted.

Optical fibre in general of two types

1-Single mode fibre (SMF)which has small core diameter and support only one mode of propagation

2-Multimode fibre; has a larger core diameter and supports a number of modes

Advantages

1-Cheaper;Opticalfibres are made from slica sio2 which is one of the most abundant material on the earth

2-Smaller in size , lighter in weight , flexible yet stronmaterial on the earth

3-Not hazardous

4-Immune to EMI and RFI

5-No cross talk

6-Wider bandwidth

7-Low loss per unit length

Optical fibre have different applications

- 1-Illumination and image transmission
- 2-Optical communications
- 3-Optical fibre sensors
- 4-Medical applications

- 5- Millitary applications
- Fibre optics is used in medical diagnostics , the fibre optic endoscope is used to inspect internal organs for diagnostic purposes , in ophthalmology , alaser beam is guided by optical fibres is used to reattach retina and to correct defective vision , in cardiology optical energy transmitted through an optical fibre is used to evaporate buit up plaque that is blocking an artery , in the treatment of cancer , the process involves injection of special chimicals that penetrate only in the cancerous cells , infrared energy is transmitted via the fibre illuminates the affected area and is absorbed by the special chemical in the cancerous cells , the heat generated destroys the cancerous cells

Telescope

Jan lippershey invented the first Telescope in 1608 ,Galileo designed in 1609 a telescope

The telescope that uses a lens as an objective is called a refracting telescope , many telescopes used a curved mirror as an objective which known as reflecting telescope

Refracting Astronomical Telescope

1-The simple astronomical telescope consists of two lenses , the objective is convex lens of long focal length and forms a real image of the distant object

2-The eyepiece is a convex lens of small focal length

3-The objective lens forms a real and reduced image AB of the object , the eyepiece enlarges this image and forms a magnified virtual image at infinity

4-The distance between the objective and eyepiece is the sum of their focal length (F+f)

5-Angular magnification M of the telescope

M=B/C=-F/f

The magnification is equal to the ratio of focal length of the objective and the eyepiece , the negative sign shows that the final image is inverted

Note ;To increase the magnification of the telescope the objective should be large focal length and the eyepiece should be of short focal length

Reflecting Telescope

1-In reflecting telescope the objective lens is replaced by a concave mirror and should have a large aperture if final details are required

2-Most of telescopes for research do not use an eyepiece and replaced by photographic film or an electronic detector

Newton telescope

1-The objective is a large concave spherical mirror made of metal alloy of copper and tin

2-The ray from the distant star are reflected from the concave spherical mirror A of large aperture and long focal length then they are reflected to one side at right angles to the axis by mean of a small plane mirror B , the final image is seen through the eyepiece

Coherent Sources

Two sources are said to be coherent if they emit light waves of the same frequency. nearly the same amplitude and are always in phase with each other. It means that the two sources must emit radiationioFttre same colour (wavelength).flnactuar practice it is not possibre to have two'independent sources which are coherent. But for experimental purposes, two virtual sources formed from a single source can act as coherent sources. Methods have been devised where (i) interference of light takes place between the waves from the real source and a virtual source (ii) interference of light takes place between waves from two sources formed due to a single source. In all such cases, the two sources will act, as if they are perfectly similar in all respects.

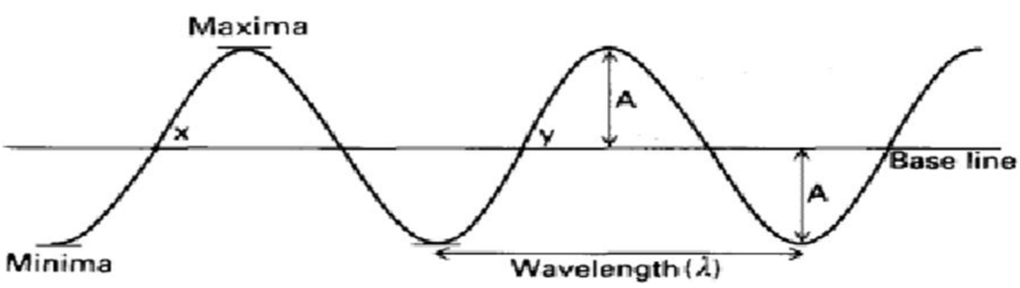
From the above examples we find that whenever the two needles vibrate with a constant phase difference, a stationary interference pattern is produced. The positions of the maxima and minima will, however, depend on the phase difference in the vibration of the two needles. Two sources which vibrate with a fixed phase difference between them are said to be coherent. We next assume that the two needles are sometimes vibrating in phase, sometimes vibrating out of phase, sometimes vibrating with aphase difference of $\pi/3$, etc., then the interference pattern will keep on changing. If the phase difference changes with such great rapidity that a stationary interference cannot be observed then the sources are said to be incoherent.

Propagation Characteristics of Light

Wave Theory of Light

Wave motion consists of a disturbance, or energy, passing through a medium. The medium itself does not move, but its constituent particles vibrate at right angles to the direction of travel of the wave

(Imagine a ribbon tied to a rope along which a wave is 'thrown'. The crest of the wave moves along the length of the rope, but the ribbon moves up and down at one point on the rope.)



m

The wavelength, λ, is defined as the distance between two symmetrical parts of the wave motion. One complete oscillation is called a cycle, and occupies one wavelength.

The amplitude ,**A**, is the maximum displacement of an imaginary particle on the wave from the base line. Any portion of a cycle is called a **phase**.

Wave motion: phase difference.

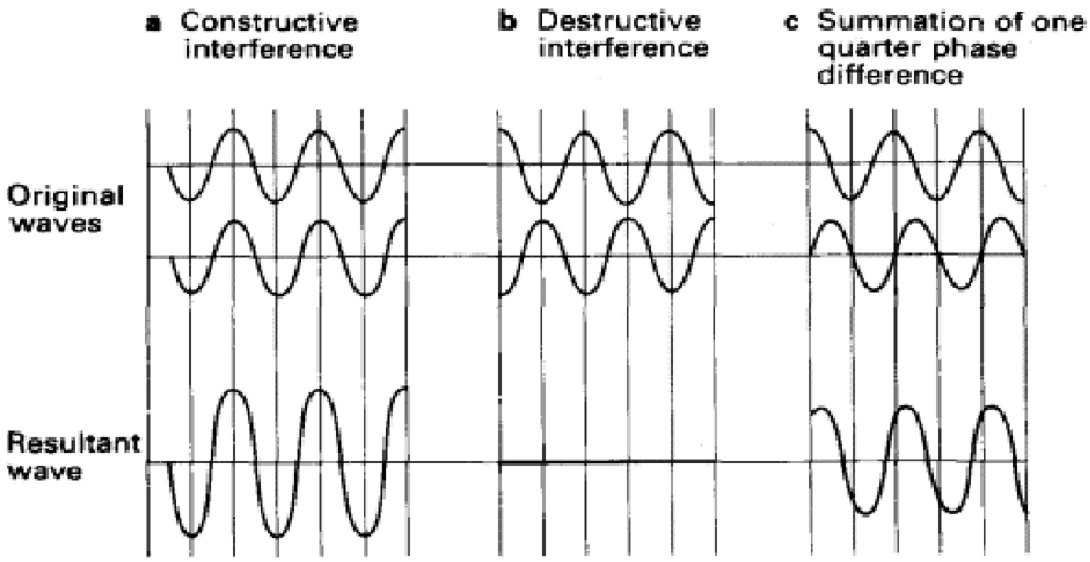
If two waves of equal wavelength (but not necessarily of equal amplitude) are travelling in the same direction but are 'out of step' with each other, the fraction of a cycle or wavelength by which one leads the other is known as the phase difference

Figure : shows two waves of equal wavelength which are out of phase by one-quarter of a wavelength (phase difference equals 90°, the complete cycle being 360°).

Light waves that are out of phase are called incoherent, while light composed of waves exactly in phase is termed coherent.

Interference

When two waves of light travel along the same path, the effect produced depends upon whether or not the waves are in phase with one another. If they are in phase, the resultant wave will be a summation of the two, and this is called **constructive** interference. If the two waves of equal amplitude are out of phase by half a cycle , they will cancel each other out: destructive interference. The final effect in each case is as if the waves were superimposed and added (in the algebraic sense) to each other. Phase differences of less than half a cycle thus result in a wave of intermediate amplitude and phase.



Interference of two waves.

If two or more waves meet at a point x, the contribution and position of the field components, E1 and E2, can be superimposed on each other. Superposition (+ Interference) does not take place if the field amplitudes are oriented perpendicular to each other.

Figure 2 shows the superposition of two sine waves. The respective amplitudes and phases differ from each other. Comparing the resultant field amplitude, E, with the individual components, E1 and E2,

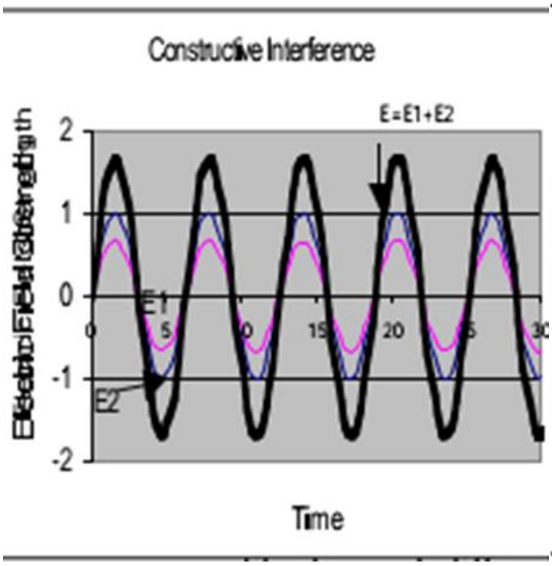


Figure 2a. Constructive interference

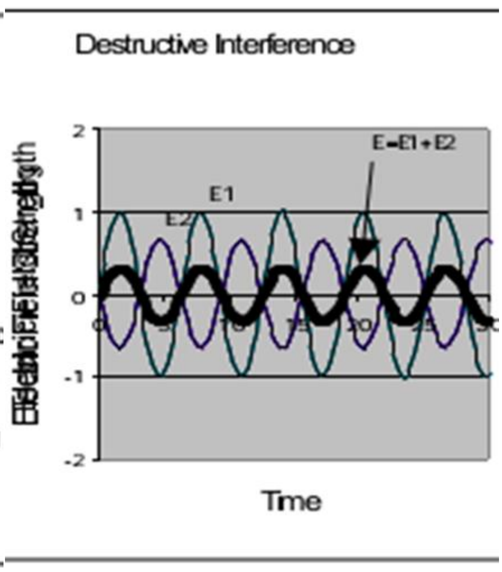


Figure 2b. Destructive interference

We observe in Figure 2a an increase in amplitude. This is constructive interference: the phase difference between E1 and E2 is zero or multiples of 2π. ($\Delta\phi = N \cdot 2\pi$, $N = 0, \pm1, \pm2, \dots$).

Destructive interference is shown in Figure 2b where there is a decrease in the resultant field amplitude. The phase difference between the two waves is half of one wavelength ($\Delta\phi=(2N+1)\bullet\pi$). If the constituent amplitudes would have the same amplitude and differ in phase by half a wavelength ($\Delta\phi=(2N+1) \bullet \pi$), the resultant amplitude would be zero.

Superposition of a constructive nature leads to an increase in light intensity (high intensity), whereas destructive interference leads to a decrease in intensity or even zero intensity. This effect can be seen in the case of two beams propagating in different directions, which simultaneously impinge on a screen at the same coordinate. One can observe the periodic pattern of light and dark stripes (double slit interference). This pattern will appear everywhere the two beams superimpose

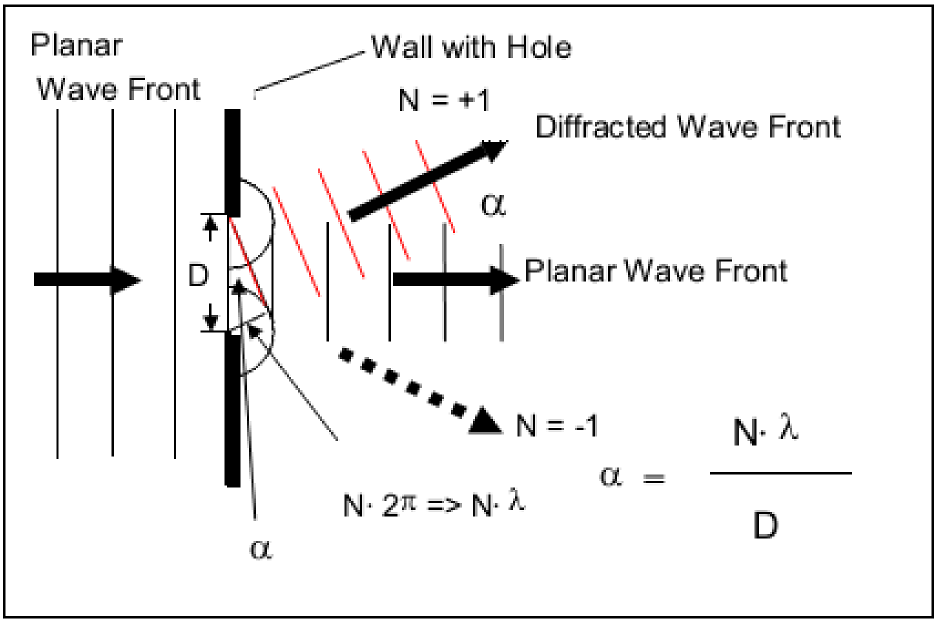
Diffraction

A plane wave impinging on a geometric structure with an opening (wall with a round opening =aperture)

will emit elementary point source waves from each opening. The projected pattern of these waves oscillates between bright and dark areas, which are not sharply separated. This oscillatory transition is the result of interference of these elementary waves. The phase difference between neighboring maxima or minima is always 2π.

Diffraction therefore means that wave fronts traveling in a straight line, which are then restricted by some opening, divert off their straight path into light/dark patterns. This assumes, of course, that the waves don’t experience other phenomena such as reflection or refraction. In Figure, one can see deviation of the diffracted light from the original angle impinging the wall. The optical path difference, ($N\bullet\lambda$) , between rays emanating from the edges of the opening and the size of the geometrical opening, D, will determine the Nth order diffraction angle.

Each N = ±1, ±2, defines a direction α, or for small angles, $N\alpha$, of an intensity maximum. The intensity pattern at the edges due to contributions from non-diffracted rays leads to a reduced sharpness of bright/dark transition. We refer to this as **reduced contrast**.

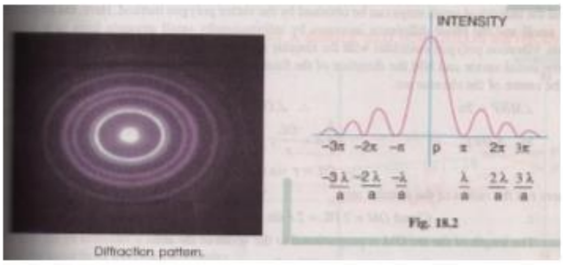


Wave front diffraction through aperture D

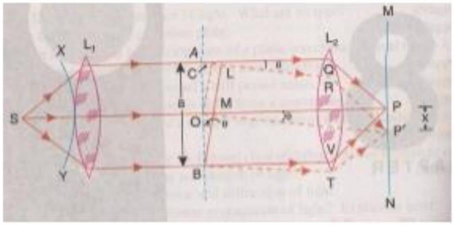
The direction of rays and therefore of diffracted rays is always perpendicular to their wave surface.

There are two types of diffractions: Franhofer diffraction and Fresnel diffraction.

Franhofer diffraction	Fresnel diffraction
1. The source and the screen are at infinite distance from diffraction element	1. Either the source or the screen or both are not at infinite distance from the diff. element.
2. Plane wave	2. Spherical wave
3. Lenses are required	3. Lenses not required



Franhofer diffraction by a single slit:



At minima

$\sin\theta = \frac{AL}{AB} = \frac{AL}{a}$

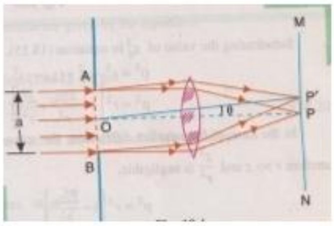
$AL = a \sin\theta$ *where AL is path deference and it equal a multiple of the wave length $= p\lambda$,*

$n = 1, 2, 3, 4, \ldots\ldots$

$\therefore a \sin\theta = n\lambda$ ……………minima

At 1^{st} minima (a=1)

$\sin\theta = \tan\theta = \theta = \frac{x}{f}$ *because θ is very small, x:reprecent half width of the pattern, if we want the width (d×2)*



$a \sin\theta = n\lambda$

$a\frac{x}{f} = n\lambda$

$\therefore x = \frac{fn\lambda}{a} = \frac{f\lambda}{a}$

Example 1: parallel beam of light of wave length 6563Å is incident normally on aslit 0.3850 mm wide. A lens with a focal length of 50 cm is located just behind the slit bringing the diffraction pattern to focus on a white screen. Find the distance from the the principal maximum to (a) the first minimum (b) the fifth minimum?

Sol:

λ= 6563 Å x_1=?

a= 0.385 mm x_5=?

f= 50 cm

a sinѳ = nλ……. Min   n=1, 2, 3,….

At first minimum (n=1)

$x_1=\frac{nf\lambda}{a}=\frac{1\times50\times10\times6563\times10^{-7}}{0.385}=0.352\ mm$

$x_5=\frac{nf\lambda}{a}=\frac{1\times50\times10\times6563\times10^{-7}}{0.385}=4.261\ mm \quad or\ x_5=5x_1$

H.w: in franhofer diffraction pattern due to a narrow slit a screen is placed 2 m away from the lens to obtain the pattern. If the slit width is 0.2 mm on either sides of the central maxima, find the wavelength of light?

H.W: plane waves of blue light, λ= 4340Å, fall on a single slit, then pass through a lens with a focal length of 85 cm. if the central band of the diffraction pattern on the screen has a width of 2.45 mm. find the width of the single slit?

Diffraction by a double slit

d=(a+b)

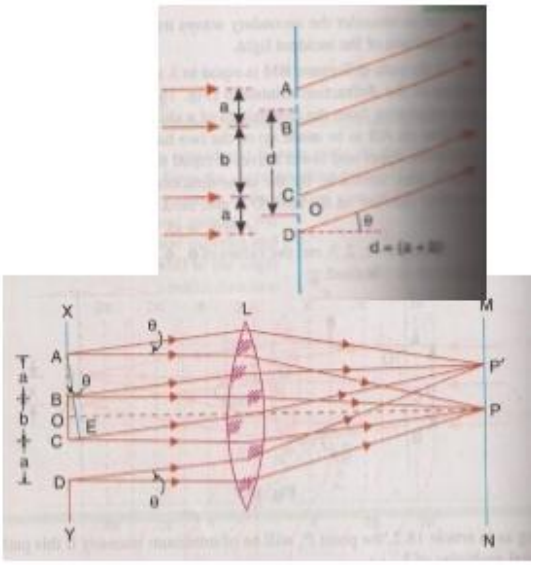
d: distance between two slits centers

b: distance between slits

a: slit width

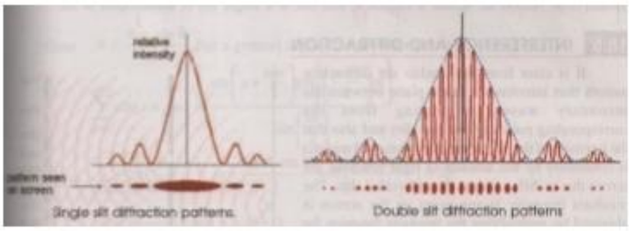
maxima: (a+b) sinѳ=nλ

minima: a sinѳ=pλ   p=1, 2, 3,….



Missing orders: $\frac{n}{p}=\frac{d}{a}$

The patterns



Ex.2: calculate the missing orders for a double slit Franhofer diffraction pattern, if the slit widths are 016 mm and they are 0.8mm a part?

Here a= 0.16 mm, b= 0.8 mm
Equation for interference maxima= (a+b) sinɵ=nλ
Equation for interference minima= a sinɵ=pλ

Missing orders: $\frac{(a+b)}{a} = \frac{n}{p}$

$\therefore \quad \frac{n}{p} = \frac{(0.16+0.8)}{0.16} = 6$

$\therefore \quad n=6p$

Thus missing orders are: 6, 12, 18,……

Vision

Elements of the Eye

Human eye is an essential part of all optical instruments, it is nearly spherical in shape and about 2.5 cm in diameter, and it contains:

1. Sclera: it is a tough outer skin, which protects the eye and gives the necessary stiffness.

2. Cornea: is a transparent spherical bulge at the front of the eye which made of tough material.

3. Iris: is a diaphragm with a circular hole in the middle called the pupil, the iris is responsible of color the person’s eye.

4. Pupil: is a black circular hole in the middle of the iris which contracts when the light that received by the eye is high and painful to the eye.

5. Crystalline lens: which is a biconvex lens made of gelatinous transparent substance, (1.437 refractive index), hard at the center and softer at the outer portions which attach to the ciliary muscle.

6. Ciliary muscles: it is at the edges of the lens which enable the eye clearly objects at different distances by pulling and pushing lens.

7. Aqueous humor: it is a weak salt solution behind the lens.

8. Vitreous humor: is a gelatinous substance which fills the eye between the lens and the retina. Both vitreous and aqueous humor have a refractive index of about 1.336.

9. Retina: is a sensitive screen at the back of the eye-ball, the retina has a shape of hemisphere and contains light receptors called rods or conse. The human eye has a total of 125 million rods and 6.5 million cones; they sense the image and transmit via the optic nerve.

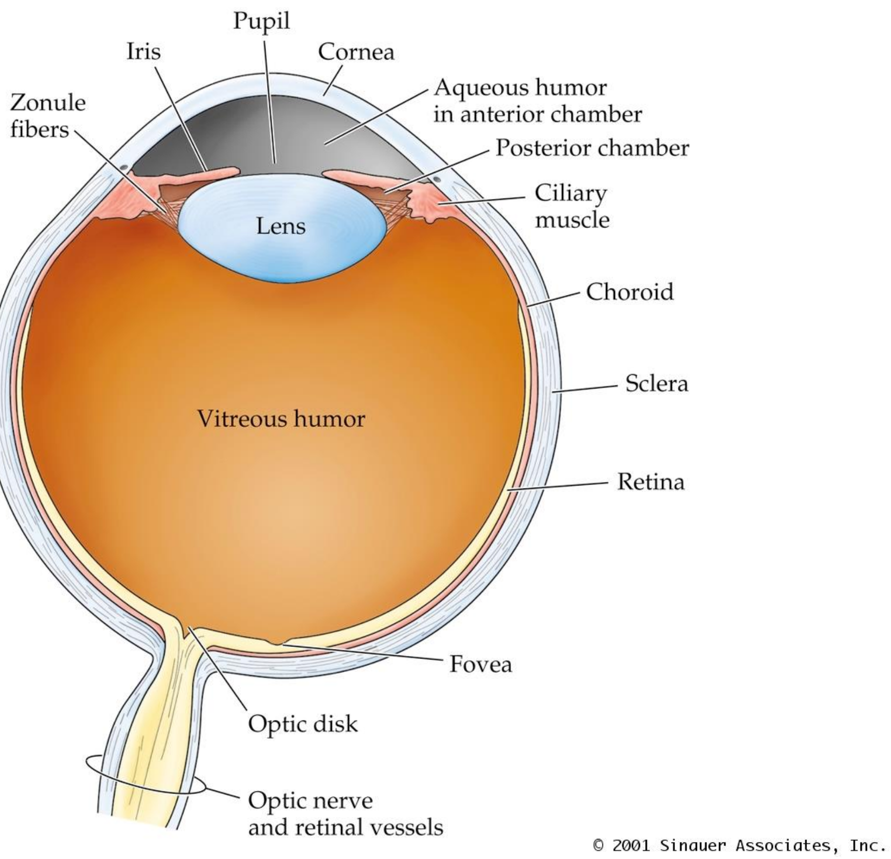
10. Optic nerve: it carries the sensation produced by the image to the brain.

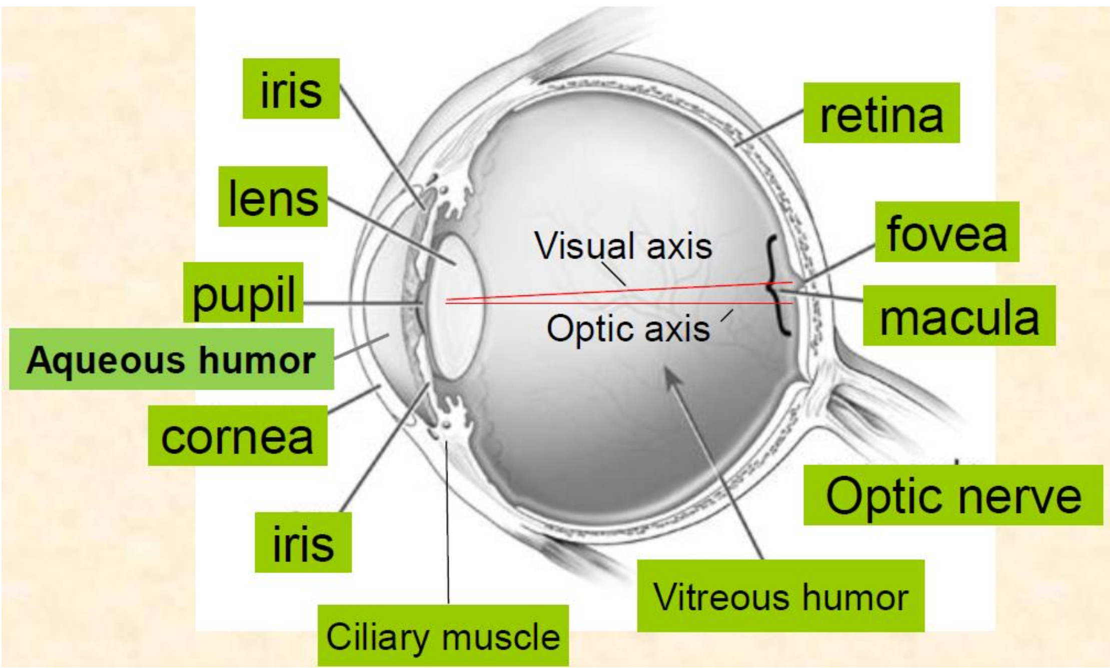
11. Blind spot (papilla): is the portion of retina where optic nerve enters the eye, in this portion there are no rods or cones, therefore it’s called blind spot.

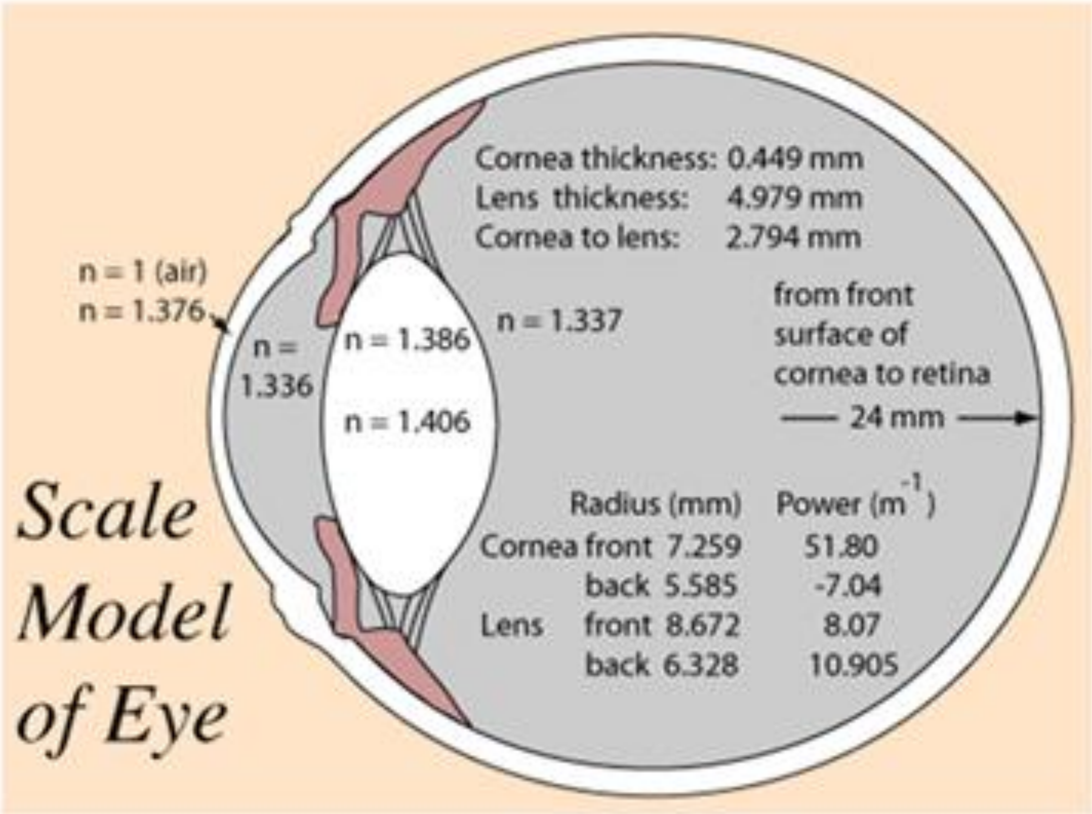
12. Macula: is the region with the highest density of color receptors. An image formed on the fovea, the central section of the macula, is characterized by best vision. Thus, macula and fovea are the most important segments of the retina.

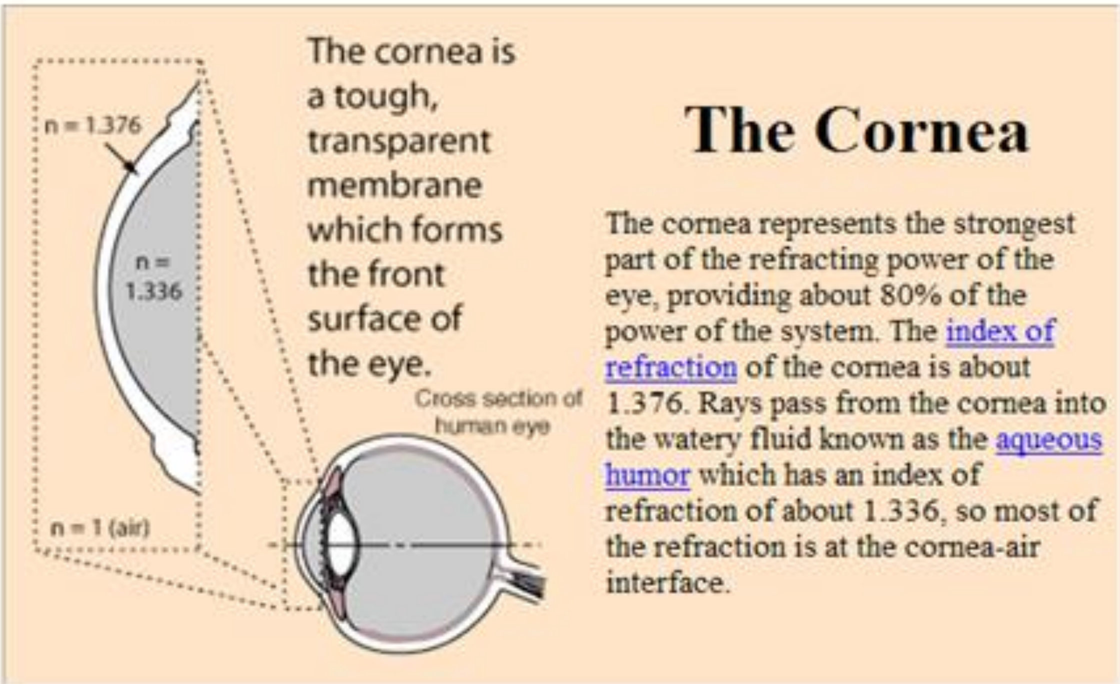
Refraction at the cornea and the lens produces a real and inverted image of the object on the retina. The optic nerve sends a signal to the brain, which makes correction necessary for us to see objects in their natural positions.

Anatomy of the Human Eye

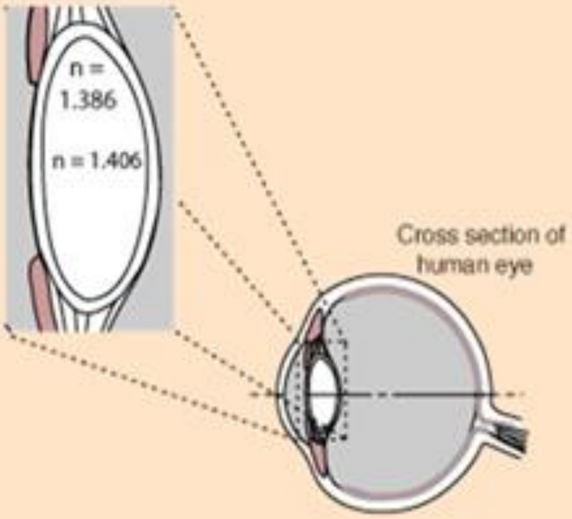





Cornea thickness: 0.449 mm
Lens thickness: 4.979 mm
Cornea to lens: 2.794 mm
n = 1 (air)
n = 1.376
n = 1.336
n = 1.386
n = 1.406
n = 1.337
from front surface of cornea to retina
24 mm
Scale Model of Eye
Radius (mm) Power (m^-1)
Cornea front 7.259 51.80
back 5.585 -7.04
Lens front 8.672 8.07
back 6.328 10.905


n = 1.376
n = 1.336
n = 1 (air)
The cornea is a tough, transparent membrane which forms the front surface of the eye.
Cross section of human eye
The Cornea
The cornea represents the strongest part of the refracting power of the eye, providing about 80% of the power of the system. The index of refraction of the cornea is about 1.376. Rays pass from the cornea into the watery fluid known as the aqueous humor which has an index of refraction of about 1.336, so most of the refraction is at the cornea-air interface.

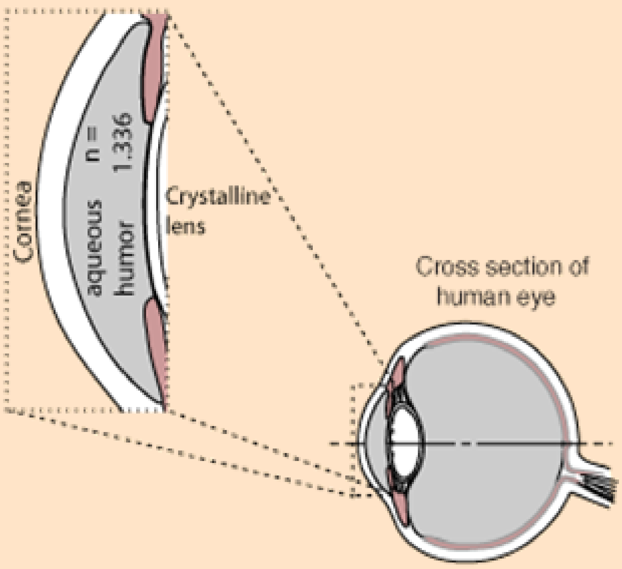
Crystalline Lens



About 9mm in diameter and 4 mm thick, the crystalline lens provides perhaps 20% of the refracting power of the eye. Hecht likens it to a tiny transparent onion with some 22,000 fine layers. The index ranges from about 1.406 at the center to about 1.386 in outer layers, making it a gradient index lens. It is pliable, and changes shape to accomplish accommodation for close focusing.

The term cataract is used to describe the condition of clouding or darkening of this lens.

Aqueous Humor



The anterior chamber of the eye is filled with the watery "aqueous humor" which has an index of refraction of about 1.336. It is positioned immediately behind the cornea. The larger chamber of the eye is filled with the gelatinous "vitreous humor", which has an index of refraction of about 1.337 .

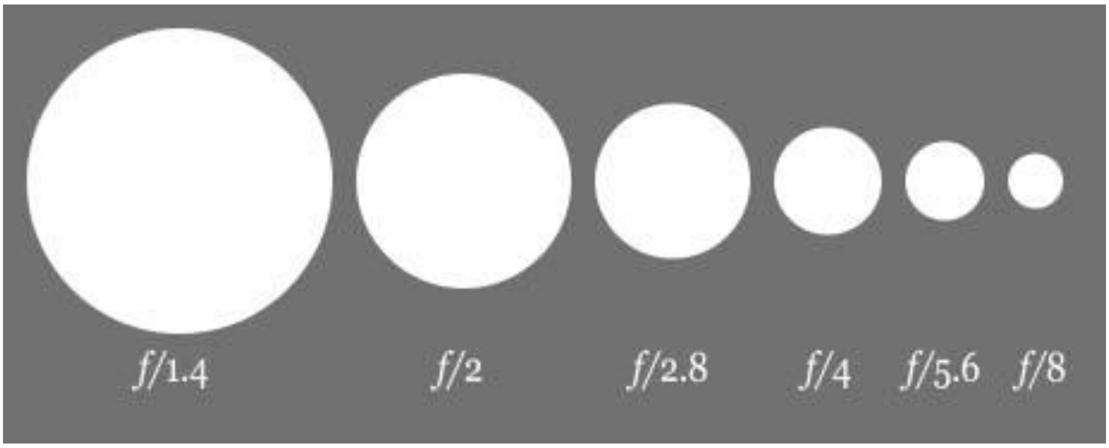
The IRIS

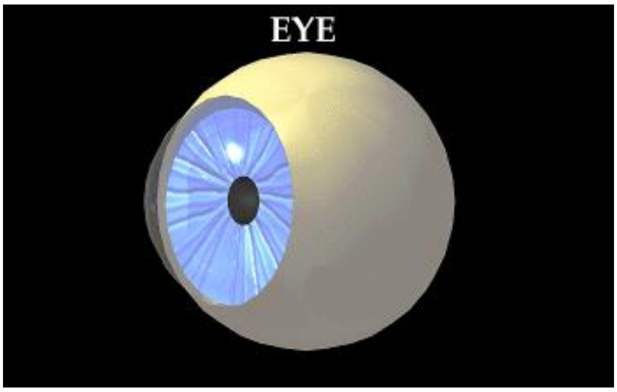
• The iris is the part of the eye that gives it color. Eye colors vary from light blue to dark brown, depending upon the amount of pigment, called melanin, that is contained in the iris.

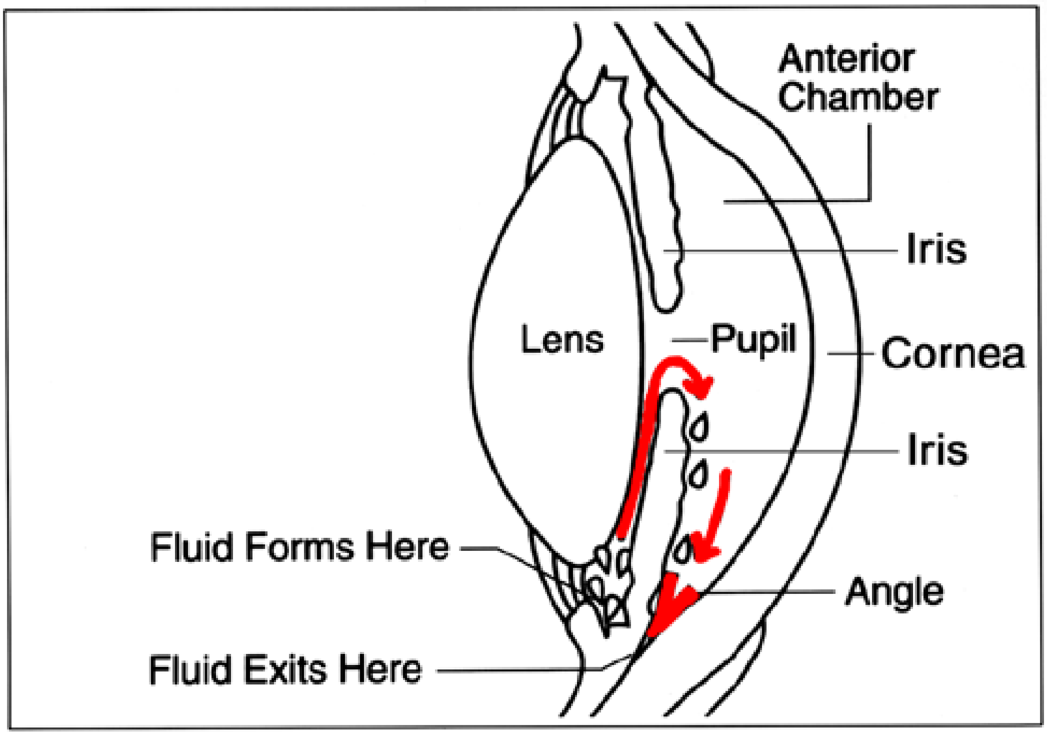
• The iris is like the aperture (diaphragm) on an automatic camera, opening and closing automatically in response to ambient light. It can vary the exposure on your eye (retina) by a factor of ≈ 20. The iris can respond in 1/5 of a second.

• When your iris is fully open, your eye has an f-number between f/2 and f/3 (this compares with f/0.9 for a nocturnal cat!)

• The main function of the iris is to control the depth of field, not the intensity of the light on your eye (retina).







Accommodation

Accommodation: Is the ability of the eye to see clearly objects at different distances with the help of ciliary muscles, the lens-to-retina distance does not change but the focal length is adjusted by varying the radii of curvature of the crystalline lens. This ability is limited with near and far points.

Interaction of light with matter

Radiation incident on a material is viewed as a stream of photons , where each photon carries an energy E=hν , we assume that the two energy levels of the atoms in the material difference $(E_2-E_1)=h\nu$

When photon travel through the medium , three different processes are likely to occurs , they are:

1-Absorption

2-Spontaneous Emission

3-Einistein s prediction (Stimulated emission)

1-Absorption

A photon of energy hν = (E2-E1) is incident on the atom it imparts its energy to the atom and disappears , the atoms jumps to the excited state E2 , the transition called an absorption transition it is also referred to as induced absorption

A+hν ⟹ A*

2-Spontaneous Emission

An atom cannot stay in the excited state for a longer time , in a time of about 10^{-8} S the reverts hν Emission of by an atom without external impetus is called Spontaneous Emission

A* ⟹ A+hν

Characteristics of spontaneous emission

1-The process of spontaneous emission is not amenable for control from out side

2-The instant of transion , direction of propagation , the initial phase and the plane of polarization of each photon are random

3-The light resulting through this process is not monochromatic

4-Light speeds in all directions around the source

5-Light emitted through this process is incoherent

3-Einistein s prediction (Stimulated emission)

An atom in the excited state need not waited for spontaneous emission for a photon , it may interact with a photon with energy hν=E2-E1 and make a downward transiting

The photon is said to stimulate or induce the excited atom to emit a photon of energy hν=E2-E1

Characteristics of stimulated emission:

1-The process of stimulated emission is controllable from outside

2-The photon induced in the process propagates in the same direction as that of stimulating photo

3-Theinduced photon has features identical to that of the inducing photon , it has the same frequency , phase , and plane of polarizion so that of the stimulating photon

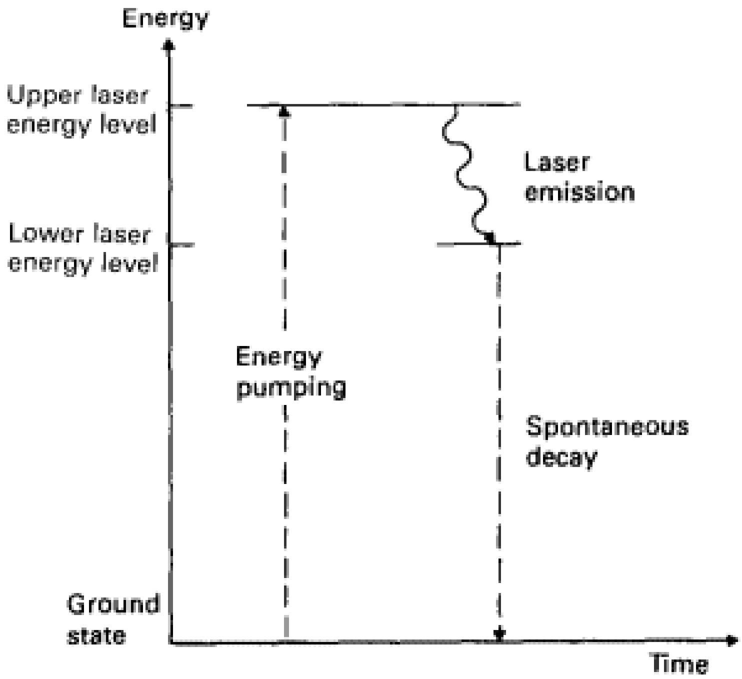
4-The outstanding feature of this process is the multiplication of photons

Lasers

LASER is an acronym for the instrument's mode of action: ***Light Amplification by the Stimulated Emission of Radiation***. Laser light is coherent: all photons have the same wavelength and are ***in phase.*** A laser beam is also collimated, i.e. the waves of light are parallel.

Production of Laser Energy

All atoms are most stable in their lowest energy state, known as the **ground state** . Energy is delivered to atoms in a laser active medium by a process called **pumping**. The **absorption** of energy by an atom elevates its electrons from their ground state to a **higher energy level**. One of these, the upper laser energy level, allows excited atoms to accumulate there.

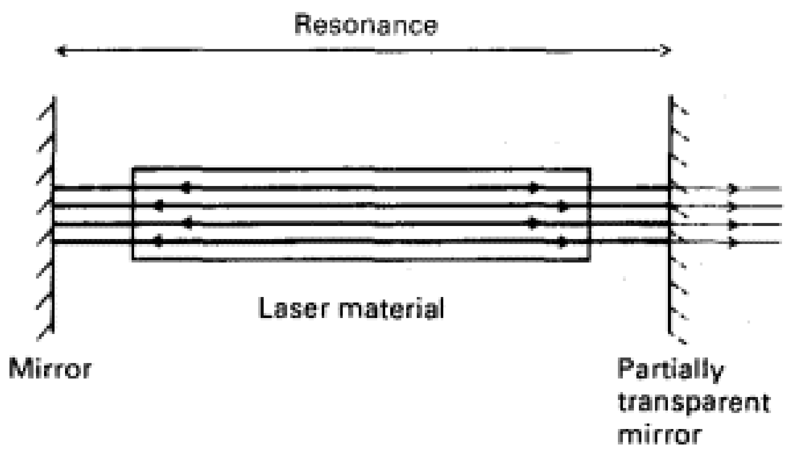


Energy levels of a simple laser.

When there are more atoms in the excited than in the lower energy level, ***population inversion*** is said to have occurred. Atoms in the excited state are unstable and their electrons tend to ***spontaneously*** return to the ground state by ***emitting light*** energy. This ***spontaneous emission*** of light is incoherent and it travels in all directions. Atoms are less stable in the lower laser energy state, and can drop back to the ground state and enter the cycle anew.

If an atom at a higher energy level is **stimulated** further by a photon whose wavelength is that which the atom would naturally emit, the resulting emission will be coherent with the stimulating photon, and the atom will drop to a lower energy level. Most of the energy released by the active medium is incoherent spontaneous emission, but the small amount released by stimulated emission can be amplified.

The active laser medium is housed in a tube which has a mirror at each end (Figure). The distance between the mirrors must equal a multiple of the wavelengths of the light emitted so that resonance can occur. When a photon encounters an excited electron and stimulated emission occurs, the light emitted travels down the tube, and is reflected and rereflected at both mirrors. Because the mirrors are precisely aligned and a whole number of wavelengths apart, the light which has traversed the tube is still exactly in phase with itself on its second and subsequent journeys. Thus it reinforces itself. This is known as ***resonance***. Meanwhile other stimulated emissions are taking place so that the light traversing the tube gets stronger and stronger while remaining exactly in phase (**coherent**) and the **lasing process is under way.**



Laser tube.

If one of the mirrors is made ***partially transparent***, some of the light may be allowed to leave the tube. This light will be ***coherent*** (the wavefronts***in phase***), ***monochromatic*** (of one wavelength) and

collimated (all the rays parallel). Light is produced continuously, and such a laser is said to be operating in **continuous-wave (CW)** *mode*.

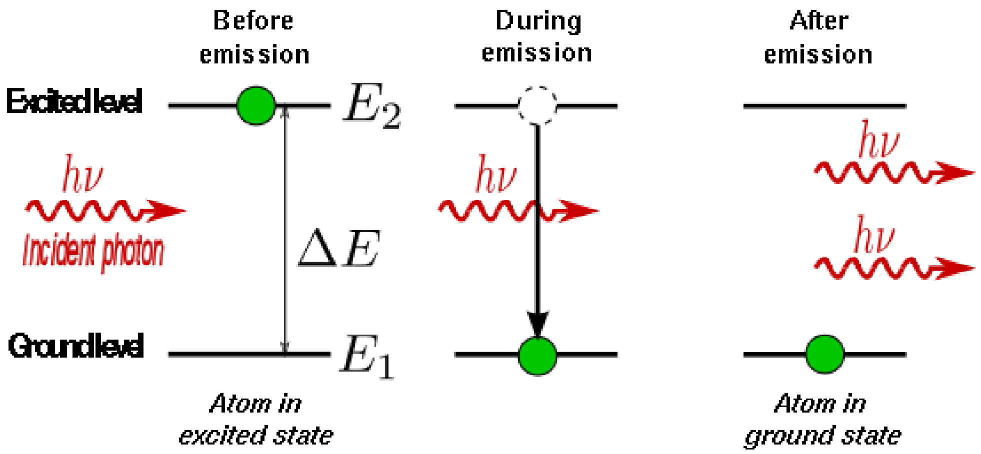
The actual luminous flux emitted by a laser is relatively small (lasers are very inefficient in that a great deal of energy has to be 'pumped' into them in order to maintain the lasing process). However, because the luminous flux is not scattered in all directions but is concentrated in a fine parallel beam, the beam of light is exceedingly bright. A laser producing approximately 5 lumens of light may have a beam of luminous intensity 500 million candela. Another useful comparison is that a 1 watt laser produces a retinal irradiance 100 million times greater than that of a 100 watt incandescent bulb.

Lasers are named after their active medium. The active medium contains the atoms or molecules which will undergo stimulated emission. It may be gas (argon, krypton, carbon dioxide), liquid (dye) or solid (neodymium supported by a yttrium aluminium garnet crystal, Nd:YAG). The source of the energy

pumped into the active medium may be electrical discharge, a second laser or incoherent light.

Production of Laser Energy

All atoms are most stable in their lowest energy state, known as the ground state . Energy is delivered to atoms in a laser active medium by a process called pump



$$E_2 - E_1 = \Delta E = h\nu$$

Types of lasers

There are several ways in which we can classify lasers into different types. We can classify lasers according to the material used as active medium. They are divided into four categories:

1. solid state lasers: such as (ruby laser, Nd:YAG laser)

2. gas lasers: such as (helium-neon, krypton, carbon dioxide)

3. liquid lasers: (dye)

4. semiconductor diode lasers

Most of lasers emit light in the red or IR regions. Lasers work in a continuous mode or in pulsed mod.

Diode lasers are used in wide variety of applications, it use in optical fiber communications, CD players, CD-ROM drives, optical reading, high speed laser printing etc.

Laser properties

1. Highly directional

2. Negligible divergence

3. High intensity

4. Coherent: (in phase)

5. Monochromatic: (of one wave length)

Laser in medicine

Lasers in Medical Surgery Almost every medical surgery in which a removal of tissue is required or a cut needs to be made can be done with a laser. In general, the results of surgery using lasers are better than the results using a surgical knife

The Advantages of Laser Surgery:

1. Dry field of surgery, because laser energy seals small blood vessels.

2. Less postoperative pain, because of the sealing of nerve ends.

3. No contact with mechanical instruments, so sterilization is built in.

4. Possibility to perform microsurgery under a microscope. The laser beam passes through the same microscope.

5. Possibility to perform surgical procedures inside the body without opening it, using optical fibers to transmit the laser beam.

6. It can be controlled by a computer, and operate with a very small area of effect under a microscope.

The Surgical Lasers

The most typical lasers and their wavelengths:

No.	Laser Acronym	Wavelength (nm)
1	CO_2	10600
2	Nd:YAG	1064
3	KTP (SHG) Nd:YAG	532
4	Ho:YAG	2130
5	Er:YAG	2940
6	Argon	514
7	Copper Vapour	578
8	Ruby	694
9	GaAlAs	800-870
10	Dye	400-800
11	Excimer	193, 284, 308, 351

In order for a laser to be suitable for use as a surgical laser, it must be powerful enough to heat up the tissue to temperature over 50 Co. A surgical laser can either be used in continuous wave or pulsed mode. These lasers can be broadly divided into three groups, according to their output:

1. Vaporizing 1-5 w.
2. Light cutting 5-20 w.
3. Deep cutting 20 – 100 w.

Medical Surgery Fields

The areas of medical laser surgery are well established, and include:

1	**Ophthalmology**	طب العيون
2	**Dentistry**	طب الأسنان
3	**Dermatology**	طب الأمراض الجلدية
4	**Urology**	طب المجاري البولية
5	**Angioplasty and Cardiology**	التقويم الوعائي وطب القلب
6	**Orthopedics**	جراحة العظام
7	**Gastroenterology**	طب الجهاز الهضمي

Lasers in Ophthalmology

- In ophthalmology, various types of lasers are being applied today for either diagnostic or therapeutic purposes. In diagnostics, lasers are advantageous if conventional incoherent light sources fail. One major diagnostic tool is confocal laser microscopy which allows the detection of early stages of retinal alterations. By this means, retinal detachment and also glaucoma1 can be recognized in time to increase the probability of successful treatment. In this section, however, our interest focuses on therapeutic laser applications.
- The first indications for laser treatment were given by detachments of the retina. Meanwhile, this kind of surgery has turned into a well-established tool and only represents a minor part of today’s ophthalmic laser procedures. Others are, for instance, treatment of glaucoma and cataract. And, recently, refractive corneal surgery has become a major field of research, too.

- The laser was invented in 1960, and in 1961 this laser (Ruby) was used by eye doctors. It is natural that the eye was chosen to be the first organ for performing medical experiments, since the eye is transparent to the electromagnetic spectrum in the visible range. Another natural device that helps was the lens in the eye, which focuses the electromagnetic radiation onto the retina. Thus, increasing the power density by orders of magnitude. The targets of all therapeutic laser treatments of the eye can be classified into:

1. The front segments consist of the cornea, iris, and lens.

2. The rear segments are given by the vitreous body and retina.

A schematic illustration of a human eye is shown in Figure. In the following paragraphs, we will discuss various treatments of these segments according to the historic sequence, i.e. from the rear to the front.

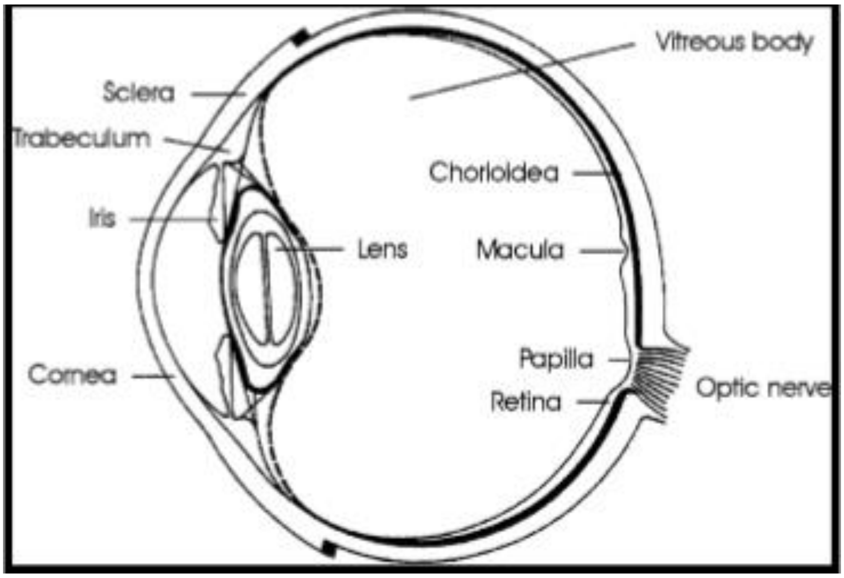
Advantages

1. Low risk of infection.

2. No-need to hospital stay.

3. Painless.

4. More precise.



Techniques of Eye Treatment by Laser

Many diseases and medical problems of the eye can be treated using lasers in a thermal regime. Here are a few of the more common treatments:

Detached Retina: where the retina comes away from the back of the eye, can treated by ‘gluing’ it back on again by photocoagulating it by using Argon ion laser.

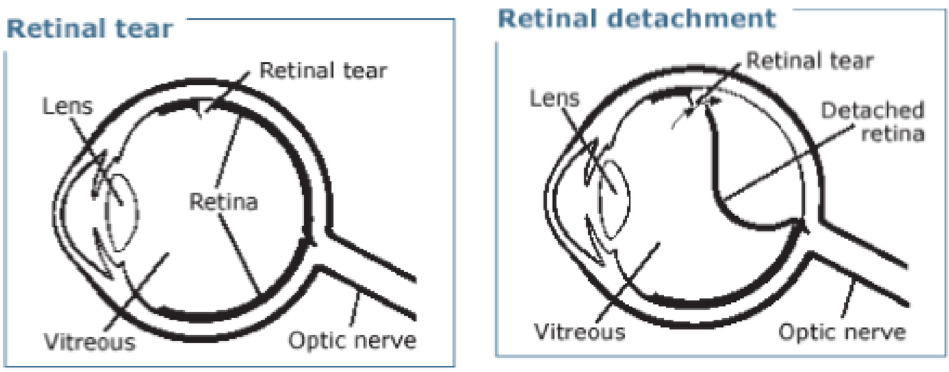


Figure shows Retinal Detachment

Glaucoma: is caused by a build-up of pressure in the eye. Closed-angle glaucoma can be treated by making a hole in the iris, thus releasing the pressure. This procedure is called laser iridotomy, Argon ion lasers or pulsed neodymium lasers are used.

Cataract: A cataract is the clouding of the crystalline lens of the eye is like looking through a dirty window. As a result of the natural aging process, the lens gradually becomes cloudy. This opacity results in distorted vision and can finally lead to blinding. The common treatment of cataract is to surgically remove the cloudy lens and put a plastic lens using argon ion lasers or pulsed neodymium lasers.

Non-thermal Treatments Techniques

Thermal effects are not always desirable, particular when attempting to ablate or cut tissue very precisely without damaging the surrounding tissue. Photoablation, plasma-induced ablation and photodisruption are all used as non-thermal means of ablating or cutting tissue.

Corneal Reshaping: to treat myopia or hyperopia (near or longsightedness) is the commonest application of lasers to ophthalmology that uses a non-thermal mechanism. Three procedures are described below: radial keratectomy, photorefractive keratectomy (PRK) and laser in situ keratomileusis (LASIK), all of which use photoablation as a mechanism to remove corneal tissue.

The difference between LASIK and PRK is that the first has a flap but the second doesn’t have.