Light in Medicine

Light has some interesting properties, many of which are used in medicine:

1- The speed of light changes when it goes from one material into another. The ratio of the speed of light in a vacuum to its speed in a given material is called the index of refraction.

2- Light behaves both as a wave and a particle. As a wave it produces interference and diffraction.

As a particle it can be absorbed by a single molecule.

3- When light is absorbed, its energy generally appears as heat. This property is the basis for the use IR light to heat tissues. Also the heat produced by laser beams is used to weld a detached retina to the back of eyeball and to coagulate small blood vessels in retina.

4- Some time when alight photon is absorbed, a lower energy light photon is emitted. This property is known as *fluorescence*.

5- Light is reflected to some extent from all surfaces.

There are two types of reflection

A- Diffuse reflection: occurs when rough surface scatter the light in many direction

B- Specular reflection: it is obtained from very smooth surface such as mirrors.

Measurement of light and its units:

• The three general categories of light-UV, Visible, and IR- are defined in terms of their wavelengths. Wavelength of light used to be measured in:

Microns 1 μ = 10^{-6}m

Angstroms 1 A° = 10^{-10}m

Nanometer 1 nm= 10^{-9}m

- Ultraviolet light has wavelengths from 100 to 400nm

- Visible light has wavelengths 400 to 700nm

- IR light has wavelengths from 700 to 10^4nm.

Each of these categories subdivided according to wavelength.

Ultraviolet **UV-A** has wave lengths from 320 – 400nm

UV-B has wavelengths from 290 -320nm

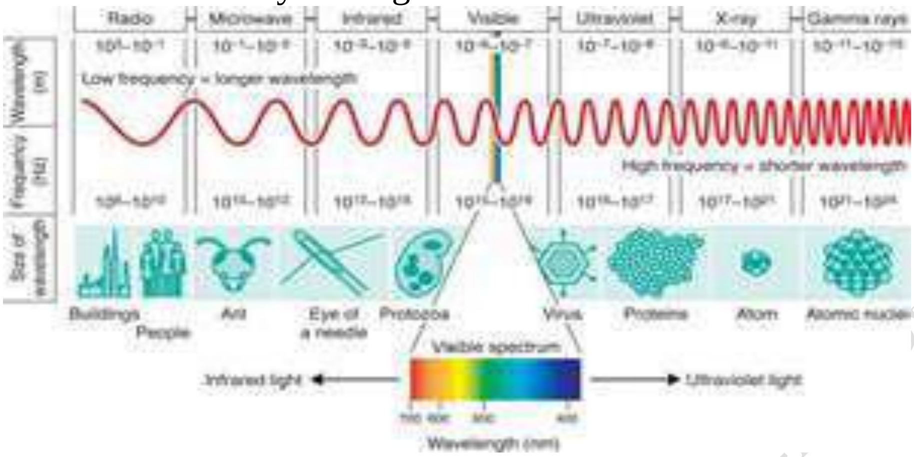
UV-C has wavelengths from 100 – 290nm

Visible light is measured in photometric units

Illuminance the quantity of light striking a surface

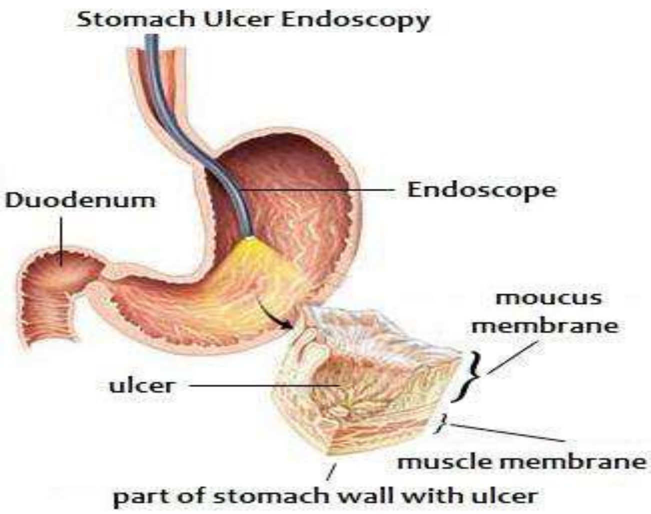
Luminace the intensity of a light source.

UV and **IR** radiation can be measured in radiometric units
Irradiance the quantity of light striking a surface.
Radiance the intensity of a light source



Applications of visible light in medicine:

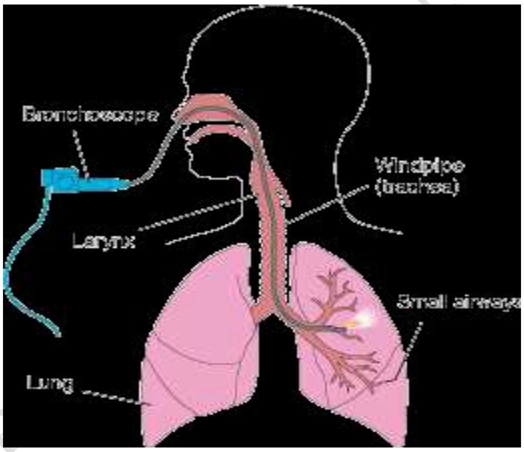
Endoscope: a number of instruments are used for viewing internal body cavities.



Cytoscopes : are used to examine the bladder.

Bronchoscope: Are used for examining the air passages into lungs. Some endoscopes are rigid tubes with a light source to illuminate the area of interest.

Flexible endoscopes can be used to obtain information from regions of the body that cannot be examined with rigid endoscopes, such as the small intestine and much of large intestine.



Applications of UV and IR light in medicine :

UV photons have energies greater than visible and IR light. Because of their higher energies, UV photons are more useful than IR photons.

-UV can kill germs and used to sterilize medical instruments.

-UV produces more reaction in the skin some of these reactions are beneficial, and some are harmful.

Beneficial effects of UV light from the sun is the conversion of molecular products in the skin into vitamin D.

Harmful effects of UV light can produce sunburn as well as tan skin. Solar UV light is also cause of skin cancer in humans. The high incidence of skin cancer among people who have been exposed to the sun a great deal, such as fishermen and agricultural workers, many be related to the fact that the UV wavelengths that produce sunburn are also very well absorbed by the DNA in the cells.

UV light has even shorter wavelengths than the visible light and is scattering more easily.

About half of the UV light hitting the skin on a summer day comes directly from the sun and other half is scattered from the air in the other parts of the sky. Thus you can get a sunburn even when you are sitting in the shade under a small tree.

-UV light cannot be seen by the eye because it absorbed before it reaches the retina.

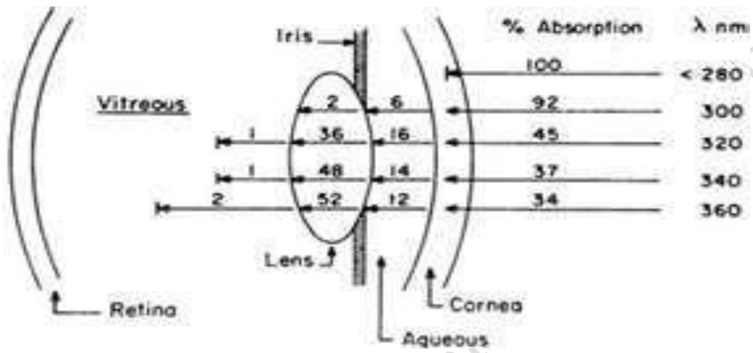


Fig shows the percentages of UV light of different wavelengths absorbed by the different structures of the eye .The IR rays are not usually hazardous even though they are focused by the cornea and lens of the eye onto the retina. However, looking at the sun through a filter (e.g., plastic sunglasses) that removes most of the visible light and allows most of the IR wavelengths through can cause a burn on the retina.

Heat lamps that produce a large percentage of IR light with wavelengths of 1000 to 2000nm are often used for physical therapy purposes.

Two types of IR photography are used in medicine:

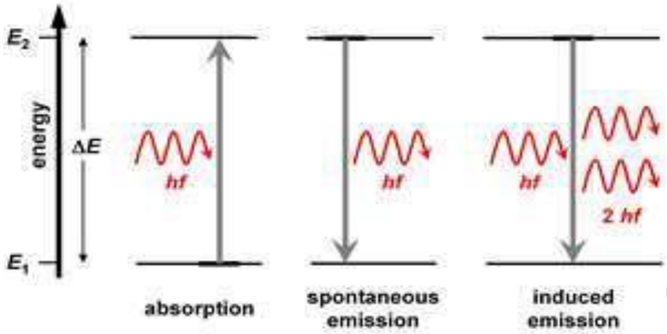
1- Reflective IR photography :which uses wavelength of 700 to 900nm to show patterns of viens just below the skin.

2- Emissive IR photography: Which uses the long IR heat waves emitted by the body that give an indication of the body temperature, is usually called thermograph.

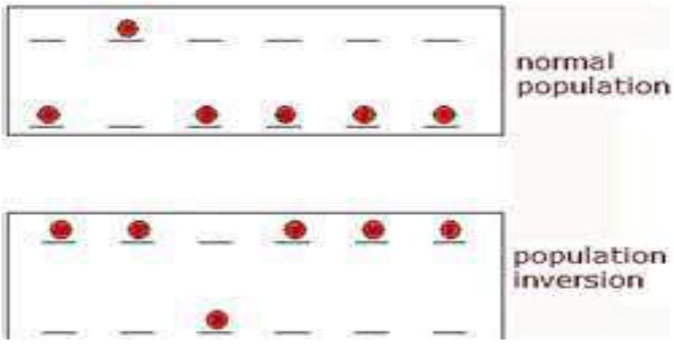
Laser in Medicine :

When an electron makes a transition from higher energy to lower energy state, a photon is emitted. The emission process can be one of two types, spontaneous emission or stimulated emission.

In spontaneous emission the photon is emitted spontaneously, in a random direction, without external provocation.
In stimulated emission an incoming photon stimulates the electron to change energy levels. To produce stimulated emission, however, the incoming photon must have energy that exactly matches the difference between the energies of two levels, namely



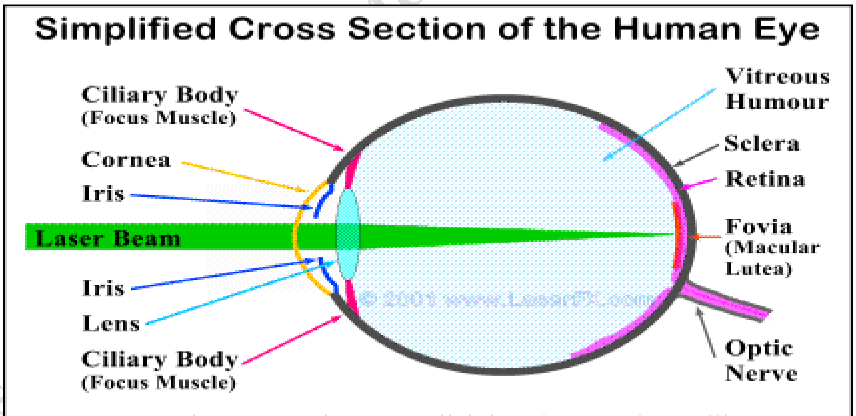
The operation of lasers depends on stimulated emission.
Stimulated emission has three important features.
1-One photon goes in and two photons come out. In this sence, the process amplifies the number of photons. This is the origin the word laser which is an a crony for light amplification by the stimulated emission radiation
2-The emitted photon travels in the same direction as incoming photon.
3-The emitted photon is exactly in step with or has same phase as the incoming photon. In other word, the two electromagnetic waves that these two photons represent are coherent.
The energy can be provided in number of ways, including intense flashes of ordinary light and high voltage discharges. If efficient energy is delivered to atoms, more electrons will be excited to a higher energy level than remain in lower energy level, a condition known as population inversion. Figure compares a normal energy level population with a population inversion. The population inversion in lasers involve a higher energy state that is metastable, in the sense that electrons remain in it for a much long period of time than they do in an ordinary excited state (10^{-3}s versus 10^{-8}s).



A laser is a unique light source that emits a narrow beam of light of single wavelength in which each wave is in phase with others near it. The physical characteristics of lasers and a few of their application in medicine.

Laser energy that has been stored in the laser material.

A laser beam can be focused to a spot only a few microns in diameter. When all of the energy laser concentrated in such a small area, the power density (power per unit area) becomes very large. The total energy of a typical laser pulse used in medicine, which measured in milli joules (mJ), can be delivered in less than a microsecond, and resultant instantaneous power may be in megawatts. The output of pulsed laser is usually measured by the heat produced.

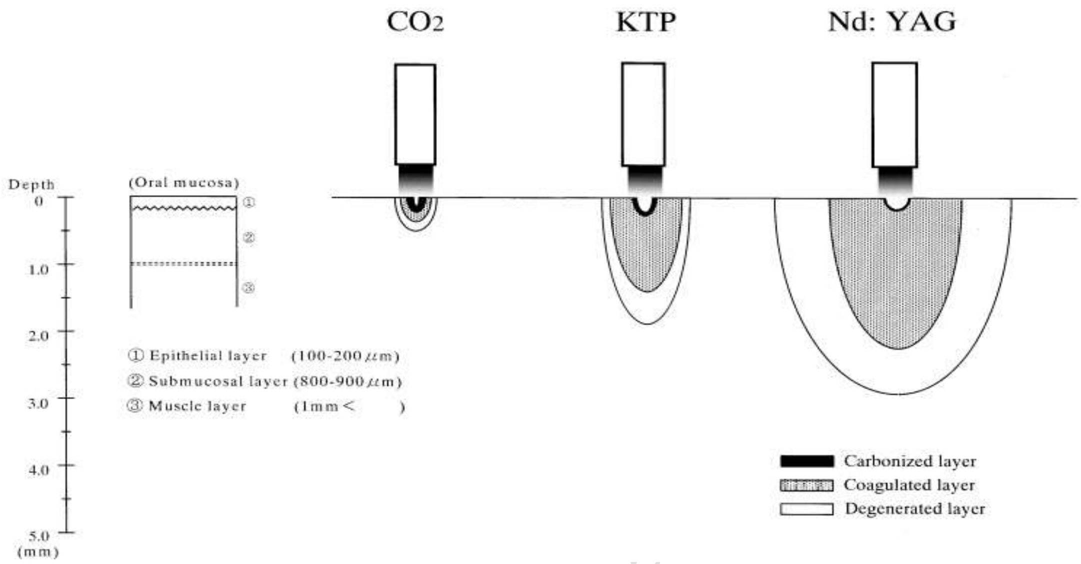


Laser beams are almost parallel thus the eye's lens will focus them down to a small spot causing retinal burns.

Since in medicine lasers are used primarily to deliver energy to tissue, laser energy directed at human tissue causes a rapid rise in temperature and can destroy the tissue. The amount of damage to living tissue depends on how long the tissue is at the increased temperature.

--*For example*, tissue can withstand $70^{o}C$ for 1 s, in general even the briefest exposure to temperatures above $100^{o}C$ results in tissue destruction. However, not all laser damage is due to heat.

The laser used in medicine as a blood less knife for surgery. It can be focused by a lens to almost a mathematical point. This means that the energy per unit area in the focal spot can be made enormous, and small regions can be vaporized without harming the surroundings.



In medicine one of the most spectacularly successful uses of lasers has been in ophthalmic surgery. In eye the retina may become detached from the choroid owing to disease, injury, or degenerative changes. The laser are primarily used for photocoagulation of the retina, the heating a blood vessel to point where the blood coagulates and blocks the vessel.

….it has been found that a 1ms flash of light from a laser focused on the retina is highly efficient in welding the retina to choroid. Further, the patient feels no pain and no anesthetic is not required. The amount of laser energy needed for photocoagulation depends on the spot size used. In general, the proper dose is determined visually by the ophthalmologist at the time of the treatment.

The minimum amount of laser energy that will do observable damage to the retina is called *Minimal Reactive Dose*(MRD).

Ex.: The MRD for a 50μm spot in the eye is about 2.4mJ delivered in 0.25 s.

Typical exposure needed for photocoagulation are 10 to 50 times the MRD (i.e., 24 to 120mJ for 50μm spot in 0.25s).

Photocoagulation is useful for repairing retinal tears or holes that develop prior to retinal detachment. When the retina is completely detached, the laser is of no help. A complication of diabetes that effects the retina called *diabetic retinopathy*, can also be treated

with photocoagulation. Because of the small spot sizes a available ($\sim \mathbf{50}\boldsymbol{\mu m}$) it is possible to use the laser even in the small region where our detail vision takes place.
Protective glasses must be worn in medical laser areas to protect the eyes of the patient and the workers. Since the laser energy is concentrated in a narrow beam for long distances, even reflected beam can be a hazard: thus the walls and other surfaces in the laser installation should have low reflectivity (e.g. flat black paint).
The area should have adequate warning and system that prevents outsider from entering while lasers are in use.

Physics of Eyes and Vision:
The sense of vision consists of three major components:
1-The eyes that focus an image from outside world on the light sensitive retina.
2-The system of millions of nerves that carries the information deep into the brain.
3-The visual cortex-that part of the brain where, it is all put together.
Blindness results if any one of the parts does not function.
The physics of the first part far better than the physics of the other two parts.
Focusing elements of the eye :
The eye has two major focusing components:
1-The cornea is a fixed focus element.
2-The lens is variable in shape and has the ability to focus objects at various distances.
The cornea focuses by bending (refracting) the light rays. The amount of bending depends on the curvatures of its surfaces and the speed of light in the lens compared with that in the surrounding material. The index of refraction is nearly constant for all corneas, but the curvature varies considerably from one person to another and is responsible for most our defective vision.
1-If the cornea is curved too much the eye is near sighted.
2-Not enough curvature results in far sightness.
3-Uneven curvature produces astigmatism.
The lens has a flexible cover that is supported under tension by suspension fibers.
1-When the focusing muscle of the eye is relaxed this tension keeps the lens somewhat flattened and adjusted to its lowest power, and the eye is focused on distant objects. The point at

which distant objects are focused when the focusing muscle is relaxed is called *the far point*.

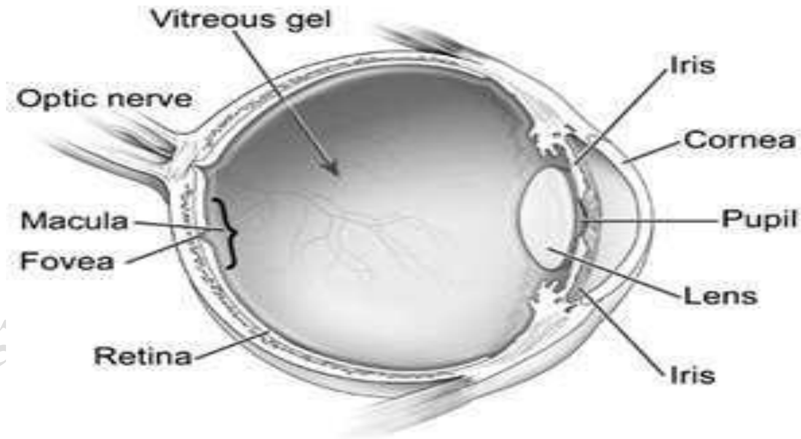
2-For a near sighted, the circular muscle around the lens contracts into a smaller circle and takes some or all of the tension off the lens. The lens then has a greater focusing power, the closest point at which objects can be focused when the lens is its thickest is called the near point.

3-Young children have very flexible lenses and can focus on very close objects. The ability to change the focal power of the eye is called accommodation.

4-As people get older, their lenses lose some accommodation, presbyopia (old sight) results when the lens has lost nearly all of its accommodation.(look below table shows the index of refraction of the cornea & other optical parts of the Eye)

Part of the Eye	Index of Refraction
Cornea	1.37
Aqueous humor	1.33
Lens cover	1.38
Lens center	1.41
Vitreous humor	1.33

Some other elements of the eye:



Pupil is the opining in the center of the iris where light enters the lens. It appears black because essentially all of the light that enters is absorbed inside the eye. Under average light condition, the opining is about 4mm in diameter. It can change from about 3mm in diameter in bright light to about 8mm in diameter in dim light. The iris does not respond instantly to a change of light levels; about 300 s are needed for it fully open, and about 5 s are required for it to close as much as possible.

Aqueous humor fills the space between the lens and the cornea. This fluid, mostly water, is continuously being produced, and the surplus escapes through a drain tube.

Vitreous humor is a clear jelly that fills the large space between the lens and the retina. It helps keep the shape of the eye fixed and essentially permanent.

Sclera is the tough, white, light-tight covering over all of the eye except the cornea.

The Retina –the Light Detector of the eye : The retina, the light sensitive part of the eye, converts the light images into electrical nerve impulses that are sent to the brain.

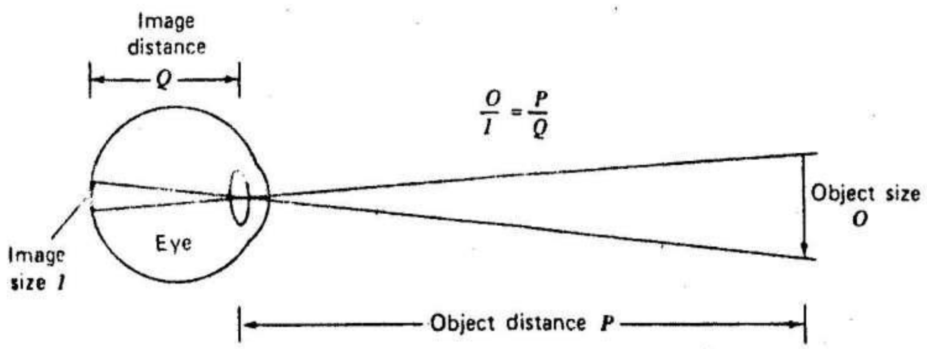
The absorption of a light photon in photoreceptor triggers an electrical signal to brain-an action potential. The light photon apparently cause a photochemical reaction in the photoreceptor which in some way initiates the action potential. The photon must be above a minimum energy to cause the reaction.

1-Infrared photons have insufficient energy and thus are not seen.

2-Ultraviolet photons have sufficient energy, but absorbed before they reach the retina and also are not seen.

The retina covers the black half of the eyeball. While this large expanse permits useful" warning" vision over a large angle, most vision is restricted to a small area called the macula lutea, or yellow spot. All detailed vision takes place in a very small area in the yellow spot (~0.3mm in diameter) called the fovea centralis .

The image on the retina is very small. A convenient equation for determining the size of image on the retina comes from the ratios of the lengths of the sides of similar triangles.



I: is image size Q: is image distance

O: is object size P: is object distance

Thus we can write …. O/P=I/Q

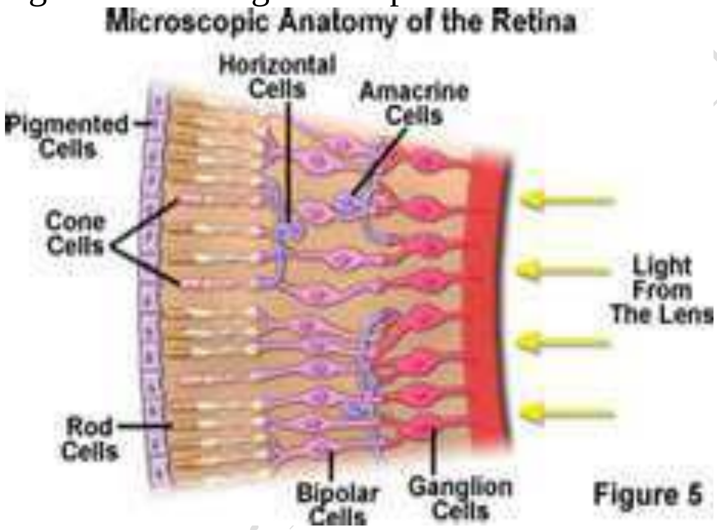
Ex.: How big is the image on the retina of a fly on a wall 3.0m away?

Assume the fly is 3mm in diameter and Q=0.02m.

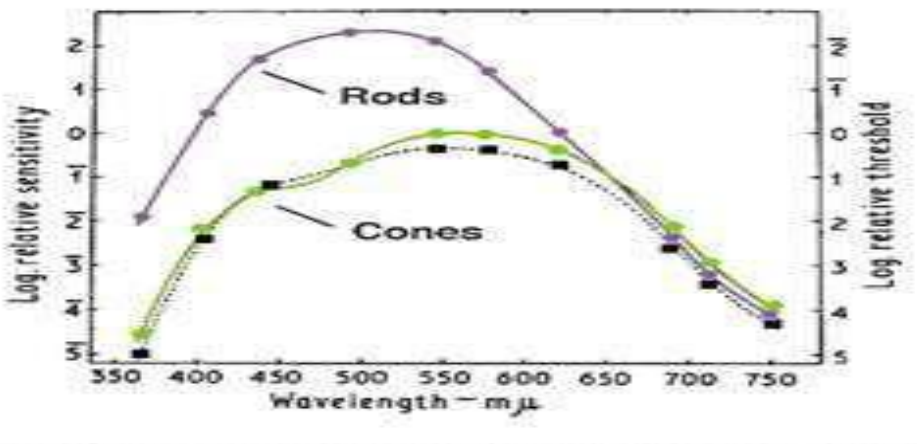
I=(0.02/3) x 0.003= 2 x 10^{-5}m=20μm

There are two general types of photoreceptors in the retina: the cones and the rods, the rods and cones are distributed symmetrically in all directions from visual axis except in one region-blind spot .

Throughout most of the retina the cones and rods are not at the surface of the retina but the lie behind several layers of the nerve tissue through which the light must passes.



The cones are used for daylight, or photopic, vision. With we can see fine detail and recognize different colors. The cones are found in the fovea centralis. Each of the cones in the fovea has its own telephone line to the brain. The cones are not uniformly sensitive to all colors but have a maximum sensitivity at about 550 nm in the yellow – green region.



The rods are used for night or scotopic ,vision ,they are not uniformly distributed over the retina but have a maximum density at an angle of about 20^0

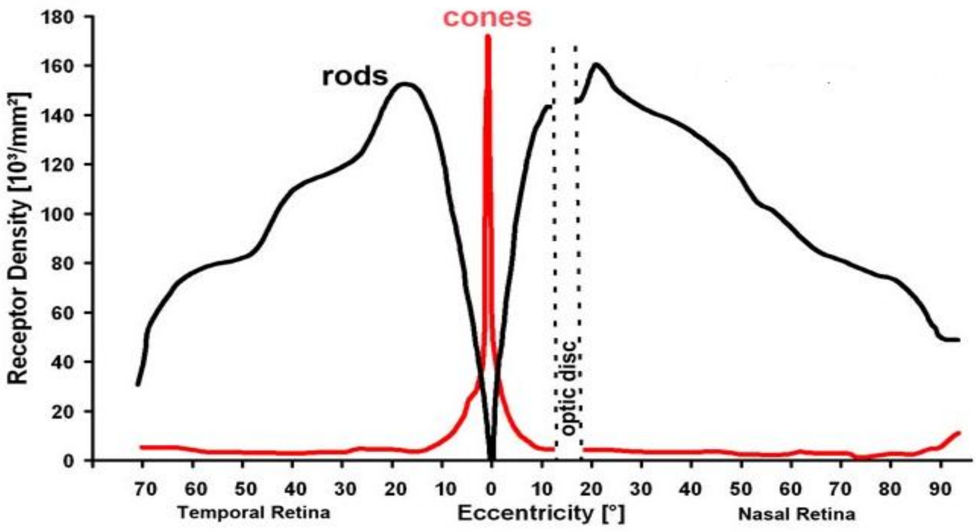


Fig. . Graph to show rod and cone densities along the horizontal meridian.

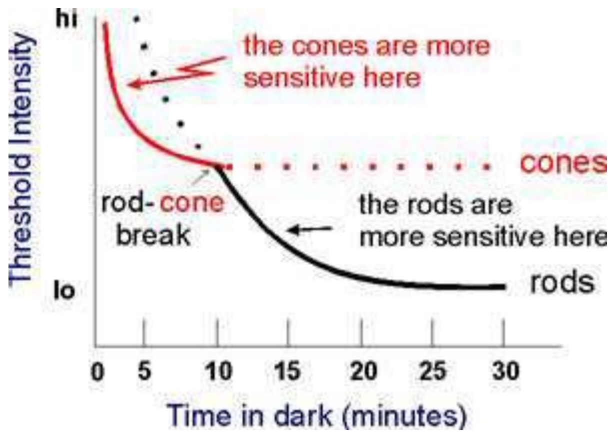
That is, if you are looking at the sky at night, the light from a faint star displaced 20^o from your line vision will fall on the most sensitive area of your retina. If you look directly toward the faint star, its image will fall on your fovea which has no rods and you will not see it.

The rods are most sensitive to blue-green($\sim \mathbf{510}\boldsymbol{nm}$) .The rods and cones are equally sensitive to red light (650 to 700nm).

Dark adaptation: is apparently the time needed for the body to increase the supply of photosensitive chemicals to the rods and cones.

The eyes do not have their greatest sensitivity to light under photopic conditions, if the light level suddenly decreases by a factor of 1000 we are momentarily "in dark", but after a few minutes we are able to see many of details that were not visible when it first became dark.

The cones adapt most rapidly; after about 5 min the fovea centralis has reached its best sensitivity. The rods continue to dark adapt for 30 to 60min, although most of their adaptation occurs in the first 15 min.

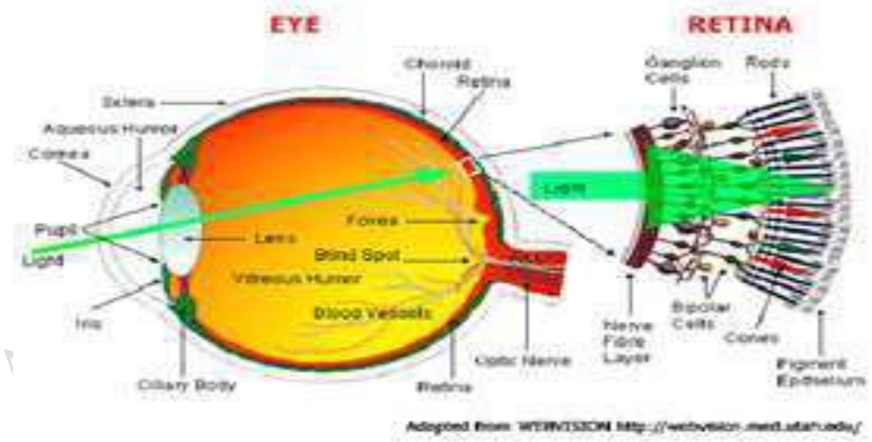


(**H.W**).:**<u>EX.</u>** If you are watching a football game from the end zone ,what size will the image of the football on your retina be when the football a at the other end of the field ?Assume the football s 30 cm long and 150 m away..(*Ans.40um*).

- **Specialists**:

1. Ophthalmologist 2. Optometrist 3. Ophthalmic technician
4. Optician 5. Orthopist

Blind spot:
That has neither rods nor cones. That there is a region from about 13^0 to 18^0 .



How Little Light Can You See?

- Two photons absorbed in the rods →generate visual signal
- Typical flashlight: 10^{18} photons per second
- Absorption of photons

1. About 3%: reflected at the surface of the cornea
2. About 50%: absorbed in the cornea, lens, humors
3. About 40%: absorbed in the backstop

4. About 10%: absorbed in the rods

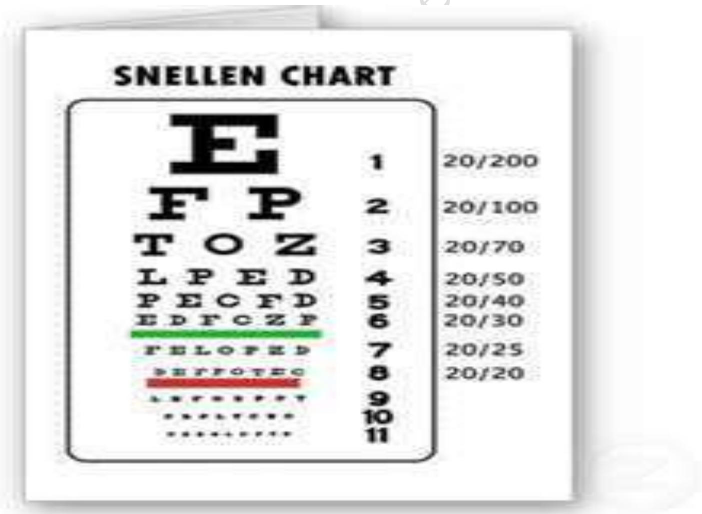
Diffraction Effects on the Eye

- Light waves passing through a small opening →diffraction (point light source →rings on the retina)
- Diffraction pattern on the retina due to the iris
- Optimal pupil diameter = 3 ~ 4 mm (normal size under good illumination)

1. Smaller pupil (~ 1 mm) →measurable effect of diffraction
2. Smaller pupil →better for reducing the effect of lens defect (aberration).

How sharp are your eyes:

The optometrist usually uses a snellen chart to test visual acuity. If he tells you that your eyes test normal at 20/20, he means that you can read detail from 20 ft that person with good vision can read from 20 ft. If your eyes test at 20/40, you can just read from 20 ft the line that a person with good vision can read from 40 ft.



The ability of the eye to recognize separate lines also depends on the relative "blackness "and "whiteness" , the contrast between two areas is defined as optical density OD

$$\mathbf{OD = Log\ (I_o/I)}$$

Where I_o is the light intensity without absorber and I is intensity with absorber.

EX.1: A piece of film that transmits 10% of the incident light has an optical density

$$OD = Log(1/0.1) = 1.0$$

EX.2: A film that absorbs 99% of the light has an optical density

$$OD = Log(1/0.01) = 2.0$$

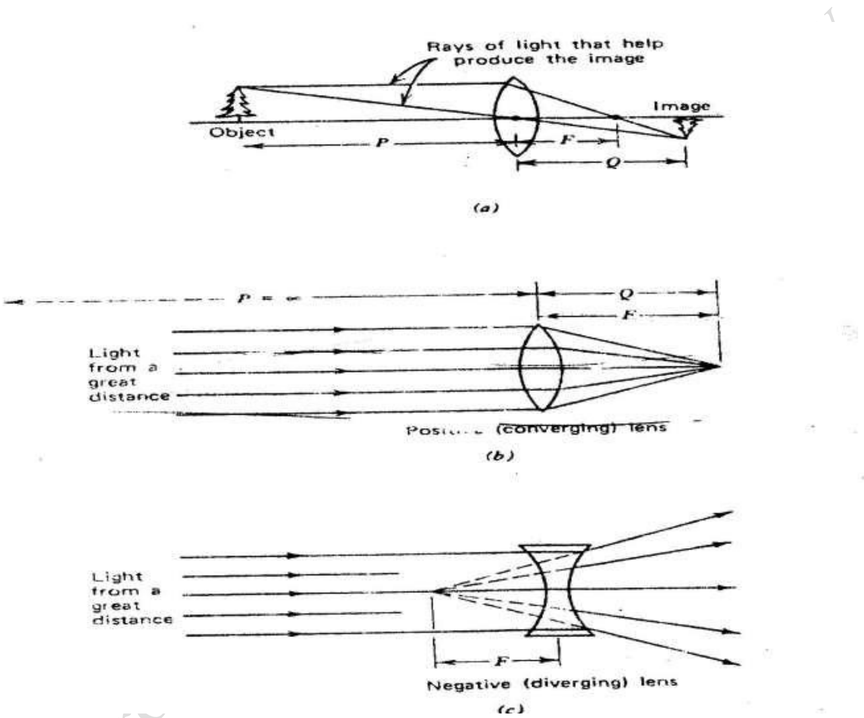
An OD=3 means that only 0.001 of the light transmitted.

Defective vision and its correction:

There is a simple relationship between the focal length **F**, the object distance **P**, and the image distance **Q** of the lens

$$1/F = 1/P + 1/Q$$

If **F** is measured in meters, then **1/F** is the lens strength in diopters **(D).**

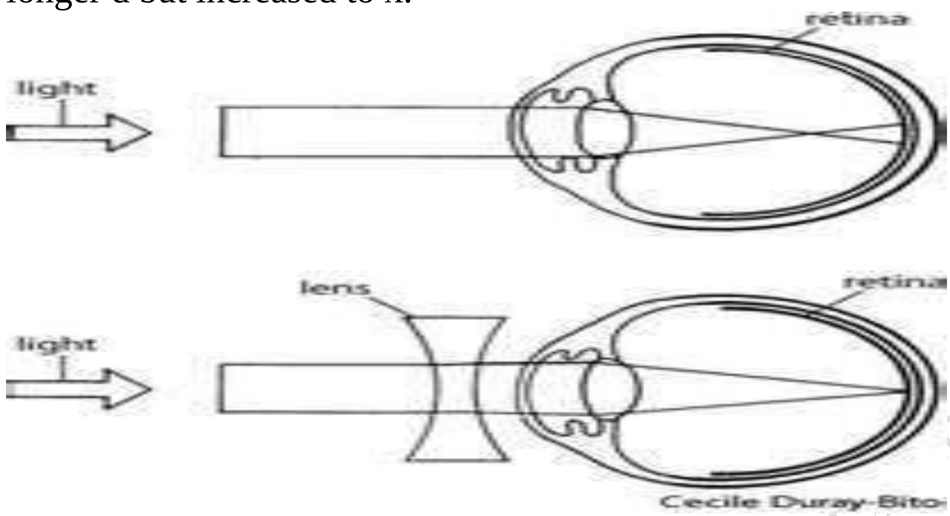


The ability of the eye to focus on objects over a wide range is called accommodation.
Power of accommodation of normal eye =
$1/F = 1/near\ point - 1/far\ point = 1 / 0.25m - 1/\infty =$ 4 Diopter

Myopia :

The eyeball is too long, and parallel rays are focused by the relaxed eye to a position in front of the retina. Only near objects can therefore be seen clearly.
This defect can be corrected by diverging lenses. If the spectacle lens is chosen to have a focal length equal in magnitude to the distance to the far point (F), then parallel rays striking the spectacles appear to the eye to diverge from the far-point. Note that the least distance of distinct vision for the spectacled eye is no

longer d but increased to x.



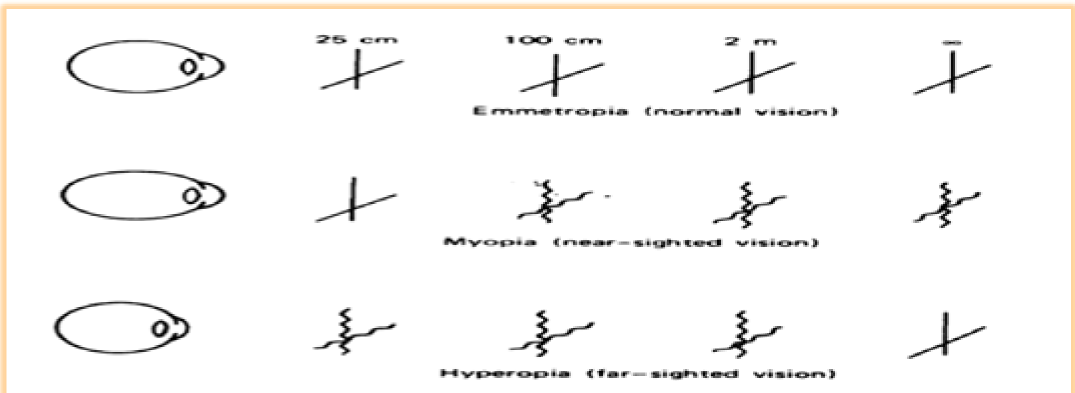
Where $1/-F = 1/x - 1/d$

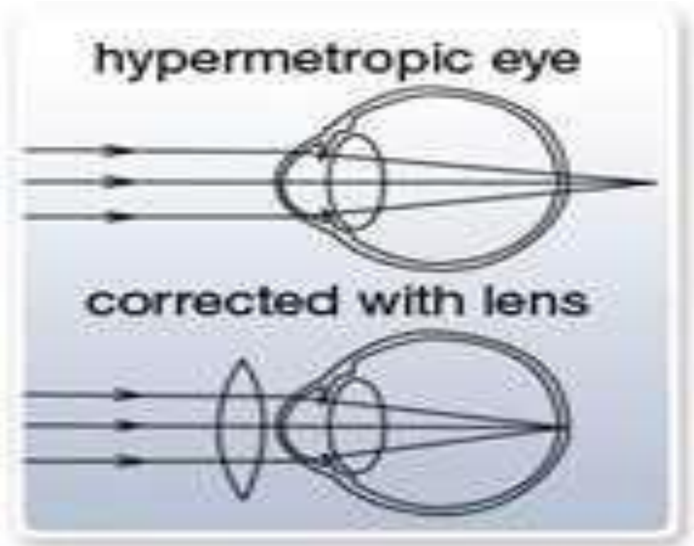
An object at distance x must produce a virtual image at d in the spectacle lens in order just to be brought to focus by the eye.

Hypermetropia :

This is the opposite effect. The eyeball is too short and parallel rays are focused to a point behind the retina, this defect is corrected by using converging spectacle lenses, if the near point is at d_1. Then an object at d requires the lens to produce a virtual image of it at d_1 which will then be visible to the fully accommodation eye in the other words the focal length of the spectacle lenses must be F.

Where $\mathbf{1/F = 1/d - 1/d_1}$



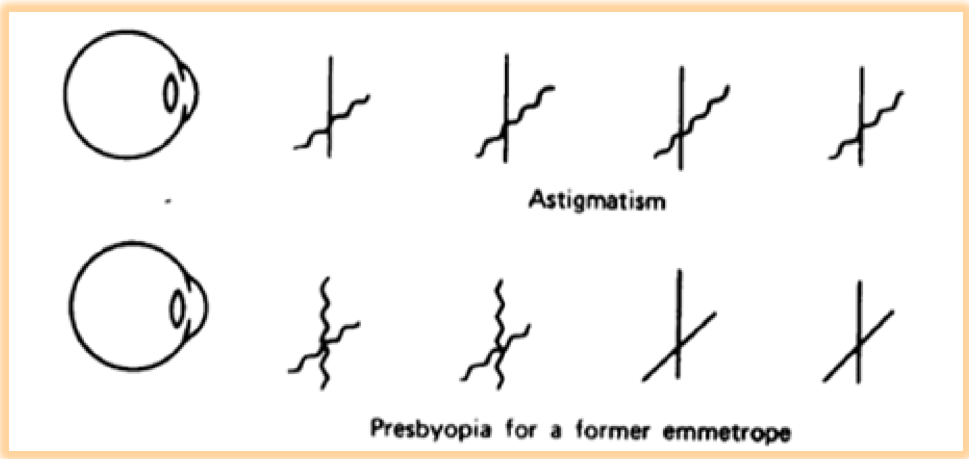


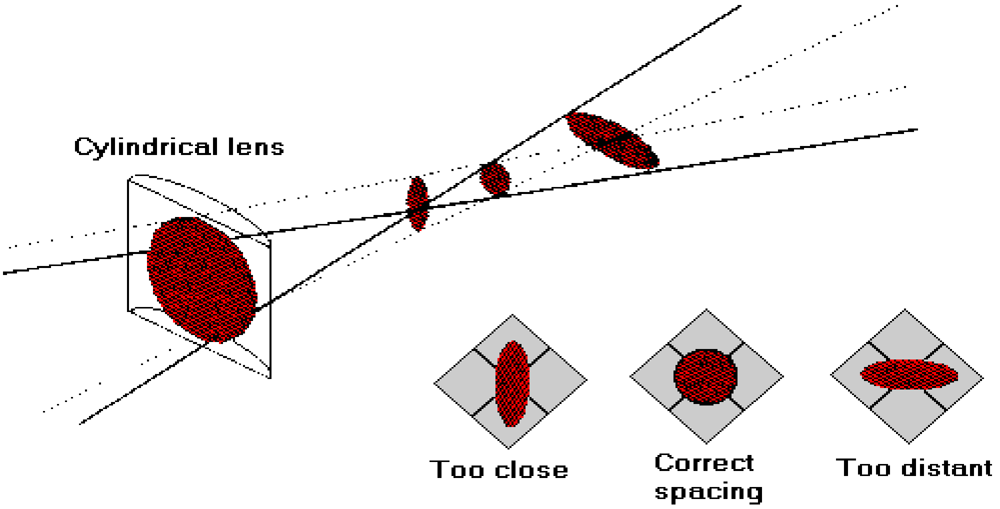
Presbyopia:

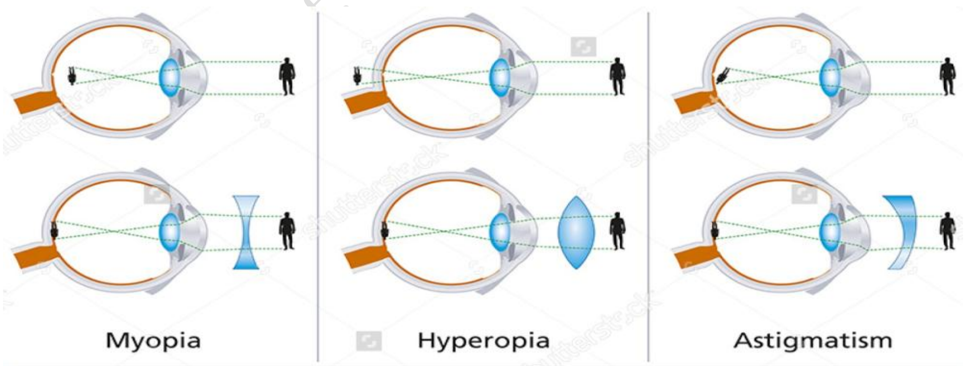
As people get older the cillary muscles weaken and lens losses some of its elasticity . The power of accommodation diminishes with age. This defect is corrected by two parts of lenses upper half of each lens is diverging and corrects the myopia when the wears is looking ahead at distance objects, the lower half corrects the presbyopia with a suitable converging lens, and the wearer looks through this part when reading .

Astigmatism:

When astigmatism is present, point objects do not form point images on the retina. This is normally due to the corneas unequal curvature in different directions. If the curvature is greater in a horizontal section than in the vertical section, rays brought to a focus more quickly in the horizontal than in the vertical plane. The defect is corrected by the use of cylindrical spectacle lenses.







EX 1: A man has a near point 50cm and far point infinity, what is his useful accommodating power.

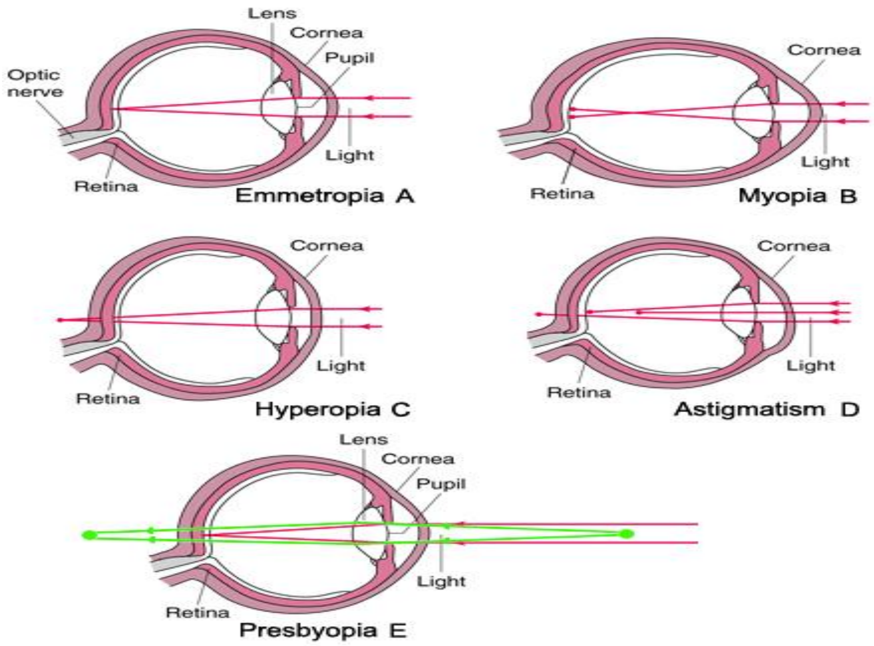
$P = 1/near\ point - 1/far\ point = 1/0.5m - 1/\infty$

$= 2\ Diopter$

EX 2: What spectacle lenses would be prescribed for the man of example 1.

$1/F_{\text{corrected}} = 1/n.p_{\text{for normal eye}} - 1/n.p_{\text{defected}}$

$1/F_{corrected} = 1/0.25m - 1/0.5m = 2$ Diopter
$F = 1/2$ Diopter $= 0.5m = 50cm$
EX 3: A myopic male has near and far point of 20cm and 250 cm respectively. What spectacle lens is prescribed for his defect and where is his near point.
$1/F_{corrected} = 1/f.p_{\text{for normal eye}} - 1/f.p_{\text{defected}}$
$1/F_{corrected} = 1/\infty - 1/2.5m = -0.4$ Diopter
$F = -2.5m$ the lens is diverging
The near point when wearing the spectacles will be
$1/F_{corrected} = 1/n.p_{\text{after wearing glass}} - 1/n.p_{\text{without glass}}$
$1/-2.5m = 1/n.p_{\text{after wearing glass}} - 1/0.2m$
$1/n.p_{\text{after wearing glass}} = 1/0.2m - 1/2.5m$
$= 5$ Diopter $- 0.4$ Diopter $= 4.6$ Diopter
$n.p_{\text{after wearing glass}} = 1/4.6$ Diopter $= 0.217m = 21.7cm$



A summary of various focusing problem and their characteristics:

Focusing problem	Common name	Usual cause	Corrected with
Myopia	Near-sighted vision	Long eyeball or cornea too curved	Negative lens
Hyperopia	Far-sighted vision	Short eyeball or cornea not curved enough	Positive lens

Astigmatism	-	Unequal curvature of cornea	Cylindrical lens
Presbyopia	Old-age vision	Lack of accommodation	Bifocals

Instruments Used in Ophthalmology

1. Ophthalmoscope: to examine the interior of the eye
2. Retinoscopy: to determine the prescription of a corrective lens
3. Keratometer: to measure the curvature of the cornea
4. Lensometer: to measure the focal length of a lens.
5. Tonometer: to measure eye pressure, applanation tonometer.

EX: If you wear corrective lenses ,you should carry a copy of your prescription .If you lose your glasses far from home ,you can have a new pair made without a re-examination .One prescription for glasses reads as follows:

	Sphere	Cylinder		Axis	Add
O.D.	-1.25	-1.25	×	180	+1.25
O.S.	-1.25	-1.25	×	180	+1.25

This means that the right eye (O.D.)(*Oculus Dexter*) needs a spherical lens of (-1.25 D) added to a cylindrical lens of (-1.25D) in the horizontal plane (180^{o}).In the reading portion of the bifocal ,a spherical lens (+1.25 D) is added to the above prescription ,that is ,the effective strength in the lower portion of the right lens is a cylindrical lens of (-1.25 D) to correct the astigmatism .
The prescription for the left eye (O.S.) (*Oculus Sinister*) is interpreted in the same way.

Color Vision and Chromatic Aberration

- Three colored cones
- Color blind: ~ 8% of men and ~ 0.5% of women
- Chromatic aberration

1. Lens defect due to change of the index of refraction with wavelength
2. Different colors are focused at different distances
3. Extreme case in Fig. 15.30 but usually not a problem.

A special color effect that is sometimes noticeable at dusk is called the *Purkinje effect* . Purkinje noticed that at dusk the blue blossoms on his flowers appeared more brilliant than the red blossoms .This effect is caused by the shift of the best sensitivity of the eyes toward the blue as the rods take over from the cones at low light levels ,since the eyes and corrective lenses are optimized for yellow light ,this shift toward the blue produces a refractive error of about(1.0D) .In other words, for night vision you should wear glasses with an additional (-1.0D)!

(H.W)

1. A man can see distinctly only objects which lie between 25 cm and 400 cm from his eye. What is the useful power of accommodation of his eyes? (3.75 D)
2. What spectacles should be prescribed for a man in problem 1? (-400 cm)
3. A hypermetropic male has a near point of 60 cm what lenses would be prescribed for him? (42.9 cm)
4. A man is prescribed spectacle lenses of focal length 75 cm.Where is the near point of his eye located? (37.5 cm)
5. A man while wearing spectacles of focal length – 200 cm sees clearly all objects lying between 25 cm and infinity. Where are the near, and far point of his unaided eye located? (22.2 cm, 200 cm).
6. A short –sighted man is prescribed diverging lenses of power 2.5 D. Where is his far point located? His near point is 10 cm from his eye, what is the closest distance at which he can see clearly when wearing the spectacles? (40 cm, 13.3 cm)
7. An elderly man can see distinctly only objects which lie in the range between 75 cm and 250 cm from his eye. What kind of spectacles does he required? (Bifocal of 37.5 cm and – 250 cm).
8. Bifocal lenses are prescribed for patient, the components having focal lengths of 40 cm and – 300 cm. What are the near and far points of the patient eye? (66.7 cm and 300cm).