PHYSICS OF EYES AND VISION

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Physics of eye and vision

By the end of this section, you will be able to:

1- Explain the image formation by the eye.

2- What is the power of the eye when viewing an object 50.0 cm away?

3- Analyze the accommodation of the eye for distant and near vision.

4- Identify and discuss common vision defects.

5- Explain nearsightedness and farsightedness corrections.

6- Explain laser vision correction.

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 <u>near sighted</u>.

2-Not enough curvature results in <u>far sightness.</u>

3-Uneven curvature produces <u>astigmatism</u>.

The lens has a flexible cover that is supported under tension by suspension fibers.

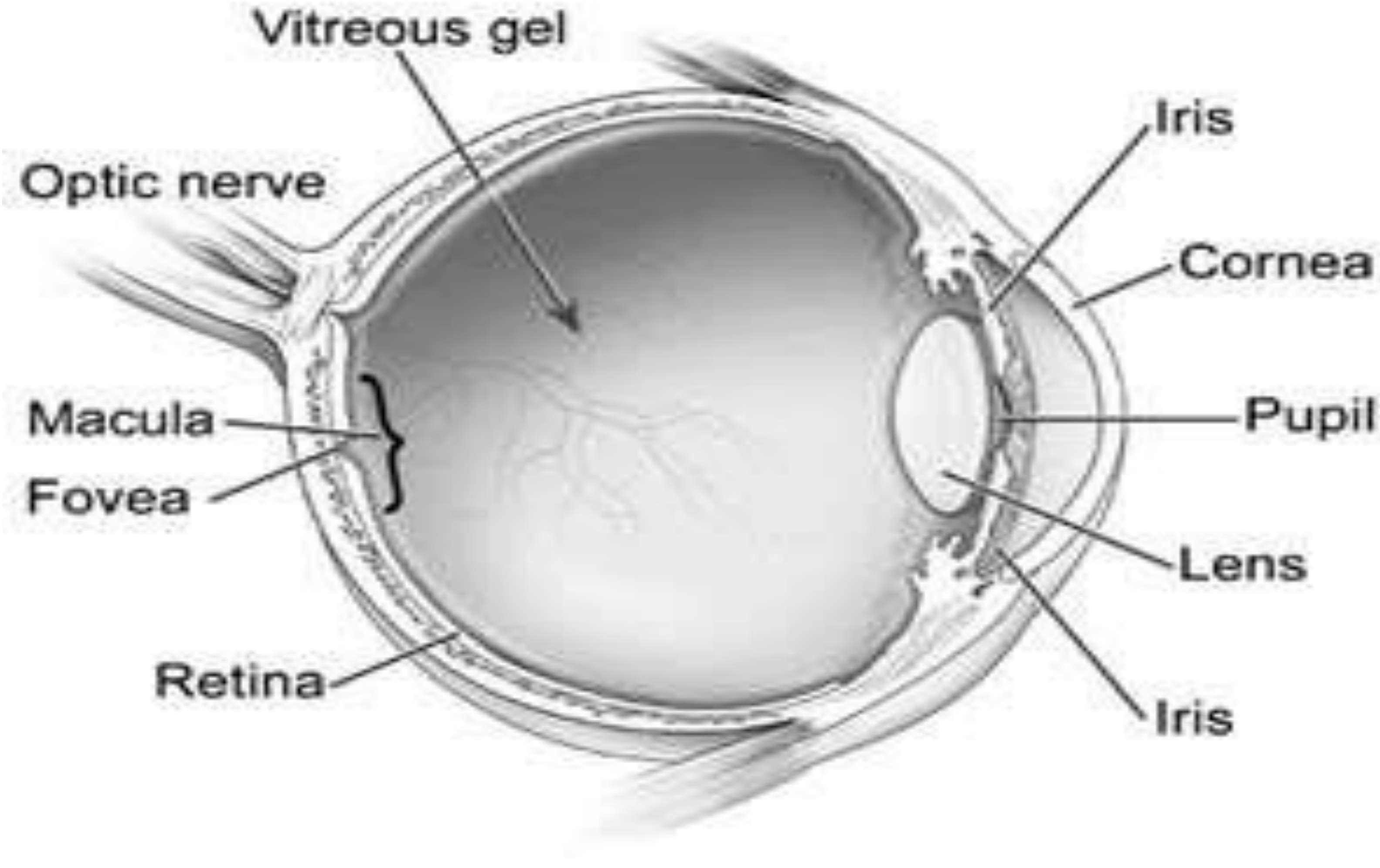
1-When the focusing muscle of the eye is relaxed this tension keeps the lens somewhat flattened and adjusted to its lowest power, and the eye is focused on distant objects. The point at which distant objects are focused when the focusing muscle is relaxed is called the <u>far point.</u>

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 <u>near point.</u>

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 <u>accommodation</u>.

4-As people get older, their lenses lose some accommodation, presbyopia (old sight) results when the lens has lost nearly all of its accommodation.

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

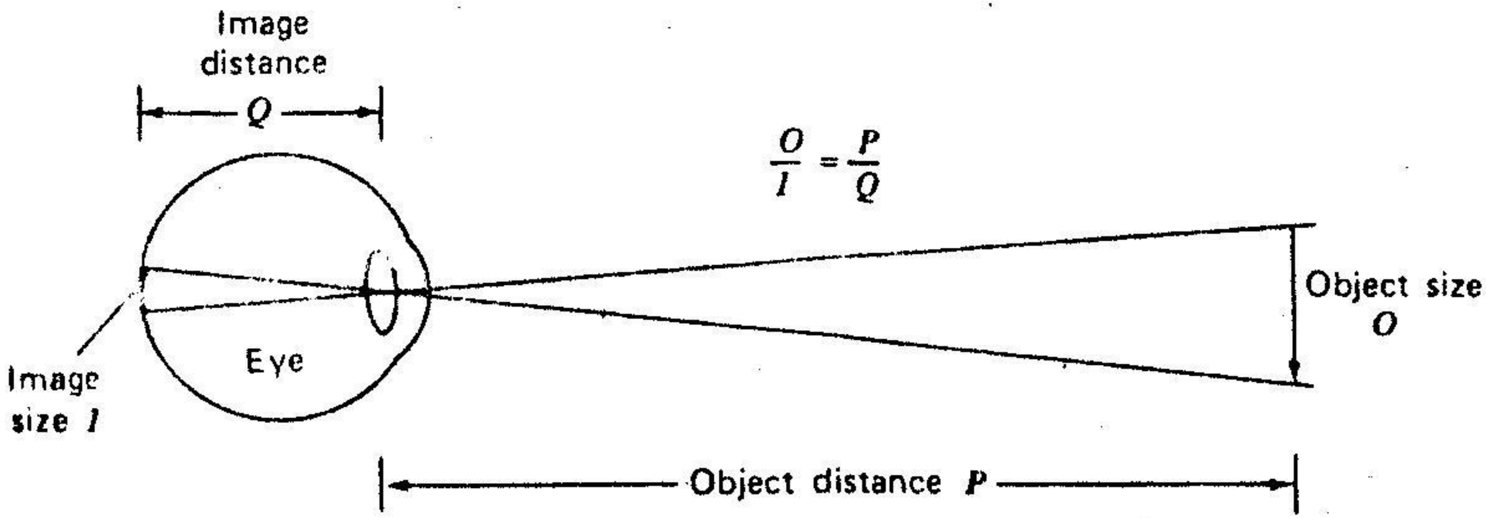
The retina, the light sensitive part of the eye, converts the light images into electrical nerve impulses that are sent to the brain. The absorption of a light photon in photoreceptor triggers an electrical signal to brain-an action potential. The light photon apparently cause a photochemical reaction 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 $O/P=I/Q$

EXAMPLE:

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.

$$I = 0.02/3 \times 0.03 = 2 \times 10^{-5}\text{m} = 20\mu\text{m}$$

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.

Microscopic Anatomy of the Retina

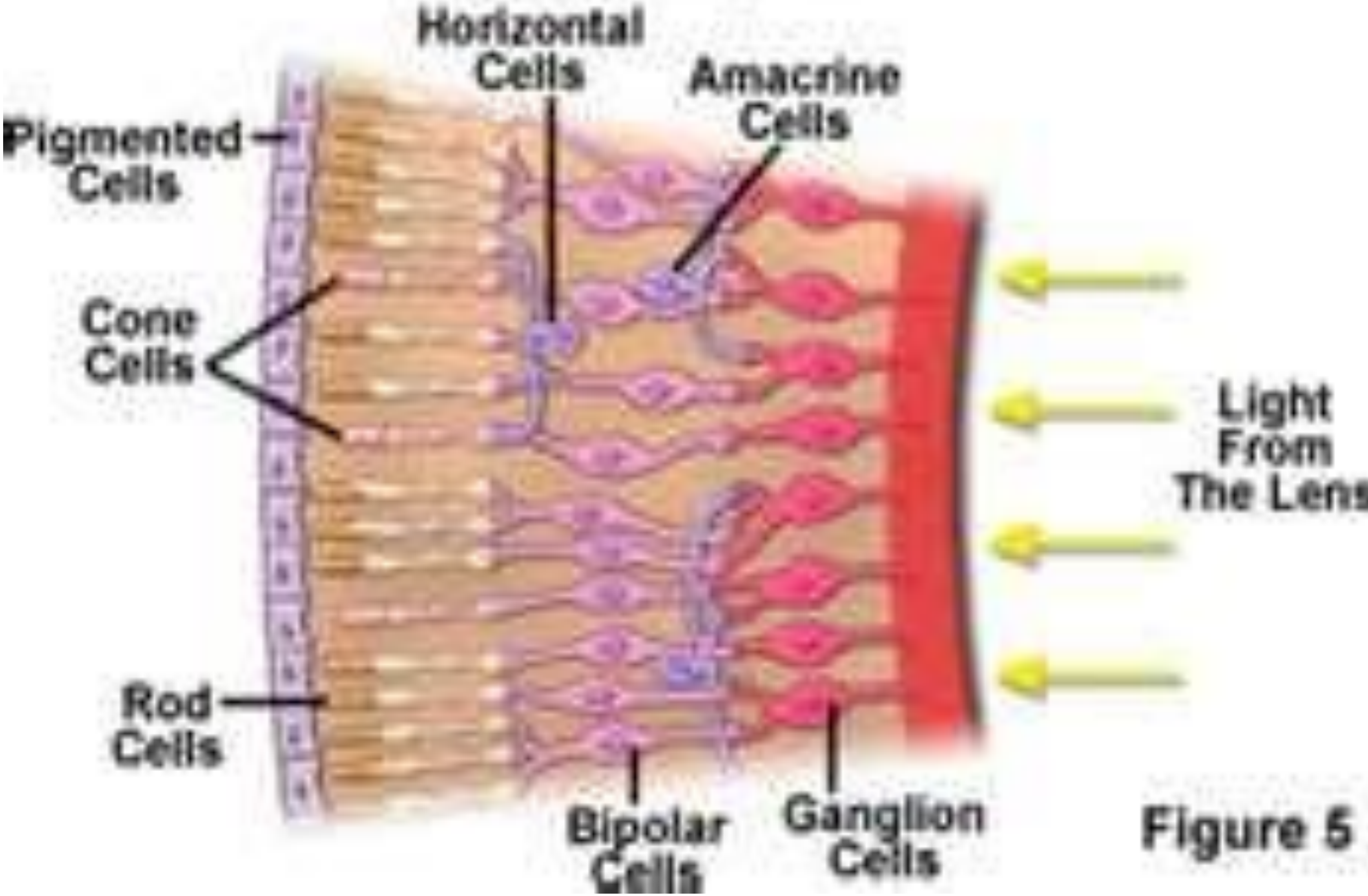
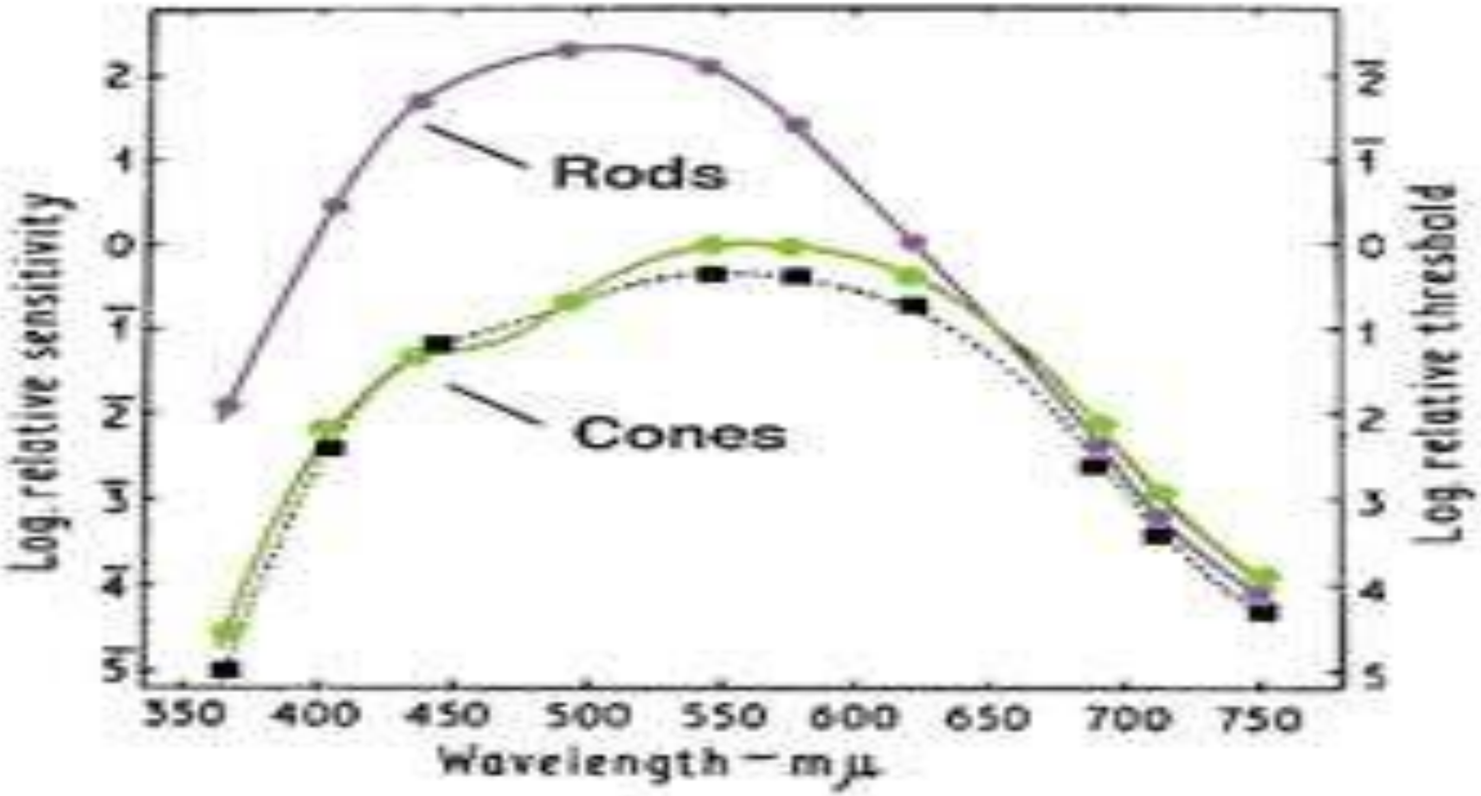
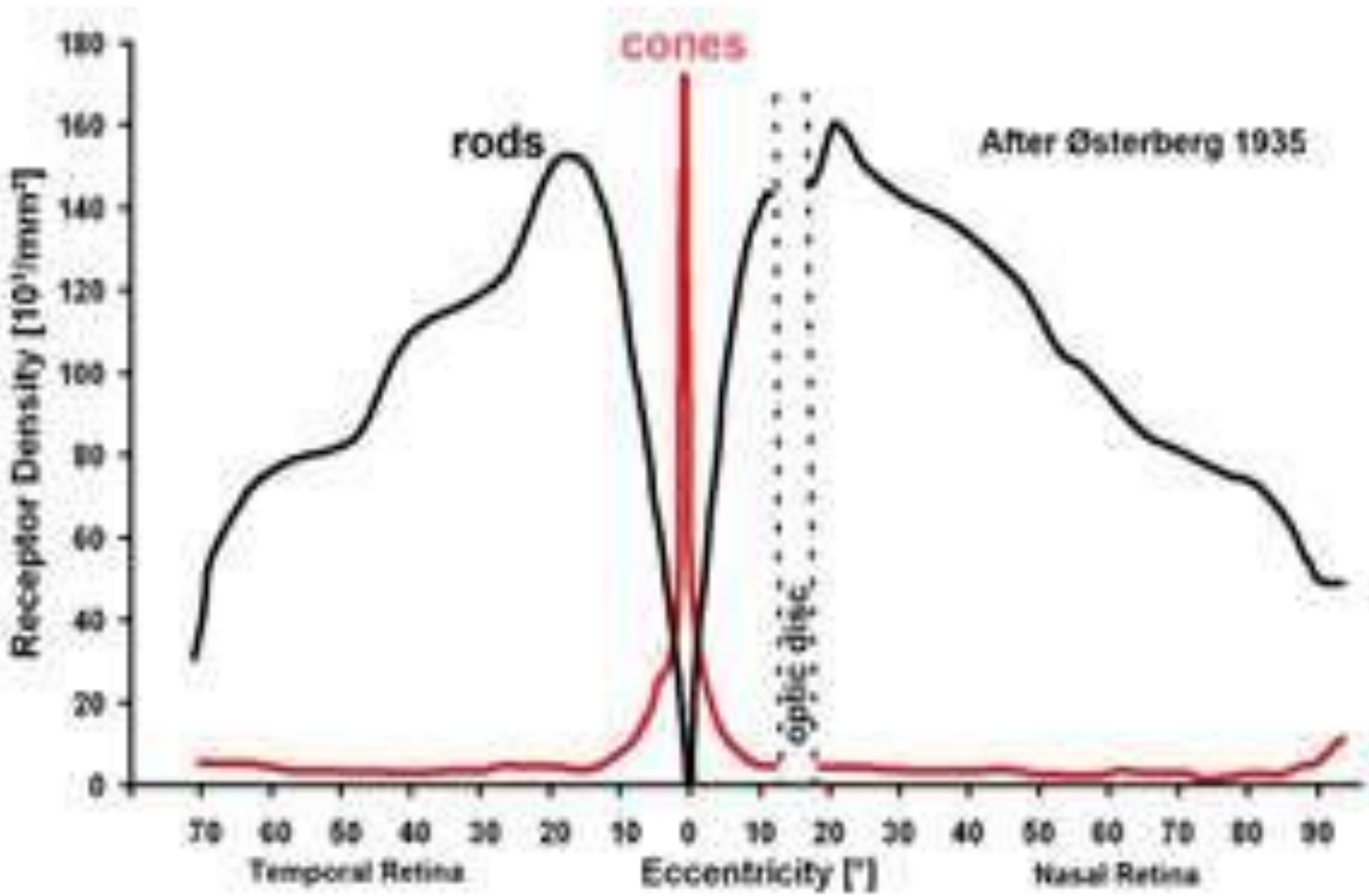


Figure 5

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 AND FOR PERIPHERAL VISION. THEY ARE NOT UNIFORMLY DISTRIBUTED OVER THE RETINA BUT HAVE A MAXIMUM DENSITY AT AN ANGLE OF ABOUT 20^{O}.


cones
rods
After Østerberg 1935
Receptor Density [10³/mm²]
180
160
140
120
100
80
60
40
20
0
optic disc
70 60 50 40 30 20 10 0 10 20 30 40 50 60 70 80 90
Temporal Retina
Eccentricity [°]
Nasal Retina

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 .

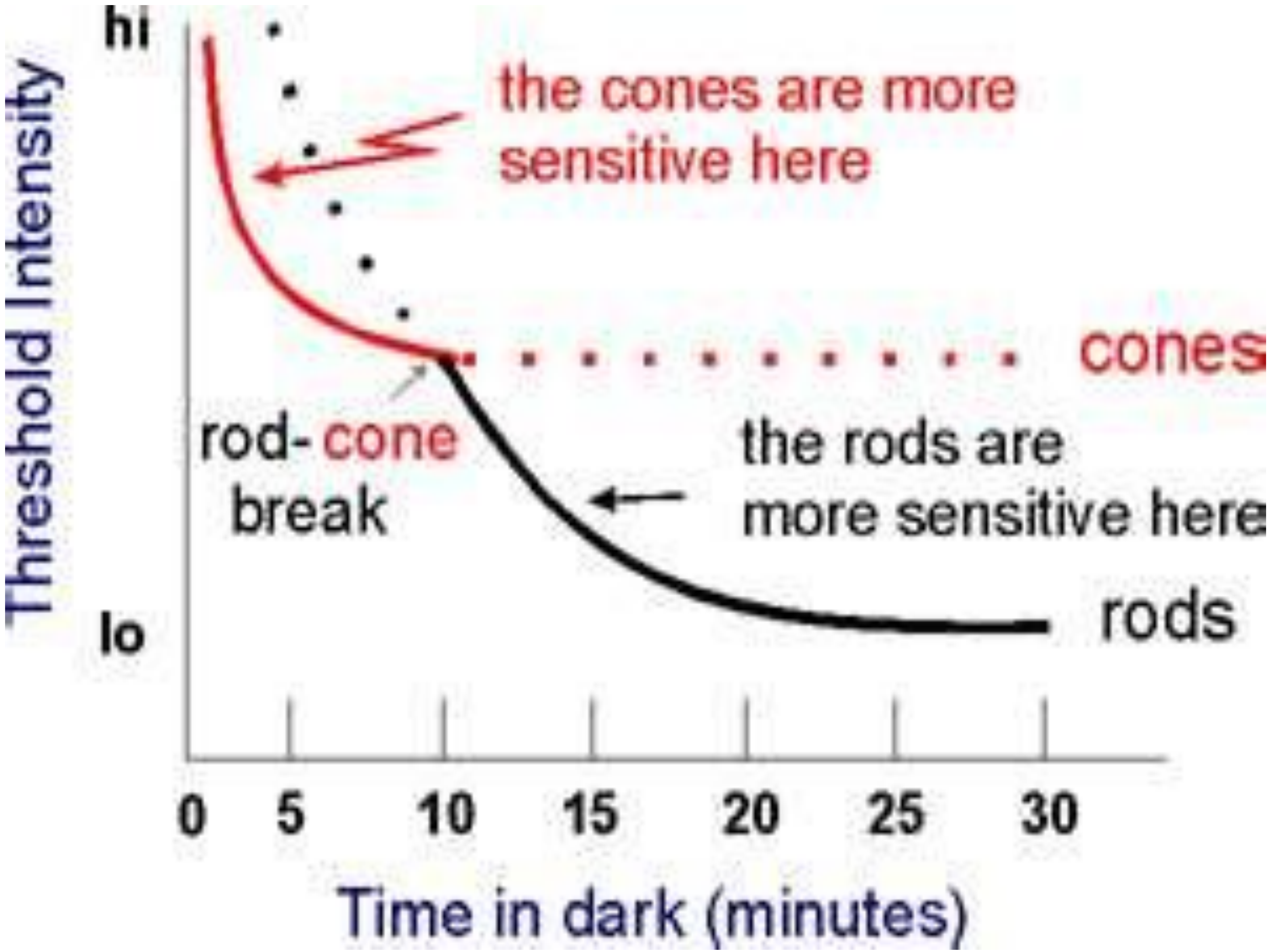
most sensitive to blue-green($\sim 510nm$)

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.

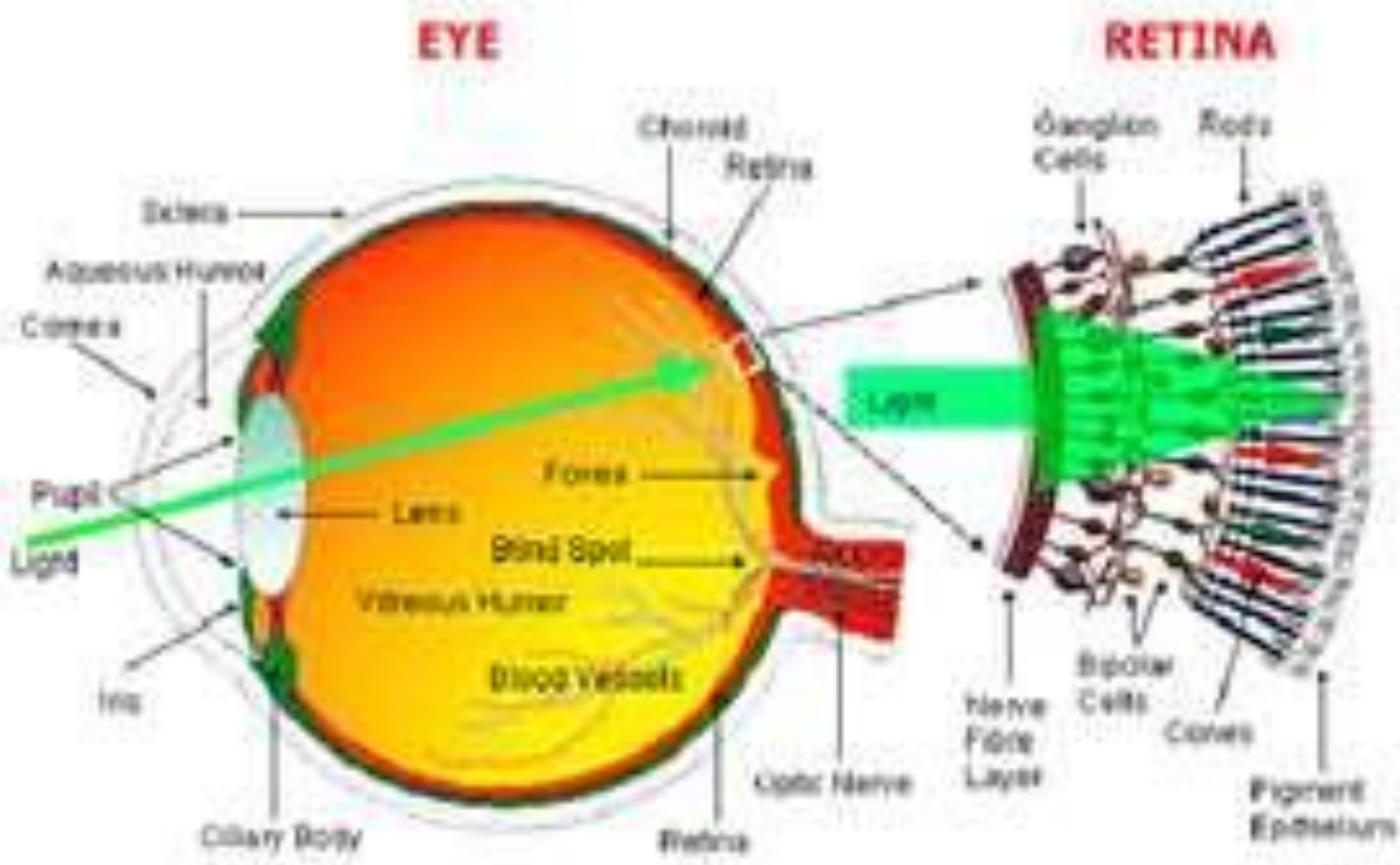
The cones adapt most rapidly; after about 5 min the fovea centralis has reached its best sensitivity. The rods continue to dark adapt for 30 to 60min, although most of their adaptation occurs in the first 15 min.



hi
lo
Threshold Intensity
the cones are more sensitive here
cones
rod- cone break
the rods are more sensitive here
rods
0
5
10
15
20
25
30
Time in dark (minutes)

Blind spot:

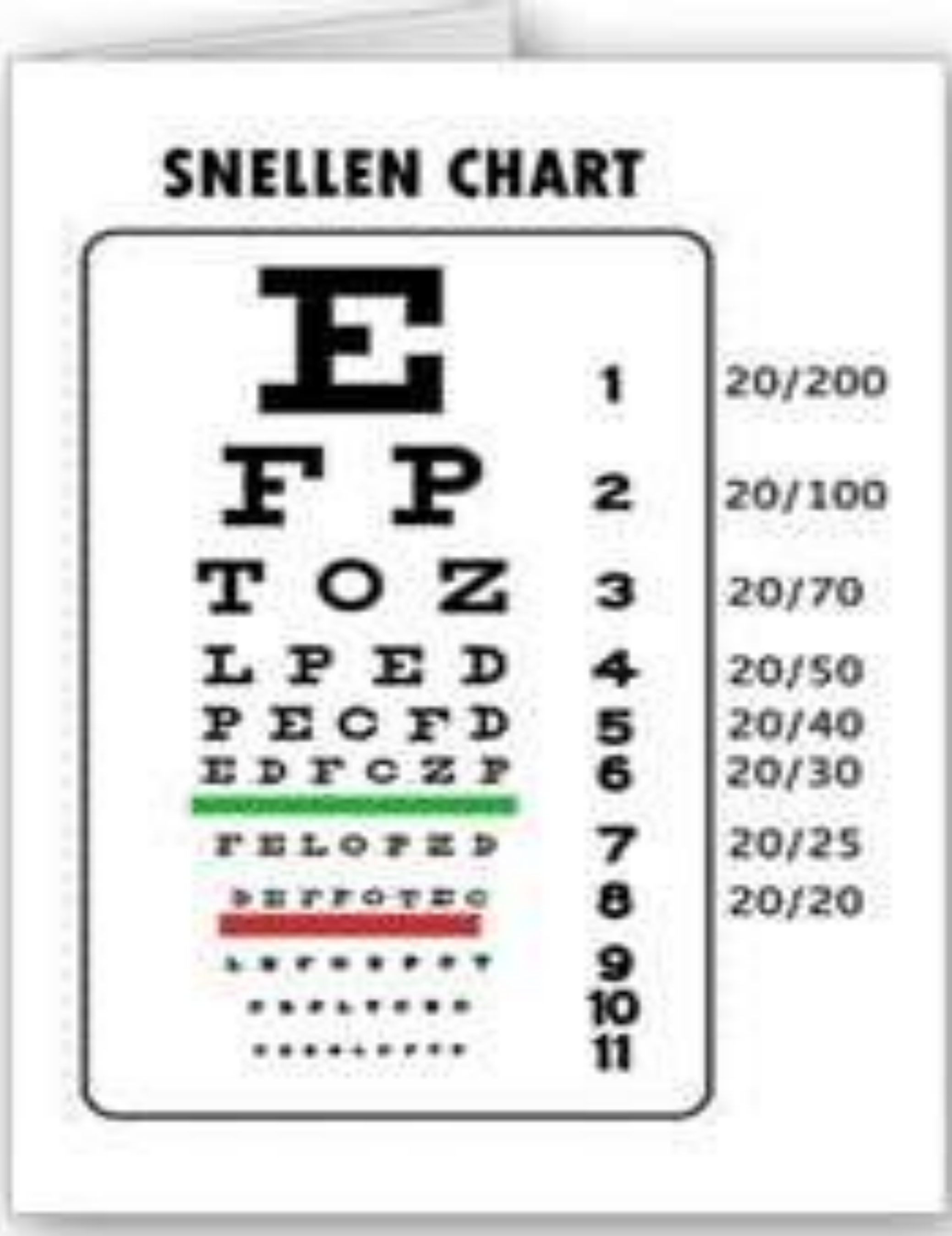
THAT HAS NEITHER RODS NOR CONES.
THAT THERE IS A REGION FROM ABOUT 13^{O} TO 18^{O}



Adopted from WEBVISION http://webvision.med.utah.edu/

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.


SNELLEN CHART
E
1
20/200
F P
2
20/100
T O Z
3
20/70
L P E D
4
20/50
P E C F D
5
20/40
E D F C Z P
6
20/30
F E L O P Z D
7
20/25
D E F P O T E C
8
20/20
9
10
11

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

$$OD = Log\ (I_o/I)$$

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

<u>EXAMPLE:</u> A piece of film that transmits 10% of the incident light has an optical density

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

<u>EXAMPLE:</u> A film that absorbs 99% of the light has an optical density

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

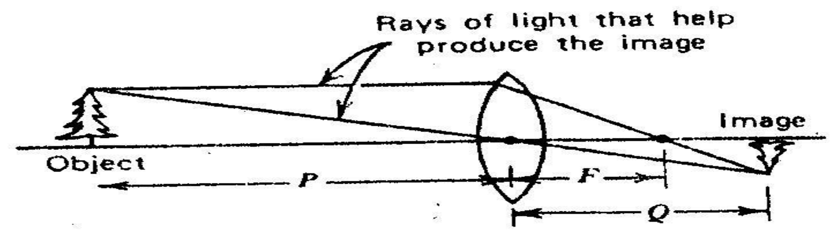
An OD=3 means that only 0.001 of the light transmitted.

DEFECTIVE VISION AND ITS CORRECTION

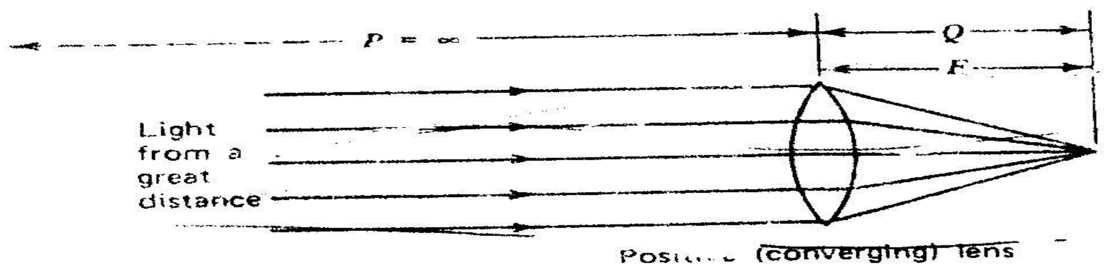
There is a simple relationship between the focal length **F**, the object distance **P**, and the image distance **Q** of the lens

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

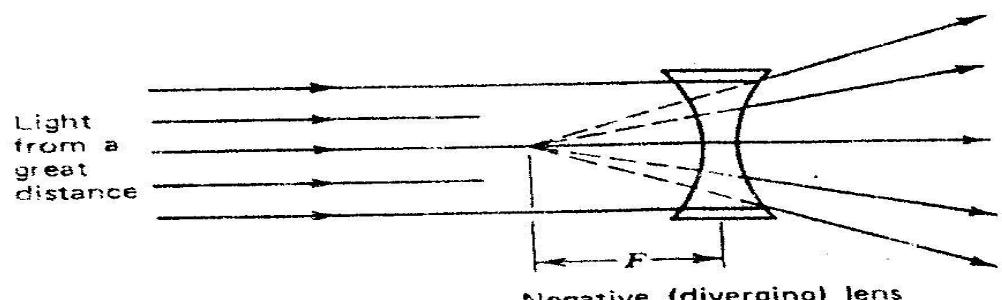
If **F** is measured in meters, then **1/F** is the lens strength in diopters **(D).**


Rays of light that help produce the image
Image
Object
P
F
Q

(a)


P = ∞
Q
F
Light from a great distance
Posit... (converging) lens

(b)


Light from a great distance
F
Negative (diverging) lens

(c)

The ability of the eye to focus on objects over a wide range is called accommodation.

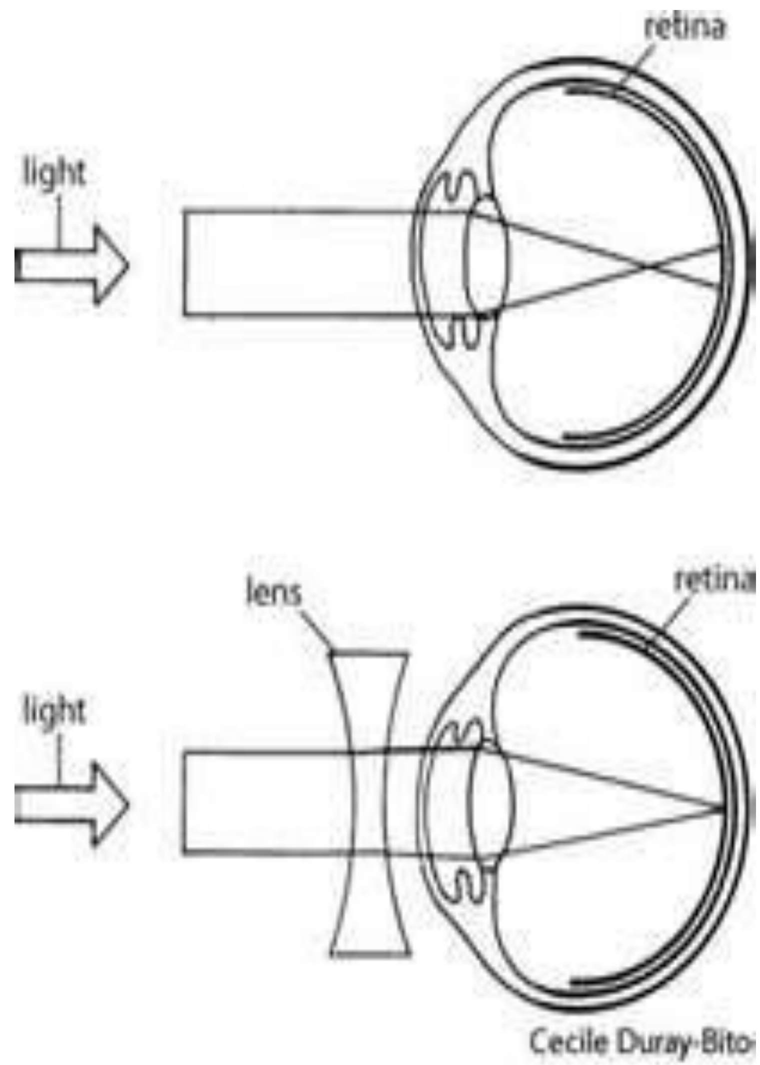
Power of accommodation of normal eye $= \frac{1}{F}$

$$= \frac{1}{near\ point} - \frac{1}{far\ point}$$

$$= \frac{1}{0.25m} - \frac{1}{\infty} = 4 \text{ Diopter}$$

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.

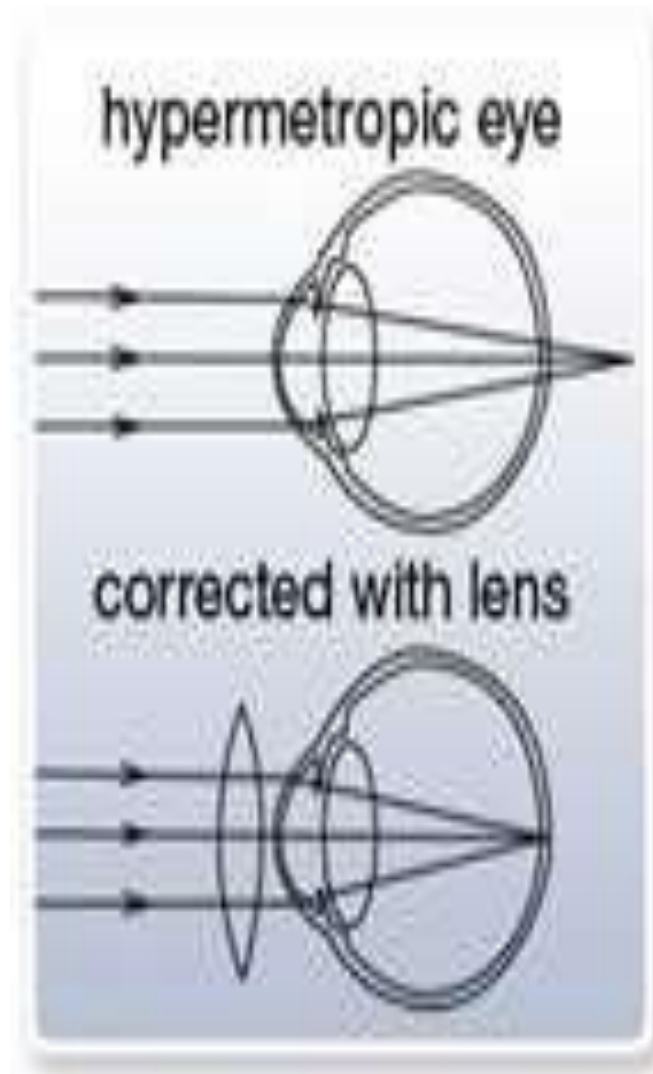


where $$\frac{1}{-F} = \frac{1}{x} - \frac{1}{d}$$

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.



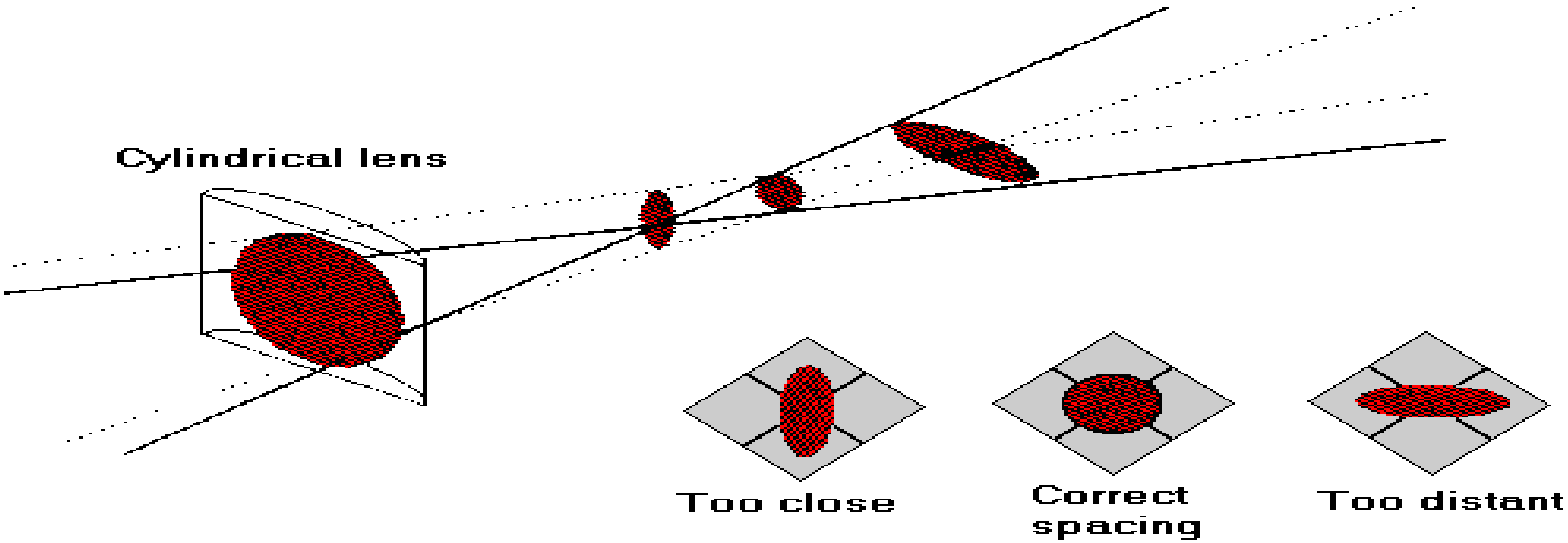
Where $$\frac{1}{F} = \frac{1}{d} - \frac{1}{d^1}$$

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

ASTIGATISM

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.

$$P = \frac{1}{near\ point} - \frac{1}{far\ point}$$

$$= \frac{1}{0.5m} - \frac{1}{\infty} = 2\ Diopter$$

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

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

$$1/F_{\text{corrected}} = 1/0.25\text{m} - 1/0.5\text{m} = 2 \text{ Diopter}$$

$$F = 1/2 \text{ Diopter} = 0.5\text{m} = 50\text{cm}$$

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.

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

$$1/F_{\text{corrected}} = 1/\infty – 1/2.5m = - 0.4 \text{ Diopter}$$

$$F = -2.5m \qquad \text{the lens is diverging}$$

The near point when wearing the spectacles will be

$$1/F_{\text{corrected}} = 1/n.p_{\text{after wearing glass}} – 1/n.p_{\text{without glass}}$$

$$1/-2.5m = 1/n.p_{\text{after wearing glass}} – 1/0.2m$$

$$1/n.p_{\text{after wearing glass}} = 1/0.2m - 1/2.5m$$

$$= 5 \text{ Diopter} – 0.4 \text{ Diopter} = 4.6 \text{ Diopter}$$

$$n.p_{\text{after wearing glass}} = 1/4.6 \text{ Diopter} = 0.217m = 21.7cm$$

H.W

1 –What is the power of the lens system of eye when the object viewed is

(a)- at infinity, (b)- at 500cm from eye, (c)- at 25cm from eye.

Answer

Power of lens = 1/ focal length = 1/F

(a)

$1/F = 1/P + 1/Q$ where P is object distance, and Q is image distance

$Q = 2cm$ or $= 0.02m$

$1/F = 1/\infty + 1/0.02 = 0 + 50 = 50$ Diopter

(b)

$1/F = 1/5 + 1/0.02 = 0.2 + 50 = 50.2$ Diopter

(c)

$1/F = 1/0.25 + 1/0.02 = 4 + 50 = 54$ Diopter

2 –What is the power accommodation of the eye of problem 1 ?

Answer

The range of vision between 0.25 m and infinity

Power of accommodation = 1/near point – 1/infinity

= 1/0.25 – zero = 4

Diopter

3 –A man can see distinctly object which lie between 25cm and 400cm from his eyes. What is the useful power of accommodation of his eyes?

Answer

Near point = n.p = 25cm = 0. 25m

Far point = f.p = 400cm =4m

Power of accommodation = 1/n.p – 1/f.p

= 1/0. 25 – 1/4

= 4 – 0.25 = 3.75 Diopter

4 –What spectacles should be prescribed for the man in the problem 3? If he reads a book while wearing these spectacles, what is the minimum distance from his eyes at which he can hold the book?

<u>Answer</u>

$1/F_{corrected} = 1/f.p_{for\ normal\ eye} – 1/f.p_{\ for\ defected\ eye}$

$1/F_{corrected} = 1/\infty - 1/4 = -0.25$ Diopter.

Negative lens, concave lens with focal length(-4m).

The minimum distance from his eyes » near point with wearing glass

$$1/F_{corrected} = 1/n.p_{after\ wearing\ glass} - 1/n.p_{without\ wearing\ glass}$$

$$-0.25 = 1/n.p_{after\ wearing\ glass} - 1/0.25$$

$$1/n.p_{after\ wearing\ glass} = 1/0.25 - 0.25 = 4 - 0.25 = 3.75\ \text{Diopter}$$

$$n.p_{after\ wearing\ glass} = 1/\ 3.75 = 0.27m = 27cm$$

5 –A hypermetropic male has a near point 60cm. What lenses would be prescribed for him?

<u>Answer</u>

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

$1/F_{corrected} = 1/0.25 - 1/0.6 = 4 - 1.66 = 2.34$ Diopter

$F_{corrected} = 1/2.34 = 0.427$ m

Positive lens, convex lens with focal length 42.7cm

6 –A man prescribed spectacle lenses of focal length +75cm. Where is the near point of his eye located?

<u>Answer</u>

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

$1/0.75 = 1/0.25 – 1/ n.p_{\text{for defected eye}}$

$1/ n.p_{\text{for defected eye}} = 1/0.25 – 1/0.75 = 4 – 1.34 = 2.66$ Diopter

$n.p_{\text{for defected eye}} = 1/2.76 = 0.375\ m = 37.5cm$

7 –A man while wearing spectacles of focal length -200cm sees clearly all objects lying between 25cm and infinity? Where are the near and far points of his unaided eye located?

$1/F_{corrected} = 1/n.p_{after\ wearing\ glass} – 1/n.p_{without\ wearing\ glass}$

$1/-2 = 1/0.25 - 1/n.p_{without\ wearing\ glass}$

$1/n.p_{without\ wearing\ glass} = 1/0.25 + 1/2 = 4.5$ Diopter

$n.p_{without\ wearing\ glass} = 1/4.5 = 0.22m = 22cm$

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

$$1/-2 = 1/\infty - 1/\ f.p_{for\ defected\ eye}$$

$$-1/2 = zero - 1/\ f.p_{for\ defected\ eye}$$

$$f.p_{for\ defected\ eye} = 2m$$

8 –Bifocal lenses are prescribed for a patient, the components having focal lengths of 40cm and -300cm. What are the near point and far points of the patient's eye.

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

$1/0.4 = 1/ 0.25 - 1/n.p_{\text{for defected eye}}$

$1/n.p_{\text{for defected eye}} = 1/0.25 – 1/0.4 = 4 – 2.5 = 1.5$ Diopter

$n.p_{\text{for defected eye}} = 1/1.5 = 0.66m = 66cm$

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

$$-1/3 = 1/\infty - 1/f.p_{for\ defected\ eye}$$

$$f.p_{for\ defected\ eye} = 3m$$

9 -A person has a myopic eye with a range of clear vision at distances from his eye of 0.15 m to 0.80m.

(a) Calculate the power of the correcting lens which would allow this eye to produce focused images of distant objects.

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

$$1/F_{corrected} = 1/\infty - 1/0.8 = -1.25 \text{ Diopter}$$

(b) Calculate the new near point position for the eye when using the correcting lens.

$1/F_{corrected} = 1/n.p_{after\ wearing\ glass} - 1/n.p_{without\ wearing\ glass}$

$-1.25 = 1/n.p_{after\ wearing\ glass} - 1/0.15$

$1/n.p_{after\ wearing\ glass} = 1/0.15 - 1.25 = 6.66 - 1.25 = 5.41$ Diopter

$n.p_{after\ wearing\ glass} = 1/5.41 = 0.184m = 18.4cm$

(b) Calculate the new near point position for the eye when using the correcting lens.

$1/F_{corrected} = 1/n.p_{after\ wearing\ glass} – 1/n.p_{without\ wearing\ glass}$

$-1.25 = 1/n.p_{after\ wearing\ glass} – 1/0.15$

$1/n.p_{after\ wearing\ glass} = 1/0.15 – 1.25 = 6.66 – 1.25 = 5.41$ Diopter

$n.p_{after\ wearing\ glass} = 1/5.41 = 0.184m = 18.4cm$

10 -A defective eye has an unaided near point at 0.65 m and an unaided far point at infinity. Calculate

(a) the power of the correcting lens needed to allow the eye to see clearly an object 0.25 m from the eye,

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

$1/F_{corrected} = 1/0.25 - 1/0.65 = 2.46$ Diopter

$F_{corrected} = 1/\ 2.46 = 0.426\ m = 42$