Anatomical considerations

- The eyeball has a diameter of about 2.5 cm. It is basically composed of three layers, which are, from without inwards, the **sclera**, the **choroid** and the **retina** .

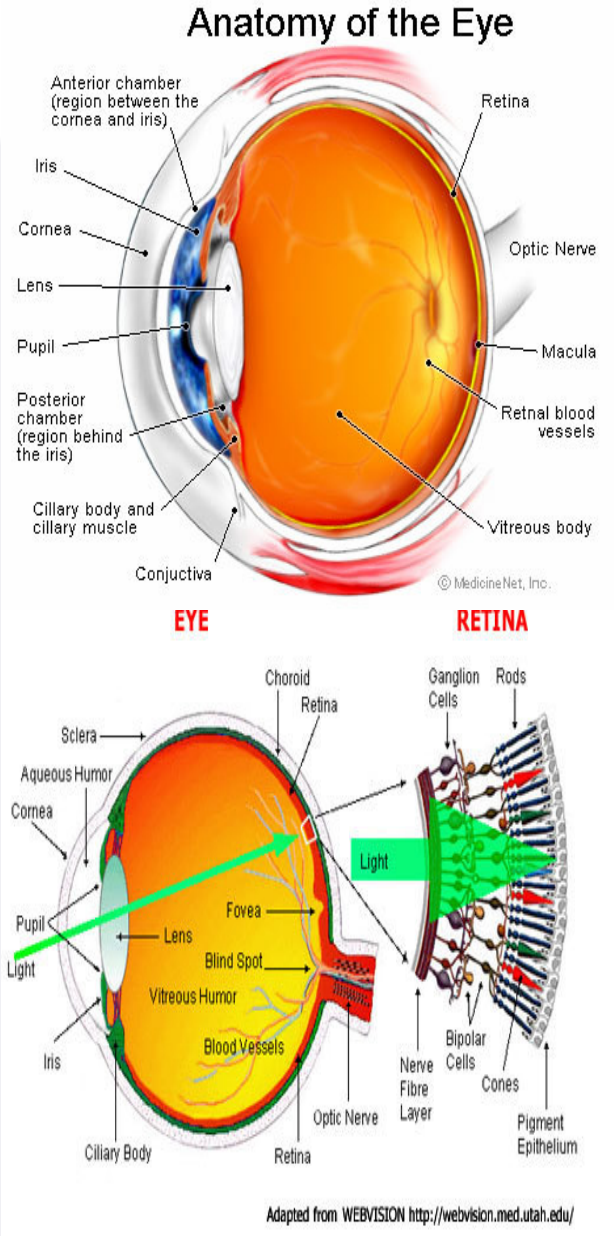
- **The sclera** consists of connective tissue, which is opaque, except anteriorly where it is modified by becoming transparent and more curved to form the ***cornea*** .

- **The choroid** is a pigmented layer with numerous blood-vessels. It is modified anteriorly to give the ciliary body and the iris.

✓ The ***ciliary body*** is a circular structure consisting of the *ciliary glands and smooth muscle.* The ciliary muscle consists of circular fibres and longitudinal fibres, which are inserted near the corneoscleral junction. Suspensory ligaments from the ciliary muscle are joined to the zonule or lens ligament. The lens is crystalline and biconvex, consisting of concentric laminae of elongated epithelial cells and surrounded by a capsule.

✓ The ***iris*** is the coloured part of the eye, with the aperture or *pupil* in its centre. It has circular smooth-muscle fibres, which constrict the pupil when they contract, and radial or longitudinal fibres, which dilate the pupil, in this way varying the amount of light that enters the eye. The circular fibres are supplied by *parasympathetic cholinergic nerves,* while the longitudinal fibres are innervated by *sympathetic adrenergic nerves.* Clinically, the pupil is usually dilated by instilling drops of atropine-like drugs into the eye, which paralyse the parasympathetic nerves.

- **The retina** lines the posterior two-thirds of the choroid and contains the receptors for light, the ***rods*** and ***cones.*** Medial or nasal to the anteroposterior axis of the eyeball is the spot where the optic nerve fibres leave the eye, called the *optic disc*, which measures about 1.5 mm in diameter. About 3 mm lateral or temporal to the optic disc and very close to the anteroposterior axis is the ***macula lutea*** (yellow spot), at the centre of which is a depression called the *fovea centralis.*



✓ The space between the retina and the lens is filled with a transparent gelatinous material, called the ***vitreous humour*** or body.

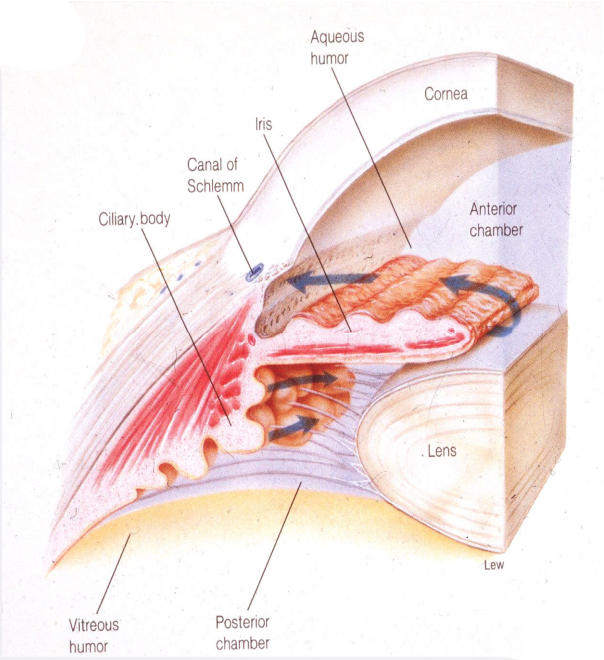
✓ The space between the cornea anteriorly and the iris and lens posteriorly is called the anterior chamber. The posterior chamber is the narrow circular space bounded anteriorly by the iris and posteriorly by the ciliary body and lens.

*Both the anterior and posterior chambers are filled with **aqueous humour.** This is a fluid similar in composition to the plasma without the proteins. but it has lower glucose and urea concentrations than in the plasma.*

- ✓ The lens is a vascular and metabolizes glucose taken from the aqueous humour.
- ✓ Aqueous humour is produced in the ciliary glands through active transport and diffusion.
  - The primary event is active transport of Na^+, followed by CI" and $HC0_3$ to maintain electrical neutrality; water follows the osmotic gradient created. Several nutrients, such as glucose and amino acids, move into the aqueous humour by carrier-mediated transport.
  - The aqueous humour moves forward in the posterior chamber, going between the lens and the iris into the anterior chamber, and moves on to the iridocorneal angle, between the cornea and iris and through trabeculae or vacuoles in the lining endothelial cells, to drain into the sinus venosus sclcrae or ***canal of Schlemm***. This continuous production and drainage into venous blood of aqueous humour maintains intraocular pressure at 10-20 mmHg.
- ✓ *A rise of pressure above 20 mmHg results in glaucoma*, one cause of which is blockage of the canal of Schlemm. ***Glaucoma*** may result in blindness because the increased pressure compresses the optic nerve fibers' and also the retinal artery at the optic disc.

External protection of the eye (a)

- The eye is protected by the **bony orbit** and by the **eyelids**, which have lashes on their edges and are lined on the inside by conjunctiva.
- Tear fluid is produced by **lacrimal glands,** which are located in the upper and outer part of the orbit. This fluid normally drains through the **nasolacrimal duct** into the nose. It is an isotonic solution of Na^+, CI^- and HCO^-_3, with a low protein content and a bactericidal enzyme called *lysozyme.*



- ✓ There is normally a film of tear fluid lining the conjunctiva and cornea.

  Blinking, occurring spontaneously at the rate of about 20 limes/min, is responsible for renewing this film. Blinking also occurs when the front of the eye is touched, when bright light is shone into the eye and in the case of a suddenly approaching object.

  In the case of irritation and when a foreign body enters the conjunctiva, the rate of tear secretion is increased, through a nervous reflex involving efferent *parasympathetic* fibers, in order to wash out the foreign body or irritant. Drainage capacity may be exceeded, in which case tear fluid spills over and runs on the checks; this is termed lacrimation (weeping). Lacrimation may also occur under emotional circumstances.

Clinical Applications

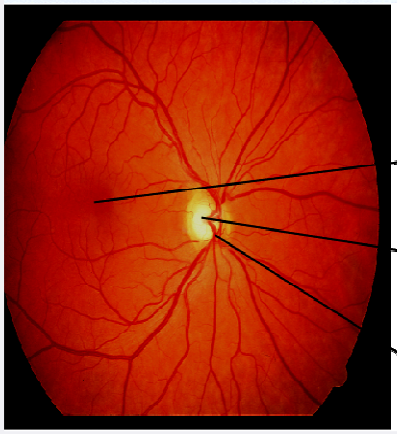
Opthalmoscopy:

- The **ophthalmoscope** is basically an instrument that illuminates the interior of the eye and the examiner, in effect, uses the eye lens of the subject as a magnifying glass to see the fundus.

✓ The optic disc is easily recognized, with retinal blood-vessels emerging from it;

✓ about two disc diameters laterally is the slightly darkish macula lutca, which is not crossed by blood-vessels.

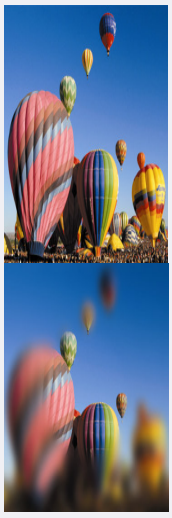
Examination of the fundus may reveal conditions **like *optic atrophy, papilledema*** *and* ***retinal detachment.*** In addition, viewing of the retinal blood-vessels constitutes the only opportunity to directly examine blood-vessels clinically. Examination of the fundus is therefore important in all diseases that may affect blood-vessels, particularly **hypertension** and **diabetes mellitus.** The retinal vessels supply the bipolar and ganglion cells of the retina. However, the receptor cells arc nourished mainly from the *capillary plexuses* present in the **choroid.** Therefore, ***retinal detachment*** is damaging to the *receptor cells.*



Disorders of the Eye and Vision:

Glaucoma

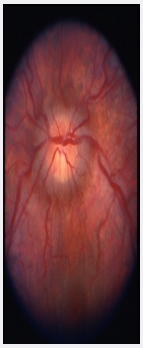
- Glaucoma is an eye condition that develops when *too much fluid pressure builds up inside of the eye.* The increased internal pressure can damage the optic nerve, which transmits images to the brain. Glaucoma usually occurs in both eyes, but it may involve each eye to a different extent.



✓ Without treatment, glaucoma can cause blindness within a few years. Glaucoma is most often inherited, meaning it is passed from parents to children. Less common causes of glaucoma include a blunt or chemical injury to the eye, severe eye infection, blockage of blood vessels in the eye and inflammatory conditions of the eye.

Papilledema

- Papilledema is the ***optic disc*** swelling that is caused by *increased intracranial pressure.* As the *optic nerve* sheath is continuous with the *subarachnoid space of the brain*, increased pressure is transmitted through to the optic nerve. Persistent and extensive optic nerve head swelling, or optic disc edema, can lead to loss of these fibers and permanent visual impairment.



Cataract

- A cataract is a painless, *cloudy area in the lens* of the eye.
- A cataract blocks the passage of light from the lens to the nerves at the back of the eye, and it may cause vision problems. Changes in the lens of the eye are part of the aging process but normally do not develop into cataracts. However, cataracts are very common in older adults. Cataracts can also occur after an eye injury, as a result of eye disease, after the use of certain medications or as a result of medical conditions such as diabetes.

Diabetic Retinopathy

- Diabetic retinopathy is an eye condition that affects people with diabetes who have high blood sugar over a prolonged period of time.
- Too much blood sugar can destroy the blood vessels in the back of the eye, causing damage to the retina. Without the retina, the eye cannot communicate with the brain, making vision impossible. In the early stages of diabetic retinopathy these blood vessels leak fluid and distort sight. In the more advanced stage of diabetic retinopathy fragile new blood vessels grow around the retina. If left untreated, these blood vessels may bleed, clouding vision or scar detaching the retina.

Photoreceptors : Rods & Cones

The retina:

- The retina has 10 layers. The arrangement of these layers can be appreciated when it is realized that the light receptors, the rods and cones, face the pigment layer towards the outer side of the eyeball, and that the rods and cones synapse with **bipolar neurons,** which synapse in turn with **ganglion cells,** the axons of which constitute the optic nerve fibres. The 10th layer is an internal limiting **membrane. Horizontal cells** make synaptic connections with and between receptors, while **amacrine cells,** having no axons but numerous processes, make horizontal connections between ganglion cells.

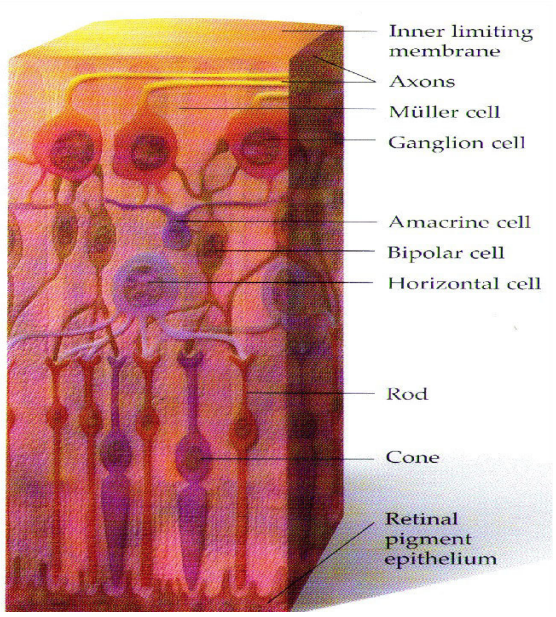
- Each eye has about 120 million rods and 6 million cones.

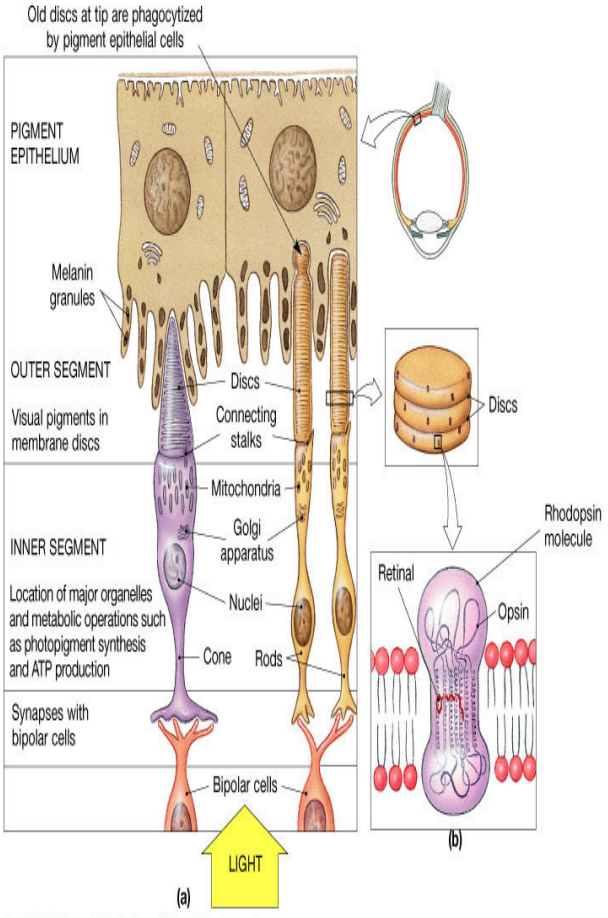
✓ Rods are extremely sensitive to light and operate under *dim light* conditions. Cones have a higher threshold and operate under *bright light* conditions.

✓ Each rod and cone has :

I. an outer segment, consisting of discs or saccules of membrane that contain a photosensitive pigment,

II. an inner segment, which is rich in mitochondria and includes the nucleus, and a synaptic terminal. The numerous mitochondria signify high metabolic activity, which is manifested by the presence of Na^+, K^+ adenosine triphosphatase (ATPase) in the membrane of the inner segments.

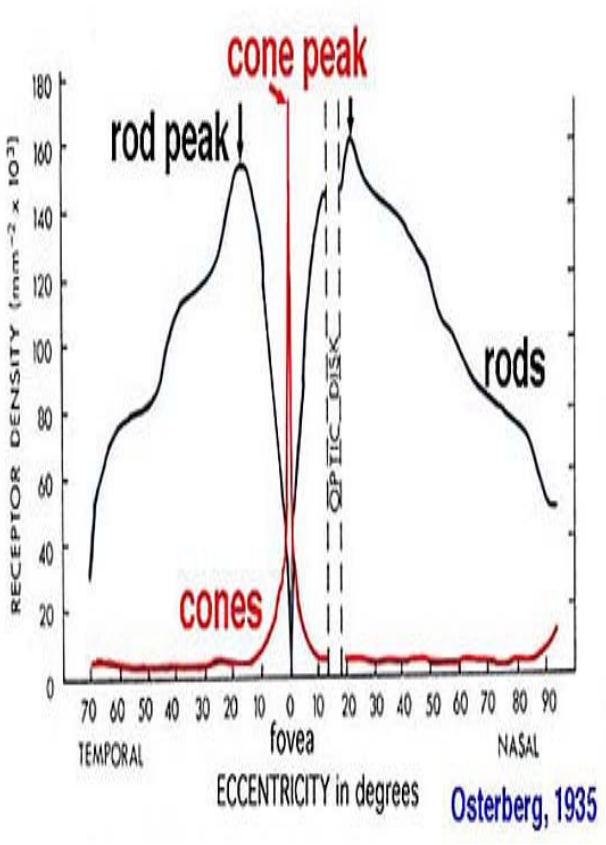




Photoreceptors : Rods & Cones

The retina:

- ✓ There are no rods or cones on the optic disc, which is consequently blind (the **blind spot).**
- ✓ The fovea centralis contains only cones. At the fovea, the blood-vessels and retinal neurons are displaced to the sides, so that light rays pass directly to the cones.
- ✓ The density of cones falls sharply in the periphery of the retina.
- ✓ The density of rods increases from outside the fovea towards the periphery of the retina.
- ✓ The fovea centralis is the spot with the highest acuity of vision: details of objects are distinguished and colour is appreciated. To see an object clearly, the head and eyes may be turned to face the object so that light reflected from it falls on the fovea centralis.

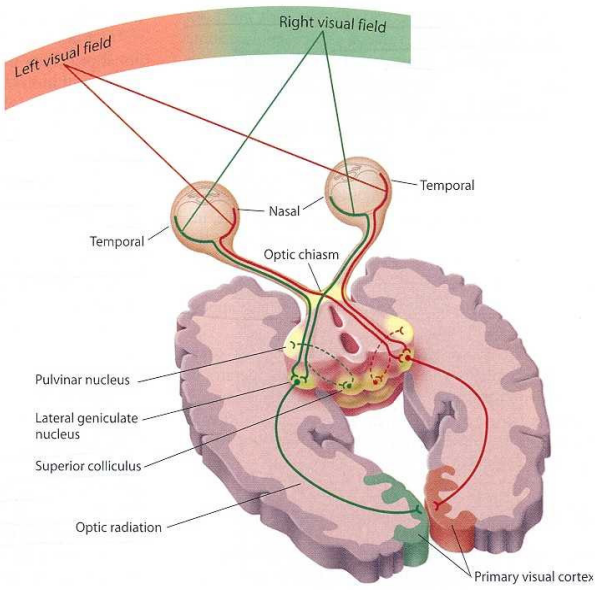


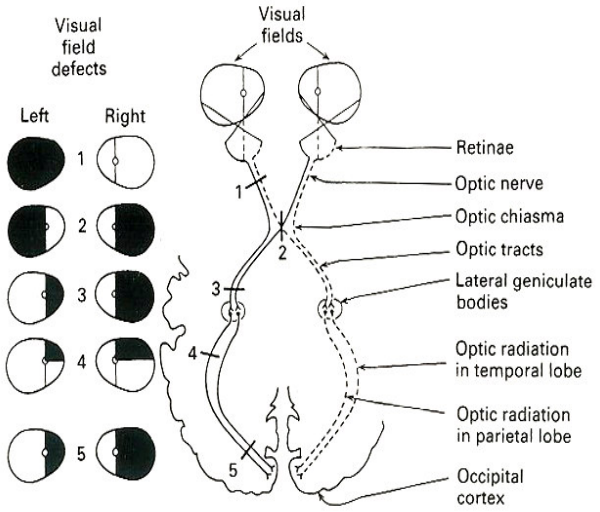
- There are 1.2 million fibres in the optic nerve. With 126 million receptors, one would expect converging connections of rods and cones with optic nerve fibres. Actually, one *foveal cone* synapses with one bipolar neuron and one ganglion cell, but about 10 *cones* in the periphery of the retina synapse with one bipolar neuron and one ganglion cell. In the case *of rods,* about 300 of them synapse with one bipolar cell and one ganglion neuron.

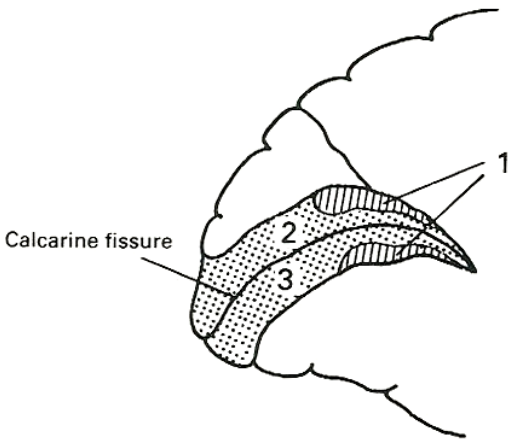
The visual pathways

Since light travels in straight lines, the right half of the retina views the left half of the field of vision and the upper half of the retina looks at the lower half of the visual field, and vice versa. It is noteworthy that, in the study of vision. the terms temporal and nasal are preferred to lateral and medial, respectively.

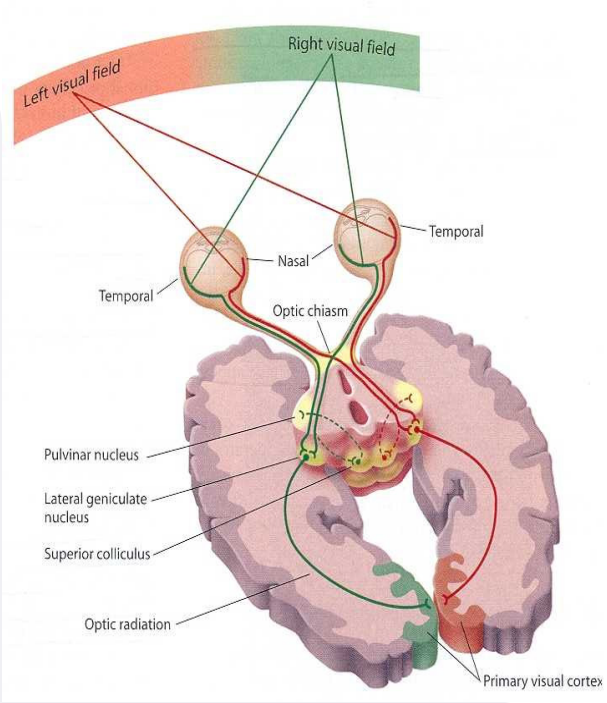
- The optic nerves emerge from the eyes to meet in the **optic chiasma,** where decussation of fibres occurs in a regular pattern: fibres from the temporal half of the retina on each side proceed on the same side, while fibres from each of the nasal halves of the retinae cross to the opposite side. Fibres from the macula on each side behave in exactly the same way. The **optic tracts** carry fibres from the retinal and macular halves of the same side, i.e. the right optic tract carries fibres from the right halves of both retinae and maculae, and fibres from the left halves of the retinae and maculae are carried in the left optic tract. For the **field of vision,** the directions are reversed, e.g. the left optic tract carries impulses coming from the right half of each field of vision. Optic tract fibres synapse in the **lateral geniculate body** of the thalamus. The grey matter of the lateral geniculate body has six layers; contralateral fibres end in layers 1.4 and 6, while fibres from equivalent spots on the ipsilatcral side of the retina end in layers 2, 3 and 5. Fibres arising from the lateral geniculate body ascend in the optic radiation to the **occipital cortex.** The **primary cortical visual area** for the same-side halves of the field of vision are projected to the inner side of the opposite hemisphere above and below the **calcarinc** fissure (Brodman's area 17). The macula is represented by a much larger area than the periphery of the retina, which is represented by small forward areas above and below the calcarine fissure. Nearby, areas 18 and 19 arc visual association areas, where recognition of objects and other cognitive functions associated with vision are performed.







The visual pathways



✓ Some fibres branch off from the optic tract just before entering the lateral geniculate body; they go to the pre-tectal area of the superior colliculus of the midbrain, where a synapse occurs and new fibres arise to go to the oculomotor (3rd cranial nerve) nucleus on both sides. This is the pathway for the *light reflex:* when light is shone on an eye, the pupil constricts; the opposite pupil also constricts—the **consensual light reflex.** The consensual reaction is due to the fact that illumination of the retina in one eye sends impulses in both optic tracts and that the fibres from the superior colliculus go bilaterally to the oculomotor nucleus. The pathway for the pupillary constriction that accompanies accommodation is some what **different,** as will be explained later.

Lesions of the visual pathways

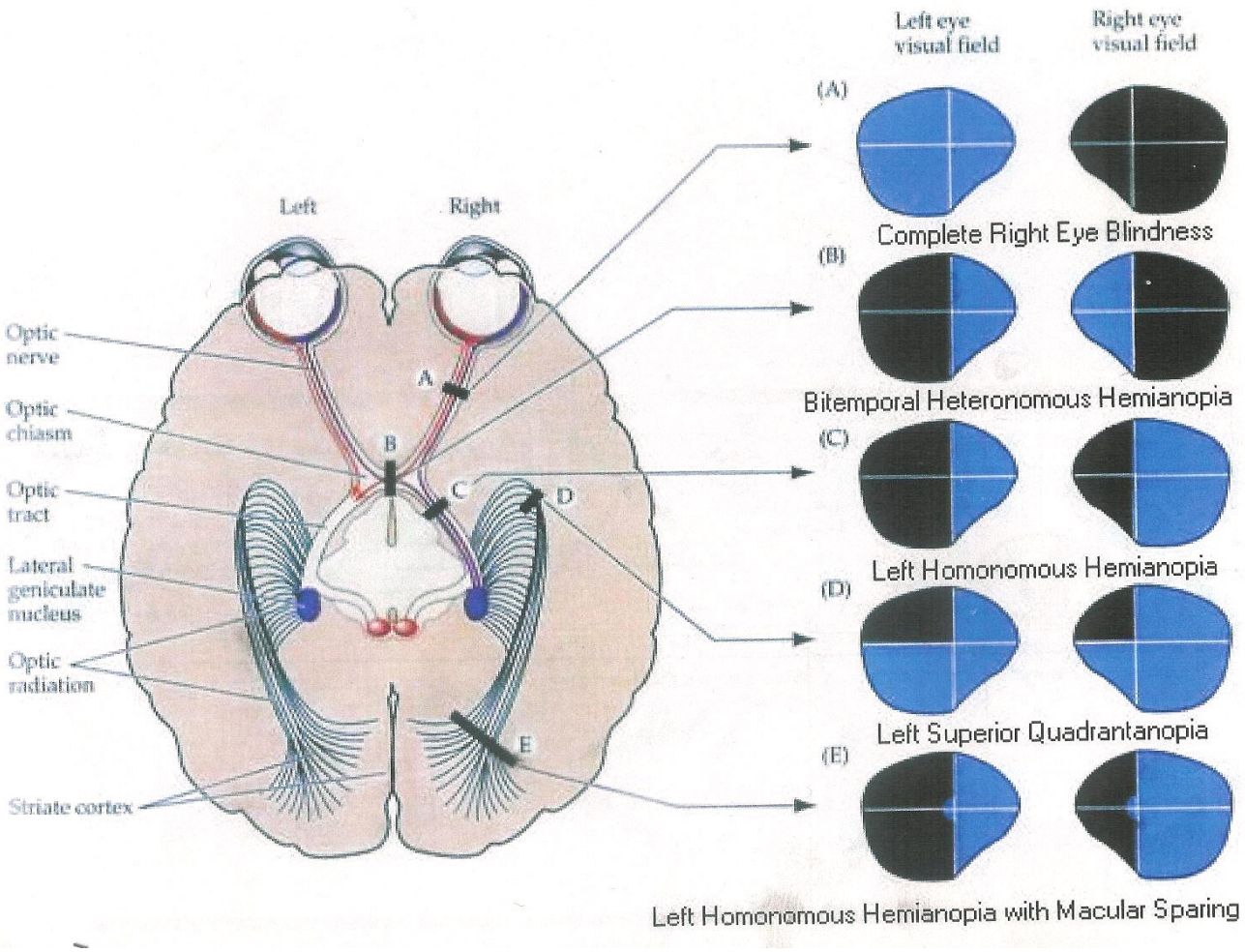
- A lesion interrupting the whole of the *optic nerve* results in complete blindness in the corresponding eye. Beyond the optic nerve, lesions may result in blindness in half the field on each side; this is termed **hemianopia**. When the same sides are affected, the hemianopia is homonymous; when opposite sides are affected it is heteronymous. The terms temporal and nasal, as well as right and left, are also used.

- If a lesion affects the central part of the *optic chiasma,* such as by pressure from a pituitary tumour, fibres from the nasal halves of both retinae are interrupted, leading to bitemporal hemianopia. which is heteronymous. A lesion pressing on the lateral sides of the chiasma would interrupt the fibres from the temporal halves of both retinae and would lead to binasal hemianopia, which is also heteronymous. Thus, chiasmal lesions lead to **heteronymous hemianopia**.

- Lesions of the *optic tracts,* optic radiation or one complete side of the occipital cortex, i.e. retrochiasmal, lead to homonymous hemianopia. There are, however, two special characteristics of *cortical lesions.* First, since the macula is represented by a much larger area than the periphery of the retina, a lesion may not destroy all macular representation, resulting in macular sparing in the field of vision. Secondly, since fibres from the upper and lower quarters of both sides of the retinae and maculae travelling in the optic radiations in the parietal and temporal lobes project to the occipital cortex, respectively, above and below the calcarine fissure, a lesion interrupting the optic radiation in either lobe may result in *quadmntic* visual field defects (4 in Fig.. A cortical lesion acting entirely above or below the calcarine fissure would also result in quadrantic defects in the field of vision.

Lesions of the visual pathways

- An important clue as to the location of the lesion in the visual pathways may be obtained by trying to elicit the **light reflex**. If light is shone on the blind half of the retina and the pupil constricts, it means that the pathway for the light reflex is intact; therefore, the lesion must be beyond the point where fibres leave the optic tract, just before the lateral geniculate body. If the light reflex is absent, the lesion must be in the optic nerve, chiasma or tracts before the fibres branch off.



The image-forming mechanism

Optics of the eye

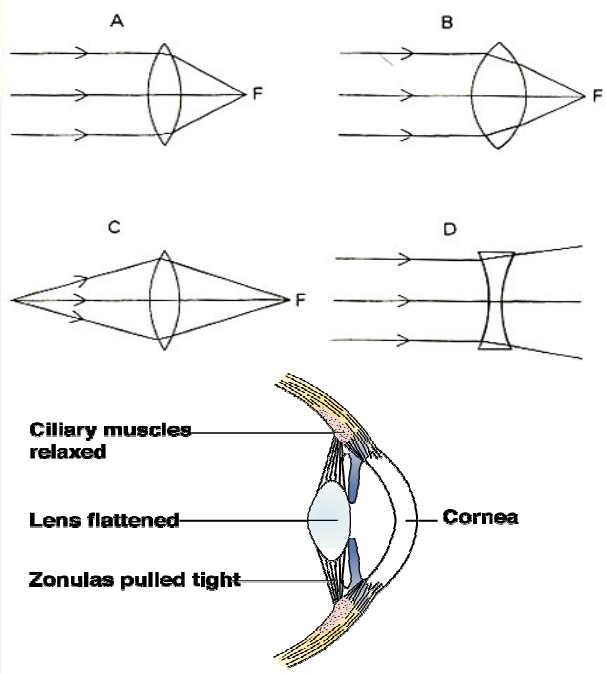
- Light rays coming from a distance greater than 6 m are considered *parallel;* those coming from less than 6 m away are considered *diverging.*

- When light passes from one medium to another medium of different density, it is **refracted** unless it strikes the interface between the two media perpendicularly.

✓ A biconvex lens converges parallel rays to a principal focus behind it (Fig. A,B,C).

✓ while a biconcave lens diverges parallel light rays, which may be extrapolated to give a **principal focus** in front (Fig. D).

✓ The more curved the lens, the more it will bend the light and the shorter will be the focal length (see Fig).



- The *power of a lens* (positive in the case of convex and negative in the case of concave) is measured in **dioptres (D).** The dioptric power of a lens is the reciprocal of the focal length in meters. Thus, a lens with a focal length of 25 cm has a power of 1/0.25 m or 4 dioptres, while a lens with a focal length of 10 cm has a power of 10 dioptres.

So .

$$\text{Dioptre (s)} = \frac{1}{\text{Focal length (m)}}$$

Cm = 1/100 m

The optically normal eye is termed **emmetropic.** In such an eye, parallel rays of light are refracted first by the cornea and then by the lens to be focused on the retina .

When a normal individual is looking at the horizon, light is coming in parallel rays, the **ciliary muscle** is *relaxed* and the lens is under tension, so that it is in its most flattened shape (see Fig) . The power of this resting eye is about 60 D, with the cornea accounting for about 40-45 D and the lens 15-20 D. While *more refraction occurs at the cornea,* the advantage of the lens is, as will be explained, its ability to become more convex and therefore increase its power.

The image-forming mechanism

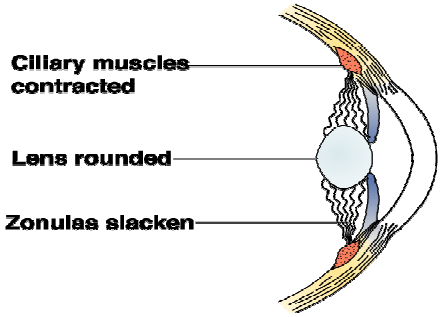
- When the gaze is transferred from a far object to a near object (from which light rays would be diverging), certain changes occur in the eye in order to focus the image of the near object on the retina. These changes are: (see Fig)

  1 Increasing the convexity or power of the lens, a process referred to as **accommodation.**

  2 Pupillary constrictions, so that light is concentrated on the more powerful centre of the crystalline lens.

  3 Convergence of the **visual axes,** such that they meet at the near object.

✓ The above changes are sometimes included under the term the *near response.*



Accommodation

At rest, the **ciliary muscle** is relaxed and the suspensory ligament is under tension, pulling the elastic lens into a flattened shape. In accommodation, both the circular and longitudinal ciliary muscle fibres *contract* and the whole ciliary body moves inward and forward, thereby relaxing tension on the suspensory ligament and allowing the *elastic lens* to become more convex. The increased convexity occurs mainly in the anterior surface of the lens. A number of dioptres are added to the power of the lens, allowing light rays to be focused on the retina (up to 12 dioptres in children).

So . according to accommodation :

- ✓ Ciliary Muscle Contracts
- ✓ Reduced Tension on Suspensory Ligaments
- ✓ Lens becomes Round
- ✓ Focus on Near Objects

Neural pathways for the near response

The ciliary muscle, the circular muscle in the iris and the two medial rectus muscles (responsible for *convergence* of visual axes) are all supplied by the oculomotor nerve, i.e. it is the final common pathway for the near response. Afferent fibres travel in the optic nerves through the chiasma to the optic tracts, synapse in the lateral geniculate body and *continue to the occipital cortex.* From there the fibres probably go lo the frontal lobes and then descend through the internal capsule to reach the oculomotor nucleus in the midbrain. It should be noted that the fibres to and from the cerebral cortex are exclusive to the neural pathways for the *near response.*

On the other hand, the fibres branching from the optic tract to the superior colliculus and proceeding to the oculomotor nucleus are exclusive to the pathway of the *pupillary light reflex.* A lesion in the pretectal region may occur in **neurosyphilis**, interrupting the **light reflex** but leaving the pathway for the near response intact, and resulting in the *Argyll Robertson pupil,* i.e. absent or sluggish response to light but constricting when looking at a near object.

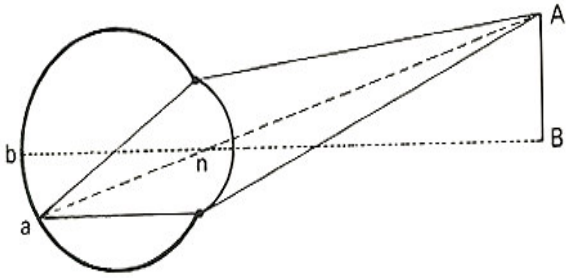
In Argyll Robertson pupils (Neurosyphilis): Pupils constrict in response: to accomodation reflex but not to the light reflex

Amplitude of accommodation and presbyopia

- If an object is brought gradually nearer and nearer to the eye, a point is reached when the object cannot be focused and appears blurred. The nearest point to the eye where an object can be clearly seen is called the **near point.** At the near point the dioptric power of the eye is maximal, being equal to the sum of the power of the eye at rest plus the number of dioptres added by increasing the convexity of the lens. These additional dioptres are the **amplitude of accommodation,** which can be obtained by subtracting the power of the eye at rest from the total power at the near point. If the resting dioptric power of the eye is taken as zero, the amplitude of accommodation in dioptres is given by the reciprocal of the distance of the near point from the eye in meters, e.g. if the near point is 10 cm away, the amplitude of accommodation would be 10 dioptres.

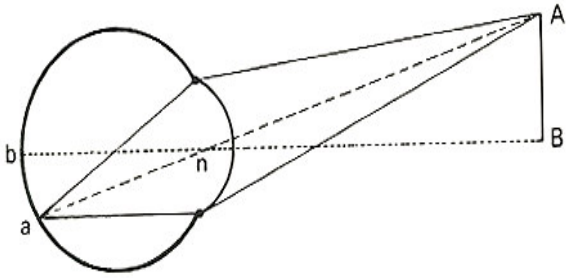
✓ With advancing age, the lens gradually loses its elasticity and therefore its capacity to increase its convexity. Consequently, the near point recedes and the amplitude of accommodation decreases with advancing age—a process called **presbyopia**. This is clearly illustrated in Table. By the age of 40-45 years, the near point starts to recede al a faster rate and close work becomes increasingly difficult. Many people beyond the age of 40 years require glasses with convex lenses for close work.

Age (years)	Near point (cm)	Amplitude of accommodation (dioptres)
10	9.0	11.0
20	10.0	10.0
30	12.5	8.0
40	18.0	5.5
50	50.0	2.0
60	83.0	1.2
70	100.0	1.0



The retinal image

The refractive index of each of the cornea, aqueous humour and vitreous humour is 1.33, i.e. about the same as water, while the lens has a refractive index of 1.42. Normally, light is refracted towards the normal by the cornea and by the anterior surface of the lens, and away from the normal by the posterior surface of the lens, to be focused on the retina. This process may be simplified by assuming that all refraction is occurring at the cornea, and by defining the optic centre or **nodal point** of the eye, as in the schematic or **reduced eye of Listing** (Fig.). Any light ray passing through the nodal point is not refracted, but rays passing through any other point are refracted to be focused on the retina. In humans, the distance of the nodal point from the retina is about 15 mm. For an object AB, the retinal image is represented by ab in Fig. 17.11. Thus, the retinal image is inverted and this inversion continues to the occipital cortex. From infancy, the brain is genetically programmed to reverse the inversion so that we see the world the right way up.



Triangles AnB and anb in last Fig. are similar and therefore:

$$\frac{AB}{ab} = \frac{Bn}{bn}$$

If the height of an object and its distance from the eye are known, and given that bn is equal to 15 mm, the size of the retinal image can be calculated.

Angle AnB is called the **visual angle.** It is the angle subtended by an object at the nodal point of the eye. Assessment of visual acuity, i.e. how well we can distinguish details in the field of vision, depends upon this angle. As long as two lines are separated by an arc of at least 1 minute and thus subtend a minimum visual angle of 1 minute at the nodal point, the distance between the two images on the retina will be 2 μm. In this case, two separate cones are stimulated by each point on the lines, leaving one unstimulated cone in between (the diameter of a cone is 1.5 μm). This means that the two lines are perceived as separate. Separation by an arc of less than 1 minute will stimulate two adjacent cones and the two lines will be perceived as a single line. Letters or symbols on charts which are used for assessing visual acuity are written so that the thickness of a line subtends a visual angle of 1 minute and the whole letter or symbol subtends an angle of 5 minutes at the nodal point. A subject stands at 6 m away from the chart and his/her visual acuity is given by the ratio d/D, where d is the distance from the chart (6 m) and D the distance indicated on the chart for the row that the subject has been able to read or identify correctly. Thus, normal visual acuity is 6/6, while a visual acuity of 6/12 is subnormal and indicates that the subject sees at 6 m what a normal subject can see at 12 m away.

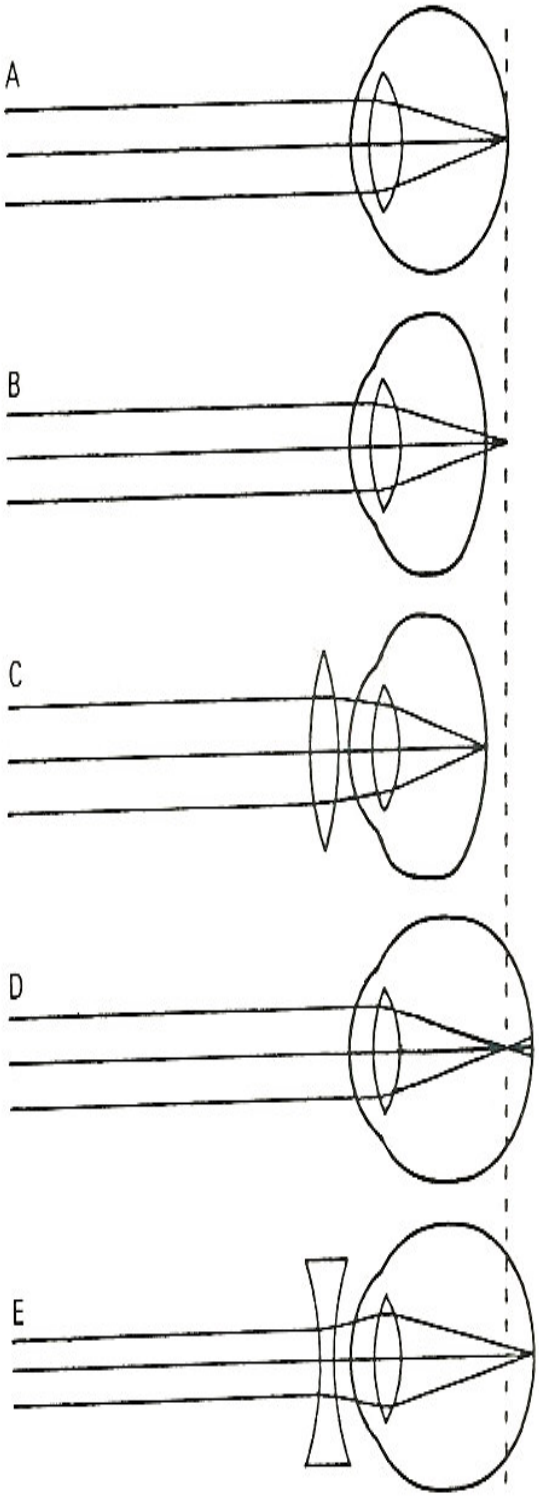
Errors of refraction

Abnormalities of the length of the eyeball or its refraetive power result in either **hypermetropia** (long-sightedness) **or myopia** (short-sightedness) (see Fig. 17.10). These abnormalities may be referred to as ametropia.

In hypermctropia the eyeball is *too short* and parallel rays of light are *focused behind the retina.* An affected individual has to employ some accommodation even for distant objects, leading to headaches and hypertrophy of the ciliary muscles from excessive use. The near point is further than the position in accordance with age so that glasses are required for close work at an earlier age. *Glasses with convex lenses are used to correct the defect.*

In **myopia** the eyeball is *too long* and parallel rays of light are brought to a *focus in front of the retina.* The far point becomes finite, i.e. the subject cannot see far, while the near point is too near for age and consequently the amplitude of accommodation is reduced. A myopic individual would not require glasses for close work, even in his/her old age. *The defect is corrected by biconcave lenses.*

Astigmatism.
This is a condition in which *the curvature of the cornea is not uniform*; rarely, the lens may be affected. Light refracted by one meridian is focused differently from light refracted by another unequal meridian. Typically, an individual affected by astigmatism cannot focus vertical and horizontal lines on graph paper at the same time. *The defect is corrected by cylindrical lenses,* which focus light to a line, thus correcting the curvature in a certain meridian and ensuring the overall uniformity of curvature.



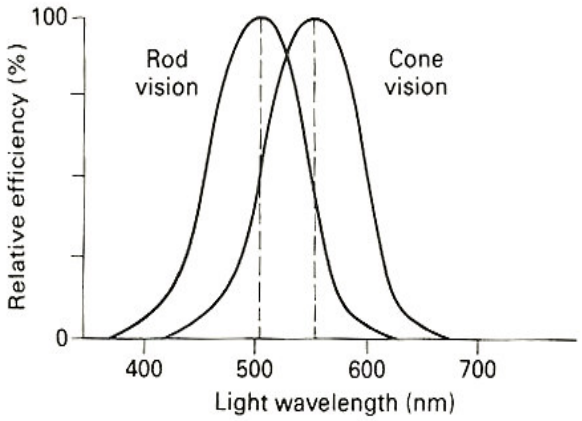
The duplicity theory

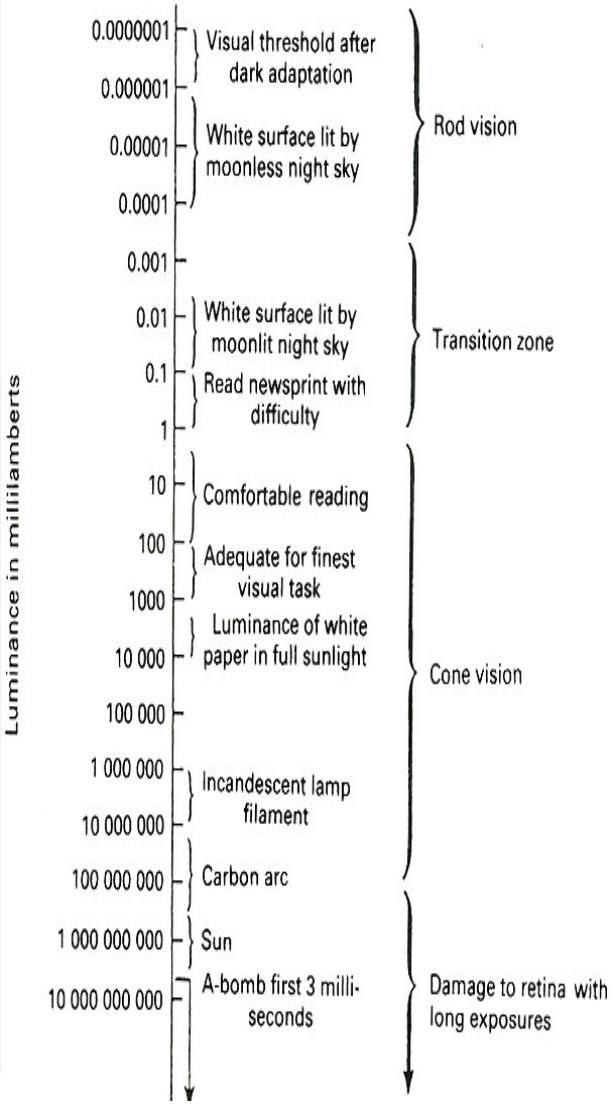
The visible spectrum extends from the 397 nm to the 723 nm wavelength of light. Within this range, the eye can function under two conditions of illumination: **dim light** and **bright light.** Vision in dim light is termed **scotopic vision** and in this type only the outline of objects in the field of vision can be distinguished; no details or colour can be appreciated. **Photopic vision** is employed in bright light and in it the details of objects, as well as their colour, can be distinguished. The presence of scotopic and photopic vision and the consequent double input from the eye to the central nervous system are the elements of the **duplicity theory.**

The scotopic visibility curve peaks at the 505 nm wavelength, while the photopic curve peaks at the 550 nm wavelength of light (Fig.).

Scotopic vision is served by the rods, while pholopic vision is due to the cones. This has been proved by the finding that the light absorbance of the rod pigments, rhodopsin, coincides almost exactly with the scotopic visibility curve, peaking at the 505 nm wavelength of light. The cones have three pigments, each most sensitive to one of the primary colours (see below). The light absorbance curve of a mixture of the three pigments also coincides with the photopic visibility curve, peaking at the 550 nm wavelength. It should be noted that the Y axis in Fig. is relative sensitivity, i.e. maximal sensitivity in both cases is taken as 100% and lesser sensitivities are expressed as a percentage. If absolute sensitivity values were employed, the curves would be of the same shape but the scotopic curve would be much higher than the photopic curve.

- ✓ Figure shows the range of luminance within which the eye may function. Note the great sensitivity of rod or scotopic vision and that there is a transition zone between rod vision and cone vision.



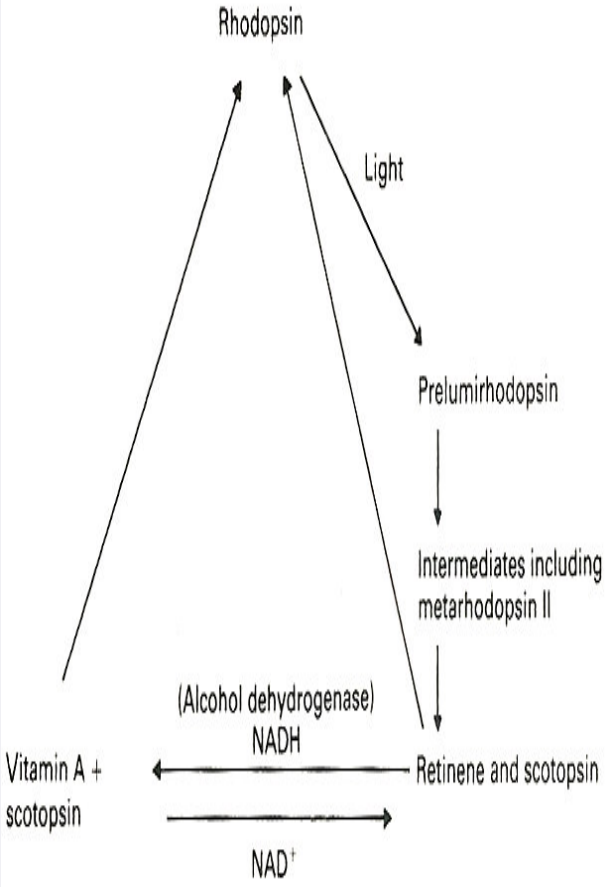


Photosensitive pigments

The pigments in the outer segments of rods and cones have two components: retinene, which is the aldehyde of vitamin A (retinol), and a protein called **opsin.** Retinene is the same in all the pigments; *differences between the pigments are in the amino acid sequence of the opsin.*

- The opsin in **rhodopsin** is termed **scotopsin.** The amino acid sequence of scotopsin is determined by a gene on chromosome 3. Light bleaches rhodopsin or separates it into *retincne and scotopsin.* Recent work has shown that light actually acts only on retinenc, changing its isomerism from the 11-*cis* form to the all-*trans* form. The shape of retinene is changed, giving rise to prelumirhodopsin, which subsequently changes to some intermediates, including metarhodopsin II, before being hydrolysed to retinene and scotopsin. Retinene and scotopsin may re-combine to reconstitute rhodopsin. More slowly, retinene may be changed back to vitamin A, under the influence of the enzyme alcohol dehydrogenase, and vitamin A with scotopsin may regenerate rhodopsin. These changes are summarized in the Fig.

- The action of light on the cone pigments is probably similar. The action of light on the photosensitive pigments in the outer segments of rods and cones results in the generation of receptor potentials, which lead to action potentials in the optic nerve fibres, as will be explained later. The role played by vitamin A in rod function explains the fact that deficiency of this vitamin leads to impairment of the ability to see in dim light and may result in night-blindness or *nyctalopia.* With persistent vitamin A deficiency, cone function may also be affected.



The cone pigments and colour vision

- The primary colours are red, green and blue. When red light (wavelength 723-647 nm), green light (575-429 nm) and blue light (492-450 nm) are mixed, white light or any spectral colour may be obtained. The **Young-Helmholtz** theory explaining colour vision in humans is now widely accepted. According to this theory, *there are three types of cones*, each containing a pigment most sensitive to one of the primary colours. Light entering the eye stimulates the cones in proportion to its spectral components and the differential discharge is coded and conveyed to the occipital cortex. *Colour is sensed by cones in the fovea centralis and appreciated within photopic vision.*

✓ Human cone pigments have been named as follows:
- The red-sensitive or long-wave pigment.
- The green-sensitive or medium-wave pigment.
- The blue-sensitive or short-wave pigment.

- Each of these pigments contains retinene and an opsin which differs among pigments in some of its amino acid sequence:

✓ The amino acid sequences of the opsins of the red- and green-sensitive pigments are very similar (96% homology), as they are both determined by adjacent genes on the X chromosome.

✓ The amino acid sequence of the opsin of the blue-sensitive pigment is determined by a gene on the autosomal chromosome 7 and has only 43% homology with each of the opsins of the red-sensitive and green-sensitive pigments.

✓ All the opsins of the cone pigments have 41% homology with the opsin of rhodopsin.

Colour-blindness

Colour-blindness may be due to weakness in detecting one of the primary colours, or to blindness to one or even two of the primary colours. Human beings may be divided into:

1 *Trichromats.* These include people who are normal in all respects in relation to colour perception, plus those with **weakness** in detecting **red, green or blue,** i.e. they need more of the affected primary colour to perceive colour normally.

2 *Dickromats.* These are **completely blind to red or green or blue** and they get their colour sensation by mixing only two of the primary colours.

3 *Monochromats.* These have only **one cone pigment;** to them the world is black and while and shades of grey.

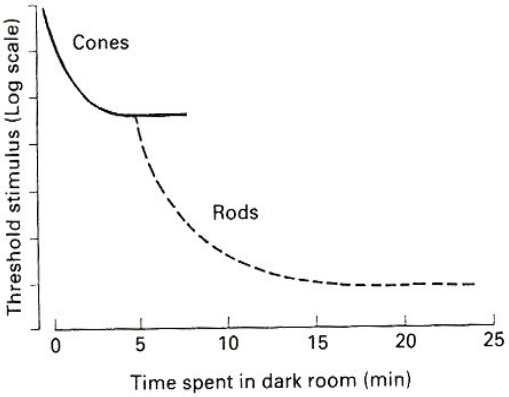
Colour-blindness commonly affects red and green and in this case is usually inherited as a recessive factor on the X chromosome. As such, it affects men more than women and, although heterozygous women do not show the defect, they transmit it to half of their sons. In people of European stock, about 8% of males but only 0.4% of females are affected by colour defects in relation to red or green. Abnormalities in relation to blue are rare and are not sex-linked when inherited. Monochromats are extremely rare and they have other neurological defects. One of the convenient methods to test for colour-blindness is to use polychromatic plates **(Ishihara charts).** These indicate numbers or lines made of spots of certain colours against a background of confusing colours; a key gives the expected responses by normal people and by people affected by colour-blindness.

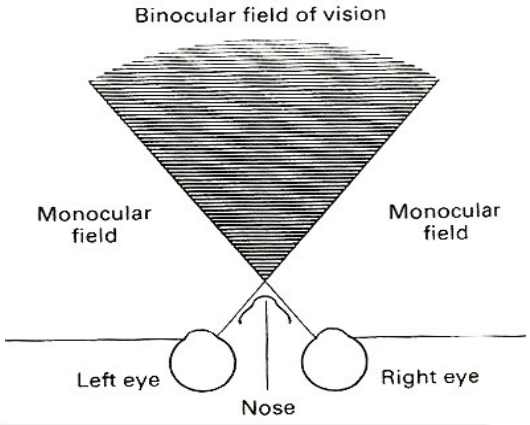
Dark adaptation

- If a person is in brightly lit surroundings, he/she is using cones. If the light is suddenly switched off, at first nothing can be seen, but gradually the outline of objects in the field of vision starts to appear and the situation improves with lime, reaching a maximum in about 20 minutes (Fig.). This is called **dark adaptation,** during which only *the gross features of objects can be distinguished—not their details or colour.*

- It has been shown that, during the first 5 minutes, the threshold for cones decreases (or their sensitivity increases). From 5 to 20 minutes in the dark, a great increase occurs in the sensitivity of the rods, which thus account for the greater share of dark adaptation.

- The main part of the time required for dark adaptation to reach its maximum is needed for ***regeneration of rhodopsin.*** so that rods can function optimally. The changes that occur in the cones during the first 5 minutes are not fully understood. If light is switched on again, the rods are knocked out of action and the cones start to function, adjusting to the level of brightness within 5 minutes; this process may be called light adaptation.





Binocular vision

- The field of vision for each eye may be mapped by using an instrument called the perimeter, the process being called perimetry. Basically, the subject looks with one eye at the point of fixation, while a target is moved along an arc at a certain meridian. The points where the target just enters into view for each meridian arc marked on a chart. The field of vision for each eye is mapped on a separate chart. When in real life we use both eyes, the areas in the centre *of* the field of vision for the two eyes overlap and any object in this area will be seen by both eyes, i.e. the vision is **binocular.** At the temporal part of each field, vision is **monocular** (Fig.).

- In binocular vision there would be two retinal images. The eyes are actually moved by the extraocular muscles in such a way as to ensure that the two retinal images fall on corresponding points on the retinae, the connections of these being organized so that the two images completely fuse at the cottical level. If one of the extraocular muscles is paralysed, e.g. the lateral rectus muscle, the affected eye is deviated inward as a result of the unopposed action of the medial rectus, and double vision or **diplopia** results, since the retinal image in the affected eye is not on the corresponding point.

Depth perception

Appreciation of depth in the field of vision is essentially monocular but is improved when using the two eyes. Two clues from the field of vision requiring only one eye are used to gauge depth: first, the relative sizes of objects—the further the object, the smaller it appears; secondly, *movement parallax,* by which near moving objects move right across the field of vision but distant moving objects appear to be almost stationary. Binocular vision contributes to depth perception through the process of *stereopsis:* a near object has its retinal image on the temporal part of the two retinae while the image of a far object falls to the nasal side towards the centre of the retina. This creates a kind of parallax in relation to location on the retina, which is, in rum, taken to the visual cortex and analyzed.

Critical fusion frequency (CFF)

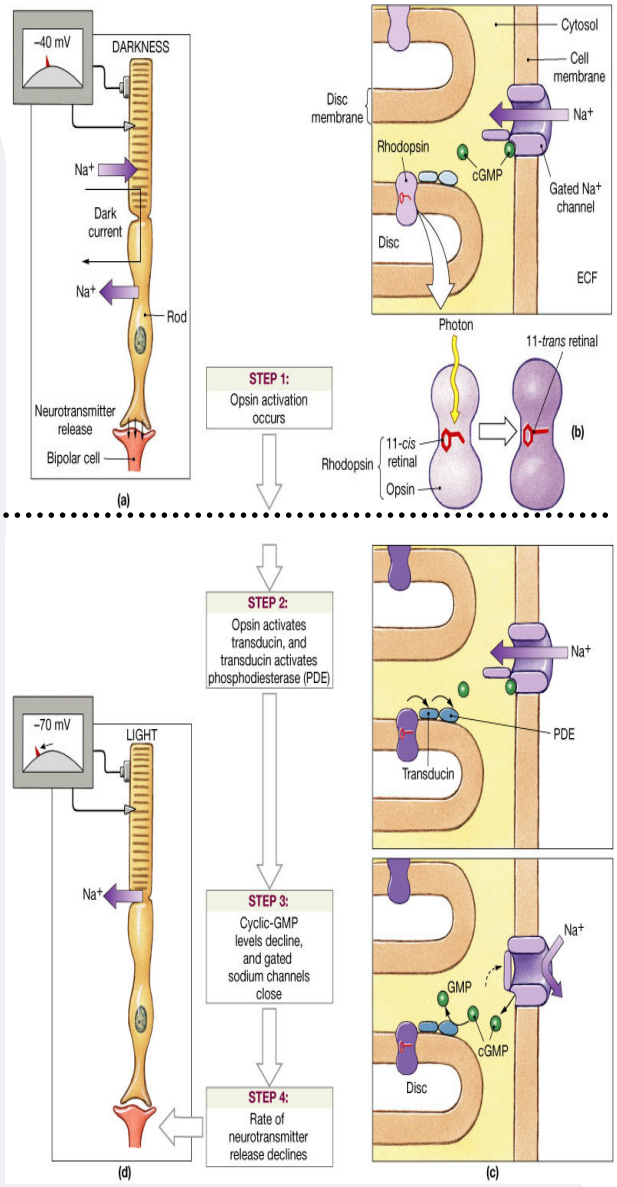
If a light source is interrupted regularly, as by a rotating notched disc, the light flickers. As the rate of interruption is increased, a frequency is reached when the flicker disappears and the light appears continuous. The frequency at which complete fusion of the successive flickering images just occurs to give an illusion of continuity is called the **critical fusion frequency (CFF).** To ensure complete fusion, the light stimulus has to be delivered at a rate just exceeding the CFF. In motion pictures, frames are usually delivered at a rate of 24 per second, which is more than the CFF. If the projector slows down and the frequency of the frames drops to below the CFF, the picture on the screen starts to flicker.

Electrophysiology of vision

When light strikes the outer segments of rods and cones, it causes changes in the photosensitive pigments. These changes lead to receptor potentials, which are converted to action potentials in the optic nerve fibres.

There is Na^+. K^+ ATPase in the inner segment of rods. In the dark, Na^+ is pumped to the outside but it re-enters through sodium channels in the membranes of the outer segments and the synaptic zone, creating continuous sodium current. When light strikes the outer segments, it changes the isomerism of retinene and produces several intermediates before complete bleaching of rhodopsin. One of the intermediates is metarhodopsin II, which leads to activation of transducin (a Gt protein). This causes activation of phosphodiesterase, which decreases intracellular cyclic guanosine monophosphate (cGMP) through converting it to 5'-GMP, and, as a result, closure of some of the sodium channels takes place in the membrane of the outer segments. This leads to less sodium entering and creates a negative potential. Thus, rods respond to light by *hyper-polarization* (Fig. 17.17). Cones also respond by hyperpolarization. While hyperpolarization in rods has a fast onset and slow offset, both processes are fast in cones.

A number of synaptic transmitters have been found in the retina, including acetylcholine, dopamine, serotonin, gamma-aminobutyric acid (GABA), substance P, somatostatin, vasoactive peptide (VIP), encephalin and other peptides. It seems that in the dark these transmitters are continuously released. By causing hyperpolarization in the receptors, light *decreases* the release of the transmitters, leading to electric potentials in **horizontal cells, bipolar neurons** and **amacrinc cells.** The depolarizing potentials in amacrine cells have been identified as the **generator potentials** leading to action potential spikes in the **ganglion neurons** and optic nerve fibres.



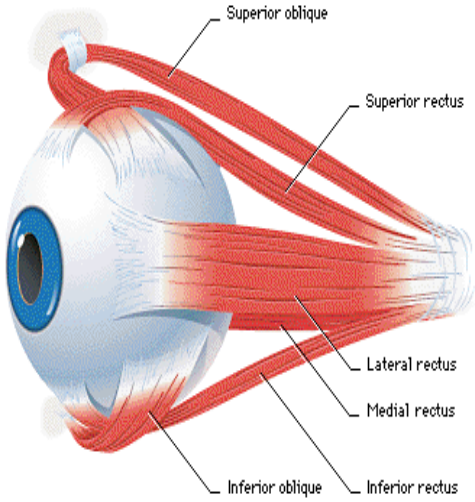
Ganglion cells in the retina respond to light in the form of circles. One-half of the ganglion neurons discharge when the centre of the circular field is illuminated but are inhibited by illumination of the periphery of the field **(on-centre cells).** The other half discharges to illumination of the periphery but is inhibited by stimulation of the centre **(off-centre cells).** Cells in the **lateral geniculate body** and some neurons in cortical area 17 respond in a similar fashion. This type of response may be responsible for demarcating the edges of objects in the field of vision.

Electrophysiology of vision

Two types of **cortical neurons** have been identified: simple cells, in area 17, and complex cells, mainly in the association areas 18 and 19 but also in area 17. Both respond to light in the form of lines. Simple cells respond according to the orientation of the line stimulus and neurons responding to the same orientation are arranged in vertical columns, called orientation columns, in the occipital cortex. Complex cells respond to the orientation of the light stimulus but discharge more when the line stimulus is moved and may thus be responsible for detecting form and movement. Most cortical neurons concerned with vision respond either to one eye or to the other. Neurons responding to the ipsilateral eye are arranged in vertical columns, alternating with columns of neurons responding to the contralateral eye; these are called **ocular dominance columns.** About half of the complex cells respond to stimuli from both eyes and may be concerned with stereopsis, which requires binocular vision.

Transmission of impulses along the visual pathways and cortical functions

Axons of retinal ganglion cells project a detailed spatial representation on the lateral geniculate body, which has six layers. Layers1 and 2 contain large cells and receive impulses from large ganglion cells; this pathway is concerned with detection of movement, stereopsis and flicker. Layers 3-6 have small cells and receive impulses from small ganglion cells, and the pathway is concerned with colour vision, texture and shape of objects. The lateral geniculate body in turn projects a point-by-poinl representation on the visual cortex, which also has six layers. There are groups of cells in the visual cortex called *blobs* which are concerned with deciphering colour. Colour and visual detail are finally projected to association areas in the anteroventral portion of the **occipital lobe** and the venteropostcrior aspect of the **temporal lobe.** Form, three-dimensional position and movement arc finally analysed at the superior portions of the **occipital lobe** and posterior **parietal lobe.**



Eye movements

The actions of the six extraocular muscles should be ascertained from an anatomy text. *Abduction* and *adduction* refer to rotation of the eyeball around the vertical axis. *elevation* and *depression* around the transverse horizontal axis and *intorsion* and *extorsion* around the horizontal anteroposterior axis. The nerve supply of the extraocular muscle may be conveniently remembered by referring to the following nonsensical formula: $LR_6(SO_4)_3$„ i.e. the lateral rectus is supplied by the 6th or **abducent nerve,** the superior oblique is supplied by the 4th or **trochlear nerve,** and the rest are **innervated** by the 3rd or oculomotor nerve. The actions of extraocular muscles are highly coordinated in order to ensure that retinal images fall on corresponding points; otherwise, *diplopia* results.

Eye movements

There are four types of eye fixation movements which are related to visual function:

1 *Saccadic movements.* These are very rapid conjugate movements of the eyes, occurring when inspecting an object, when the gaze shifts from one object to another or during reading. Since they are present most of the time, they may be responsible for prevention of adaptation to the retinal image, which, if allowed, might lead to disappearance of objects under constant view! Sometimes eye movements responsible for preventing visual adaptation are referred to as **physiological nystagmus.**

2 *Smooth pursuit movements.* As the name implies, by these movements the eyes follow or track moving objects.

3 *Vergence movements.* **Convergence** occurs when the gaze is changed from a far to a near object or when fixing on an approaching object. **Divergence** of the visual axes occurs when the gaze is transferred from a near to a far object or when watching an object moving away.

4 *Vestibular movements.* These occur in order to maintain visual fixation when the head moves. During rotation the eyes move in the opposite direction in order to maintain fixation. When the limit is reached, the eyes snap back, and the process is repeated, leading to **nystagmus.**

All these movements are initiated in neural pathways related to their function, e.g. vestibular movements are initiated by stimuli in the semicircular canals and travel in the vestibular pathways, but the final common pathway is constituted by the nuclei of the 3rd, 4th and 6th cranial nerves, which innervate the extraocular muscles.

The end