B.Sc. Semester III, Physiology (General) Theory
(CC3/GE3)

VISION

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- Histology of retina
- Scotopic and photopic vision
- Photoreceptors
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- Phototransduction by rods
- Dark adaptation
- Accommodation of eye
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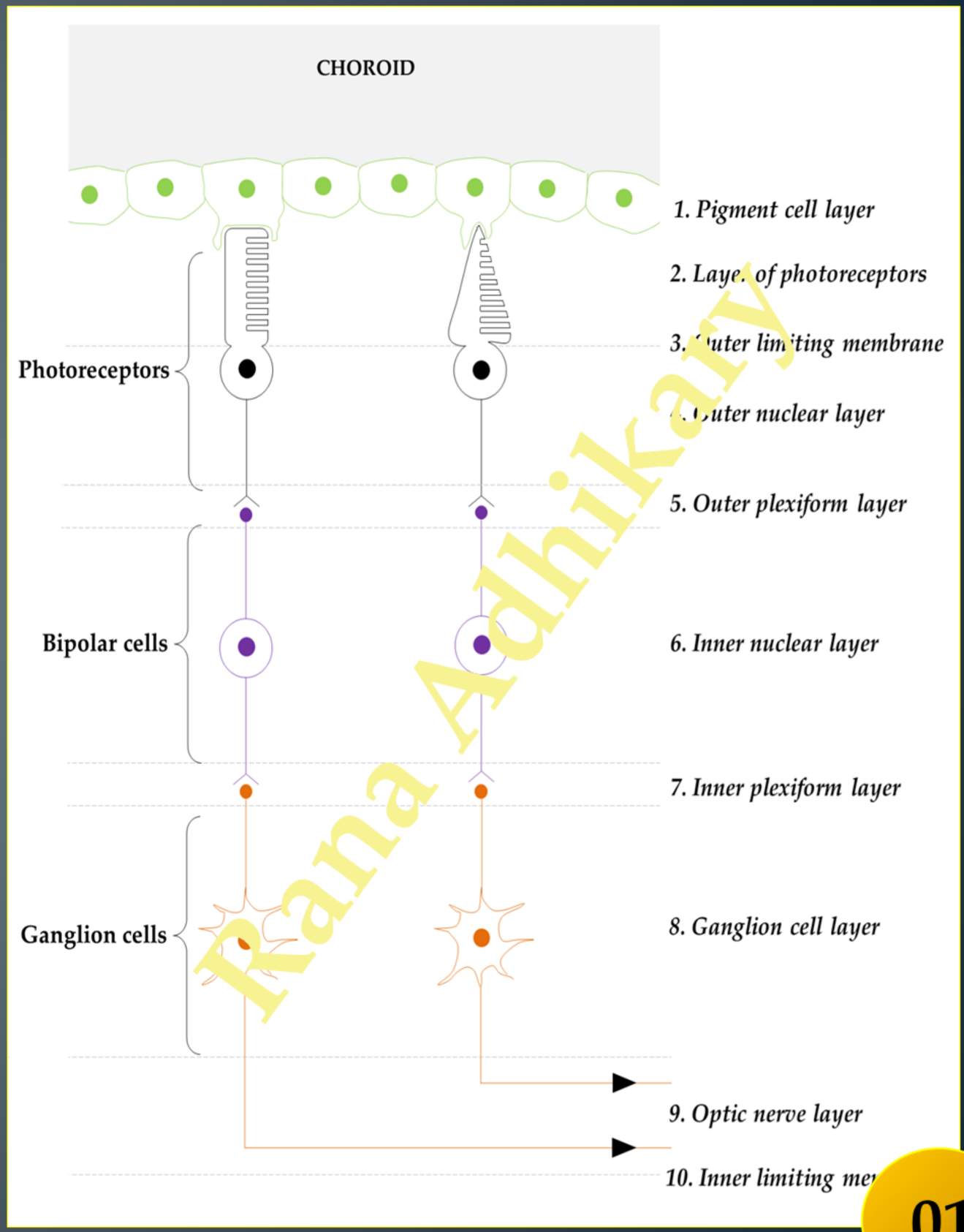
- Color vision

RETINA: THE SENSORY SURFACE OF VISION

- Present between the vitreous humor and choroid
- Consists of photoreceptors – the receptors of light

Retinal histology shows 10 different layers:

1) Pigment cell layer: Phagocytosis and absorption of excess amount of light
2) Photoreceptor layer: Phototransduction
3) Outer limiting membrane: Hypothetical membrane
4) Outer nuclear layer: Contains cell bodies of photoreceptors
5) Outer plexiform layer: Signal transduction between photoreceptors and bipolar cells
6) Inner nuclear layer: Contains cell bodies of bipolar cells
7) Inner plexiform layer: Signal transduction between bipolar cells and Ganglion cells
8) Ganglion cell layer: Contains cell bodies of Ganglion cells
9) Optic nerve layer: Carry impulses from retina to higher centres via optic tract
10) Inner limiting membrane: Separates retina from vitreous humor



CELLS FOUND IN RETINA

Cells of retina	Location	Type of neurotransmitter released
Rod cells	Photoreceptor layer of retina	Glutamate (excitatory)
Cone cells	Photoreceptor layer of retina	Glutamate (excitatory)
Bipolar cells ➢ **Invaginating bipolar cells (On-bipolar cells)** ➢ **Flat bipolar cells (Off-bipolar cells)**	Inner nuclear layer of retina	 Glutamate (excitatory) Glutamate (excitatory)
Amacrine cells	Inner nuclear layer of retina	GABA (inhibitory)
Horizontal cells	Inner nuclear layer of retina	GABA (inhibitory)
Ganglion cells ➢ **On-ganglion cells** ➢ **Off-ganglion cells**	Ganglion cell layer of retina	 Glutamate (excitatory) Glutamate (excitatory)
Müller cells (supporting glial cells which provide nutritional and structural support to the retinal)	Into the space between outer and inner limiting membranes	- None -

SCOTOPIC & PHOTOPIC VISION

	Scotopic vision	Photopic vision
Definition	Ability of eye to detect objects in dimlight	Ability of eye to detect objects in bright light
Visual mode	Monochromatic:, *i.e.*, black and white	Polychromatic, *i.e.*, colour vision
Photoreceptor	Rod cells	Cone cells
Sensitivity	High sensitivity, faster saturation	Low sensitivity, slower saturation
Discriminative power	High	Low

The term '***scotopic vision***' refers to the ability of eye to detect objects in dimlight and the term '***photopic vision***' refers to the ability to see objects in bright light. We already know that there are two types of photoreceptors present in retina, *i.e.*,rods and cones. The differential responses of rods and cones are due to the presence of different photosensitive pigments.

There are around 10^8 photoreceptors present inside the retina. The two subtypes of photoreceptors have differences in their functions too, *i.e.*, rod cells are responsible for dimlight vision (***scotopic vision***); on the other hand cone cells are responsible for bright light vision (***photopic vision***). Rods can sense the black and white, *i.e.*, makes the pencil sketch; whilst cones sense all the colours in this colourful world, hence both are required for perception of images.

RETINAL DISTRIBUTION OF PHOTORECEPTORS

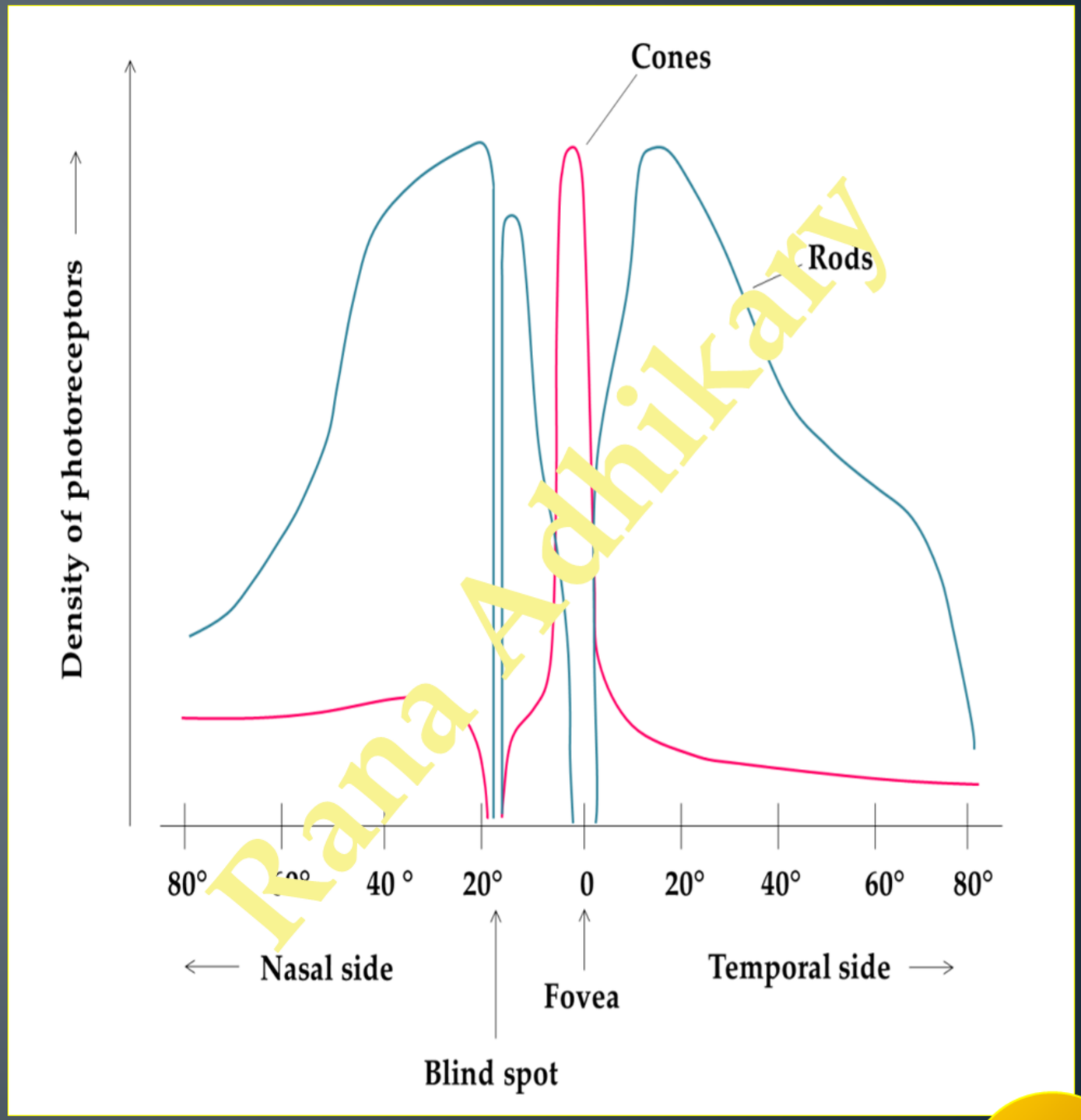
The two types are photoreceptors are not equally distributed all along the retina. Regional variations in rods and cones are prominent in the receptive field of vision.

Macula lutea: The region on retina where most of the light rays are focussed, it is rich in cones, lesser number of rods are also found.

Fovea centralis: The central region of macula lutea which contains highest amount of cone cells.

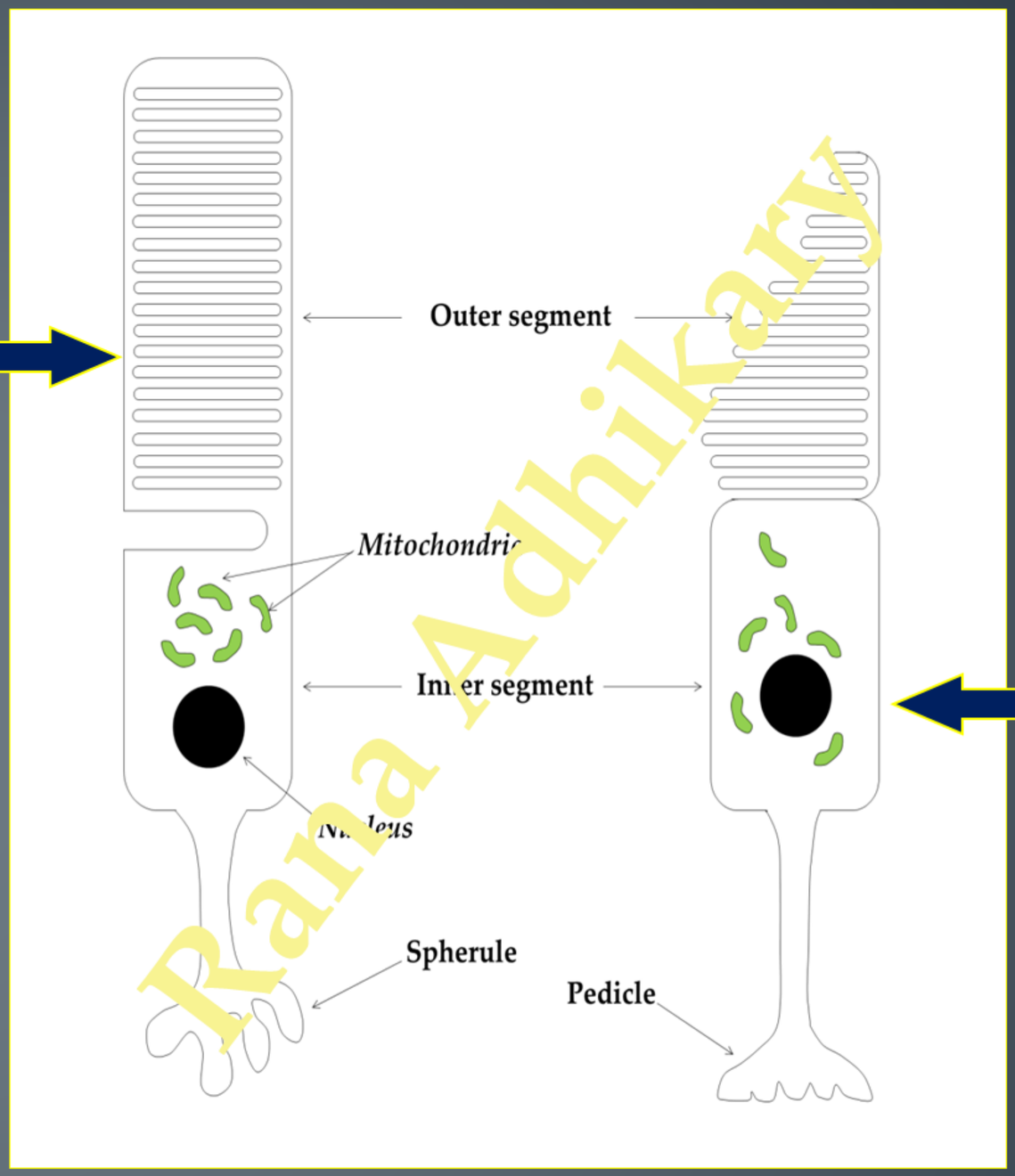
Blind spot: The region of retina where the optic nerve leaves the eye ball lacks rods and cones, and therefore is known as ***blind spot***.

Moving away from fovea centralis both in the direction of nasal or temporal parts of retina it reduces the number of cone cells. The number of rods also increases when moving from the nasal and temporal sides towards the fovea.



PHOTORECEPTORS OF RETINA

Rod cell



Cone cell

Photoreceptor	Dark	Dimlight	Low intensity light	High intensity light
Rod cells	Inactive	Active	Saturation	Saturation
Cone cells	Inactive	Inactive	Activation	Saturation

VISUAL PATHWAY

Fibers of Ganglion cells from nasal and temporal halves of retina ascend as optic nerve

↓

Nasal fibers cross to opposite side near optic chiasm

↓

Above optic chiasm the temporal fibers from same side and nasal fibers from opposite side ascend as optic tract

↓

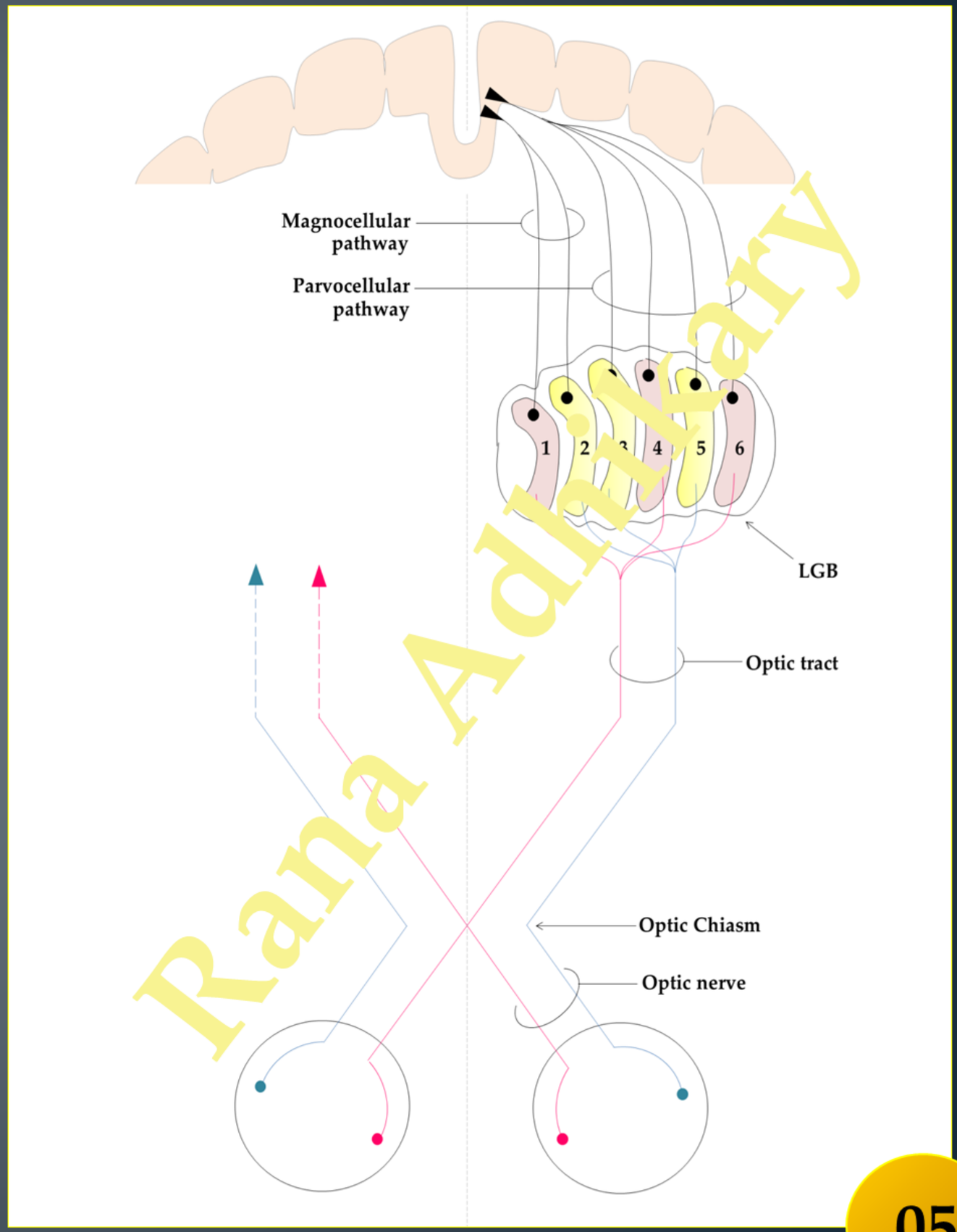
Optic tract reaches lateral geniculate body of thalamus (LGB)

↓

Nasal fibers end at 1st, 4th, and 6th LGB layers; temporal fibers end at 2nd, 3rd, and 5th layers of LGB.

↓

Fibers from LGB ascend to visual cortex



LIGHT REFLEXES

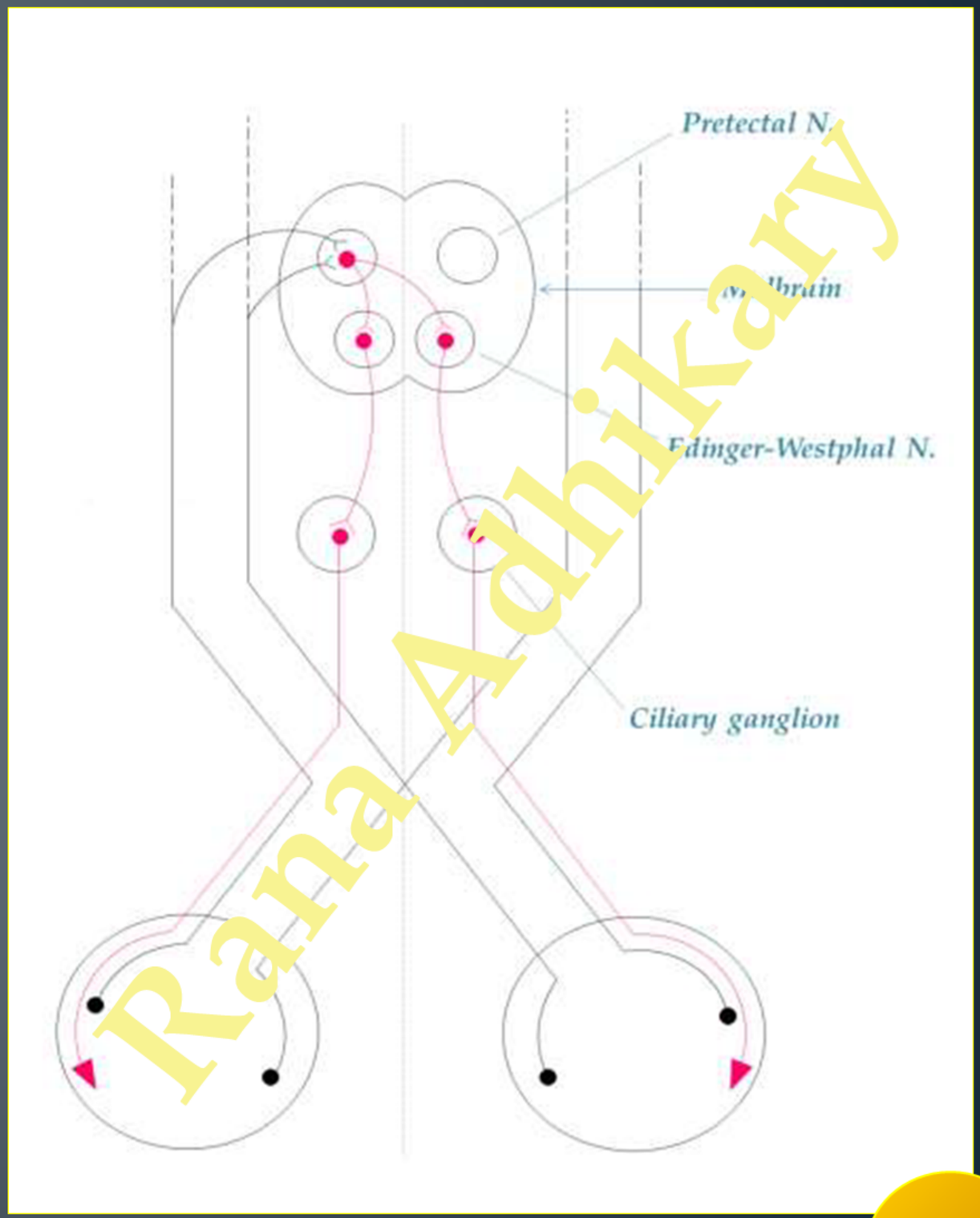
1. Pupillary light reflex

This sort of visual reflex ensures that a certain amount of light enters retina, i.e., this is a regulatory reflex.

Components of pupillary light reflex are -

- ❑ Receptors: Rods and cones
- ❑ Afferent pathway: The optic tract; collaterals are often given towards pretectal nucleus of midbrain
- ❑ Reflex centre: Edinger-Westphal nucleus situated at midbrain
- ❑ Efferent pathway: Parasympathetic neurons which emerge from Edinger-Westphal nucleus to ciliary ganglion
- ❑ Effector: Pupillary muscles and ciliary muscles

Pupillary reflex regulates amount of light entering into retina via regulation of the pupillary diameter.



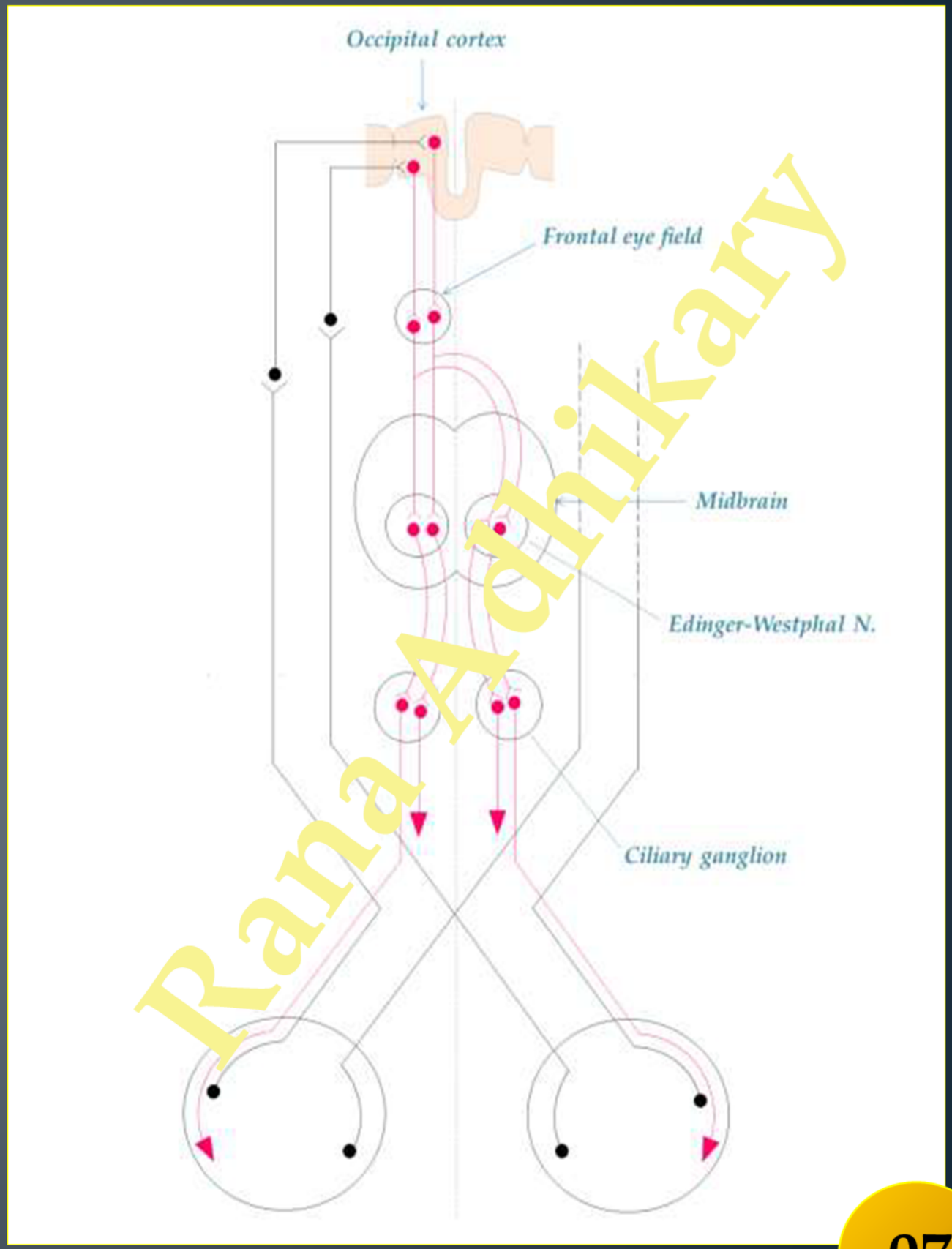
2. Accommodation reflex

This is also known as *near response* and *convergence reflex*. This is another type of visual reflex, which confers the ability to focus on a nearby object.

Components of accommodation reflex are-

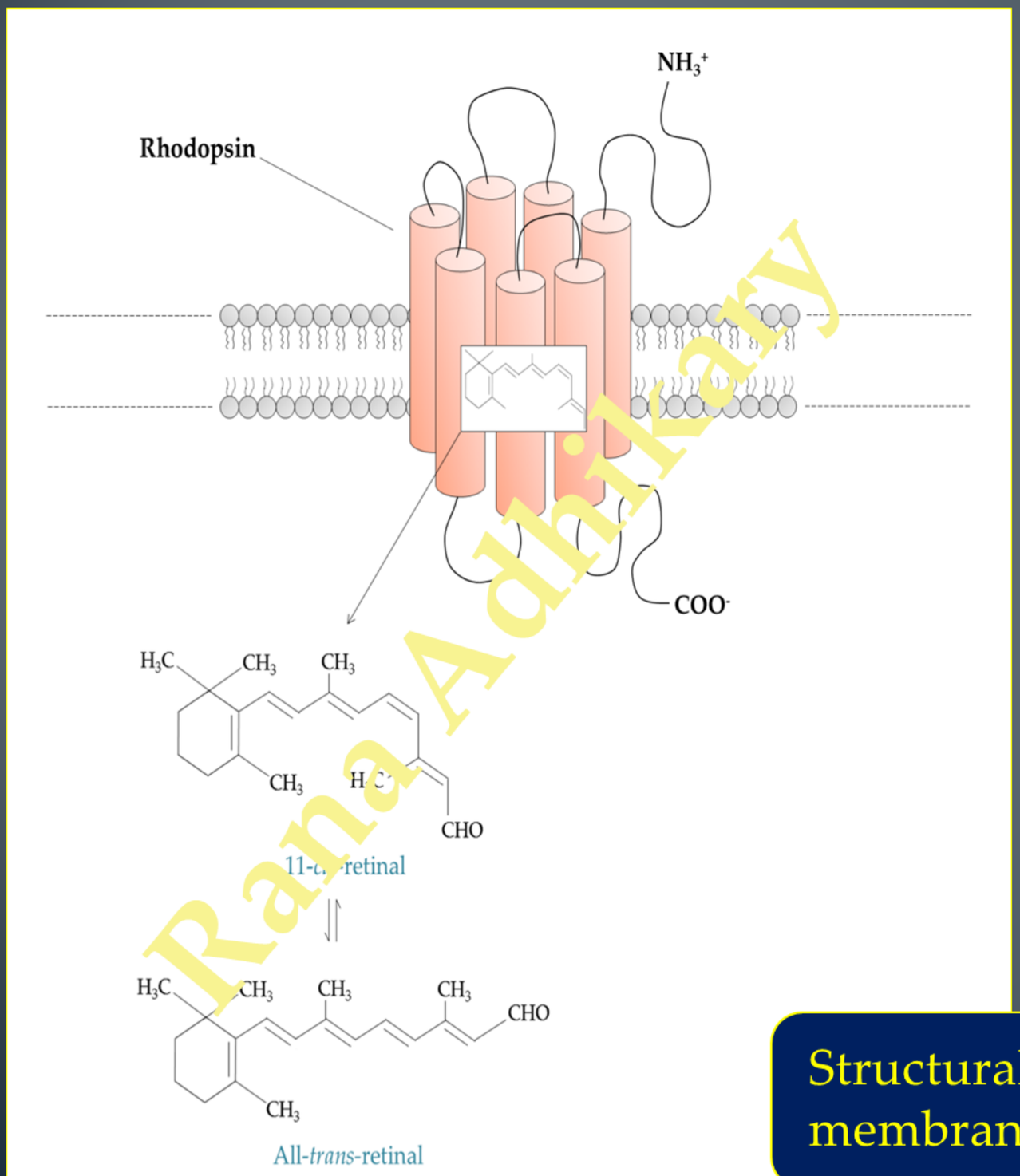
- ❑ Receptors: Rods and cones
- ❑ Afferent pathway: The optic tract to occipital cortex; occipital cortex to frontal eye field; from frontal eye field to midbrain
- ❑ Reflex centre: Edinger-Westphal nucleus situated at midbrain
- ❑ Efferent pathway: Fibres from Edinger-Westphal nucleus to ciliary ganglion of both sides
- ❑ Effector: Pupillary muscles and ciliary muscles

Accommodation reflex adjusts the curvature of lens in order to focus the divergent rays correctly onto the fovea centralis of macula.



PHOTOTRANSDUCTION BY ROD CELLS

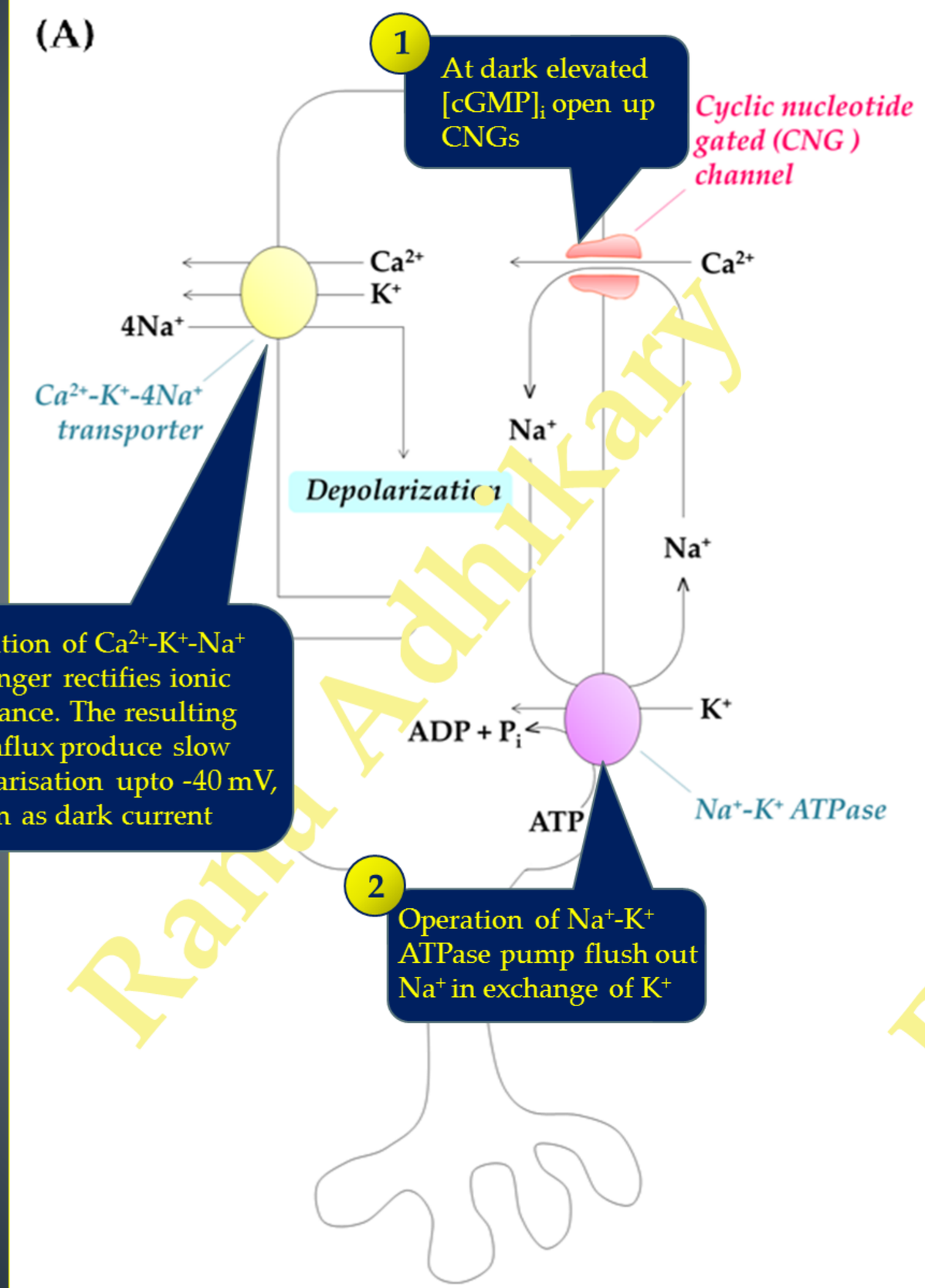
Light energy → Chemical changes → Electrical energy

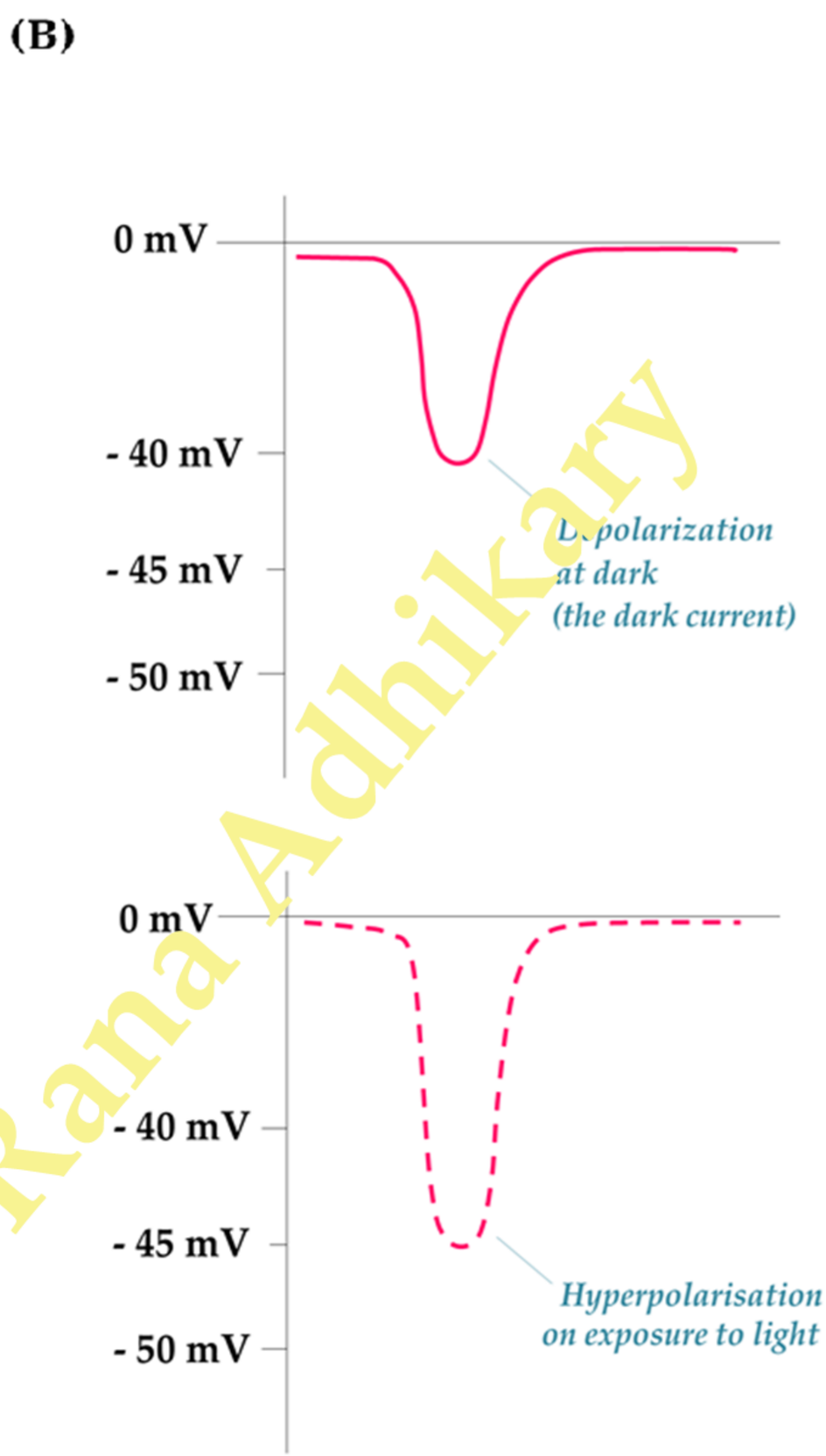


- The photopigment of rod cell is – rhodopsin.
- The protein part of it is opsin, which is a 7TD G-protein coupled receptor (GPCR)
- Opsin contains all-*trans*-retinal as co-enzyme group; it the chromophore for rhodopsin.
- The opsin is coupled with transducin (G_t), a trimeric GTP-binding protein (G-protein).
- Upon light evoked activation of rhodopsin, it triggers a signal transduction cascade which terminates after activation of phosphodiesterases.

Structural orientation of rhodopsin located on the membrane of photoreceptor discs

ROD CELL RESPONSE AT DARK: DARK CURRENT





ROD CELL RESPONSE AT DIMLIGHT

The co-enzyme part of rhodopsin, i.e., all-*trans*-retinal behaves like a chromophore, *i.e.*, it capture photons (hυ).

Absorption of hυ

⬇

Isomerization of all-*trans*-retinal into 11-*cis*-retinal

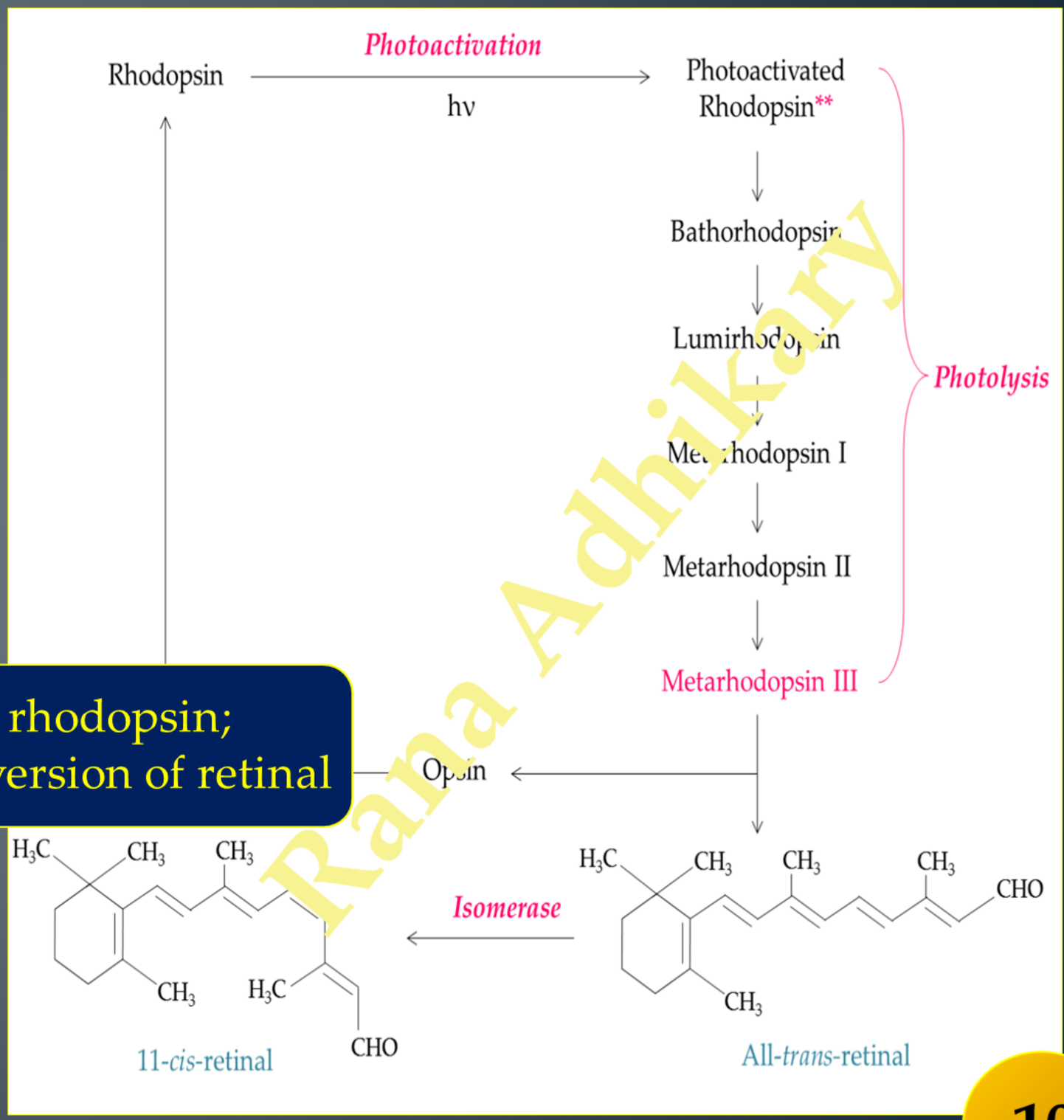
⬇

Photoexcitation

⬇

Photolysis or photobleaching

Light evoked chemical changes in rhodopsin; photobleaching and cis-trans conversion of retinal



Photoexcitation and photobleaching

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Metarhodopsin mediated activation of transducin (G_t)

↓

Activation of PDE results in drastic fall in $[cGMP]_i$

↓

CNG closure

↓

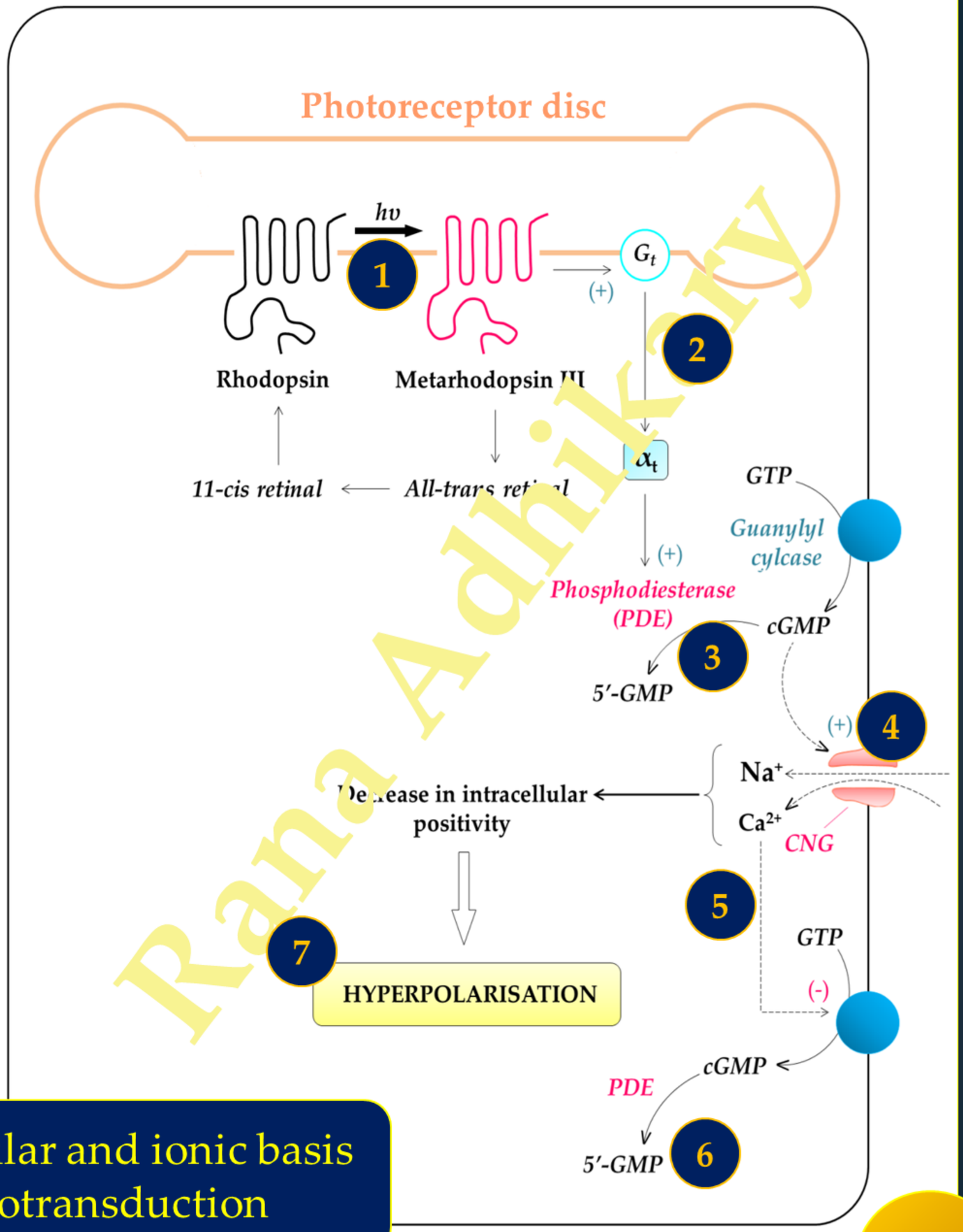
Ca^{2+} mediated inhibition over GC is withdrawn

↓

PDE counteracts GC mediated $[cGMP]_i$ elevation

↓

Stable hyperpolarization (-45 mV) and reduction in release of gluatamate



Molecular and ionic basis of phototransduction

ROD CELL RESPONSE AT BRIGHT LIGHT

Brief flashes of bright light on retina

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Elevation in photobleached rhodopsin concentration

↓

Rhodopsin kinase mediated phosphorylation of photobleached rhodopsin

↓

Photobleached rhodopsin binds with arrestin

↓

Saturation in PDE activity

↓

Much fall in$[cGMP]_i$

↓

Closure of more and more CNGs

↓

Rod cell saturation

Constant bright light on retina

↓

Over activity of PDE and too low $[cGMP]_i$

↓

CNGs remain closed for prolonged period

↓

Prolonged hyperpolarisation decreases RMP near to -50 mV

↓

$[Ca^{2+}]_i$ level remains low for prolonged period

↓

Inhibition over GC is withdrawn ; and $[cGMP]_i$ starts to rise again

↓

CNGs also start to reopen, which raises membrane voltage upto -45mV again [Light adaptation]

DARK ADAPTATION

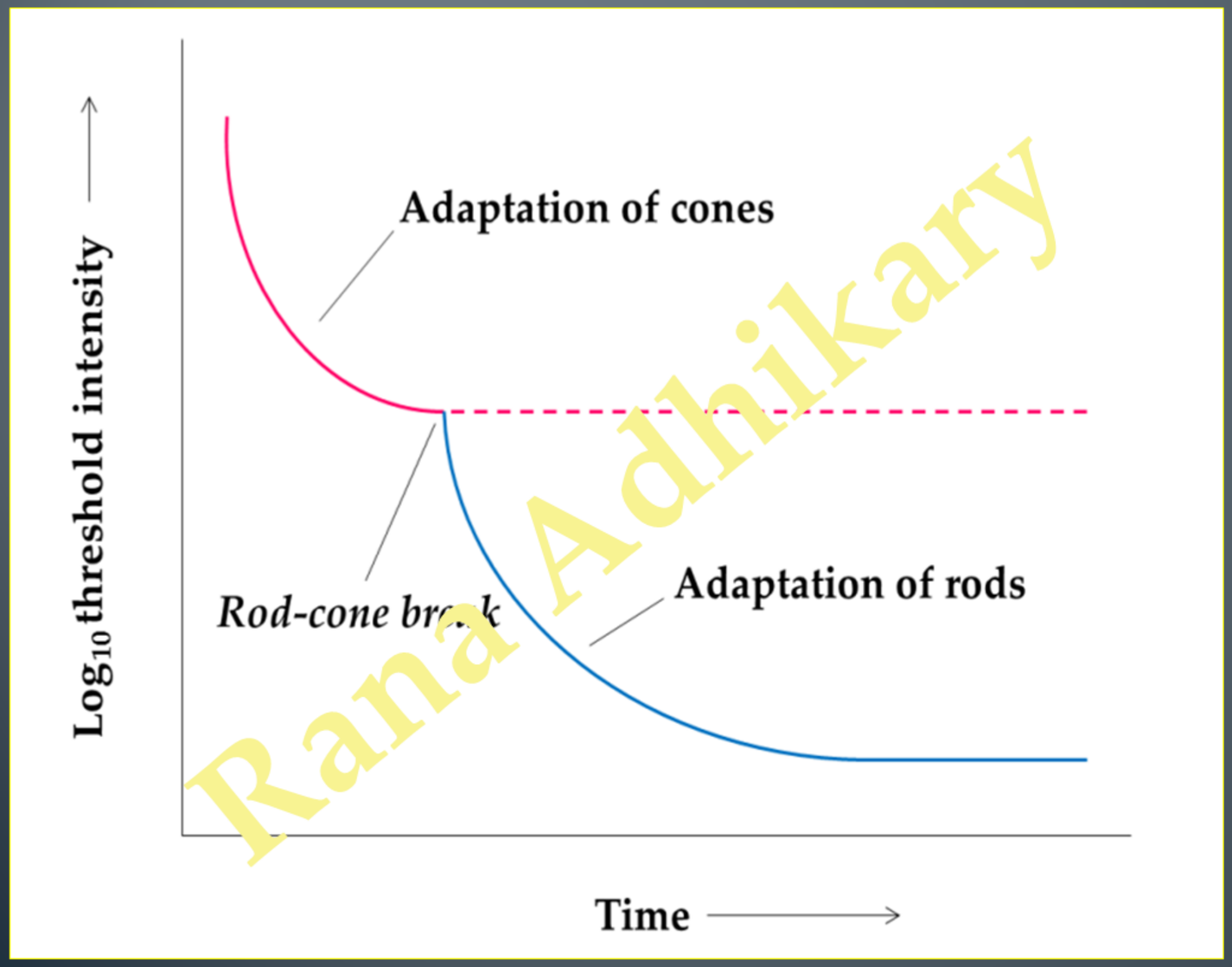
Exposure to bright light

⇩

Complete photobleaching of the various photopigments found in rods and different population of cones ⇨ Relocation at dark ⇨ Regeneration of bleached photopigments

⇩

Subject gradually retrieves normalcy in retinal photoreceptor functions [Dark adaptation]

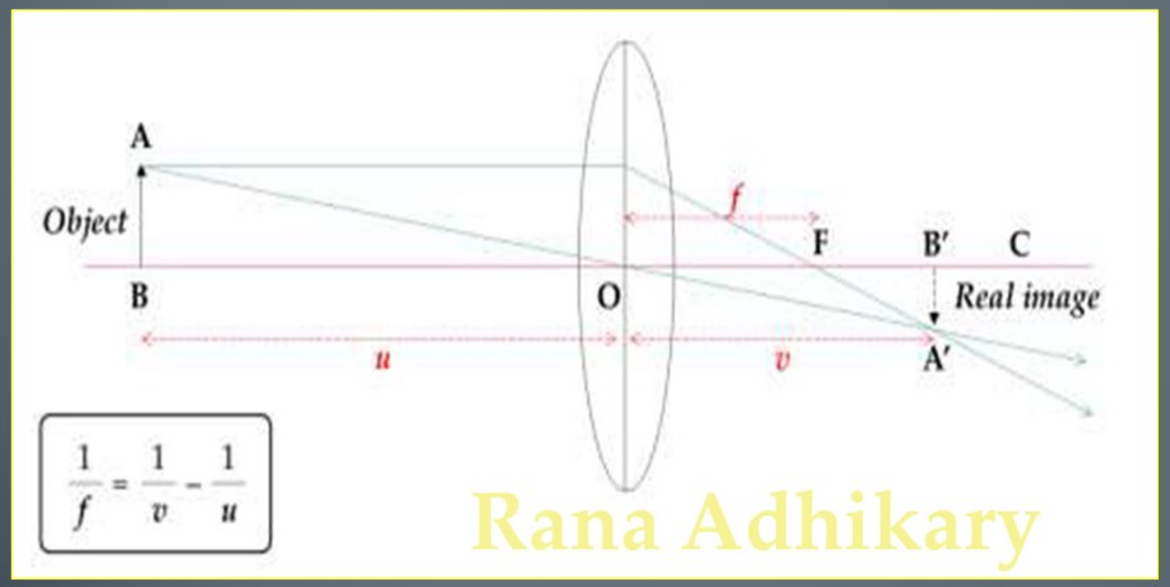


The components of dark adaptation curve are -

- Cone adaptation: Rapid, takes 8-10 mins
- Rod-cone break: Refers to sudden change in slope of the curve
- Rod adaptation: Slow, completes within 20-30 mins

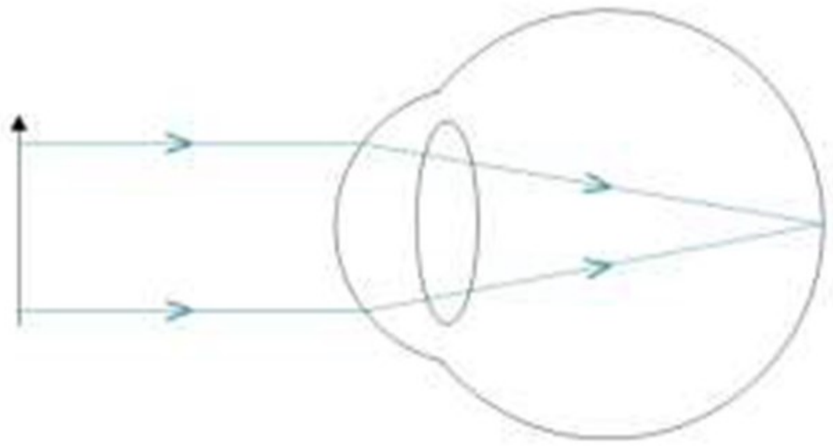
ACCOMMODATION OF THE EYE

The formation of image on retina has similarities with image formation by lenses. In case of a biconvex lens the antero-posterior line passing through the centre of curvature is called ***principal axis***. Light rays show no deviation when passing through the centre of curvature. The ***optical centre*** (O) or ***nodal point*** of the lens is the point through which light rays pass without any angular deviation. In case of the eye the light rays coming from the object are passed through the cornea, which acts as a concave lens and here occurs refraction of the light rays (***convergence***). The converged light rays from the cornea passes through the lens and again converged at a single point on retina *i.e.*, fovea centralis of macula.



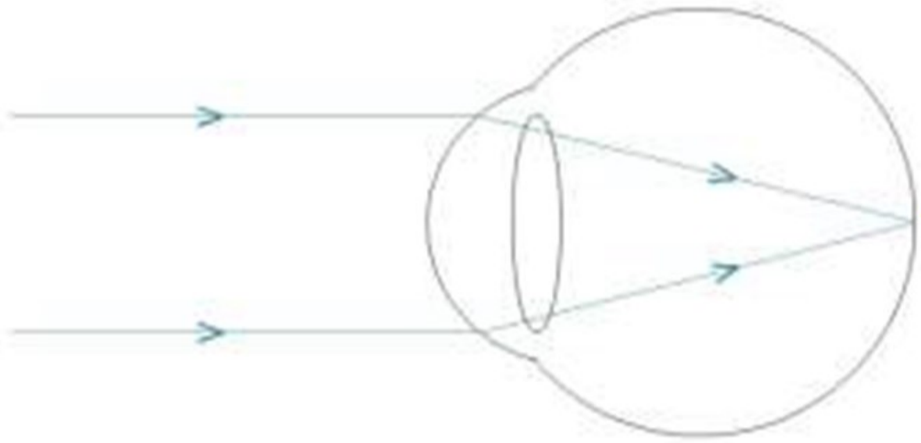
The minimum distance from where an object can be seen clearly by an ametropic eye is called ***near point*** or ***punctum proximum.*** It is about 7 cm in young age and increases gradually with advancement of the age. Detection of any object nearer than this point requires accommodation, *i.e.*, contraction of the ciliary muscles to increase the antero-posterior thickness of the less in order to focus all the light rays coming from that object on retina. On the other hand the maximum distance at which an object can be seen clearly without any adjustment of the visual apparatus is called ***far point*** or ***punctum remotum***. It is about 6 meters in length. To focus the objects away from far point it requires relaxation of the ciliary muscles to decrease the curvature of the lens.

Normal eye: Object is at focal distance



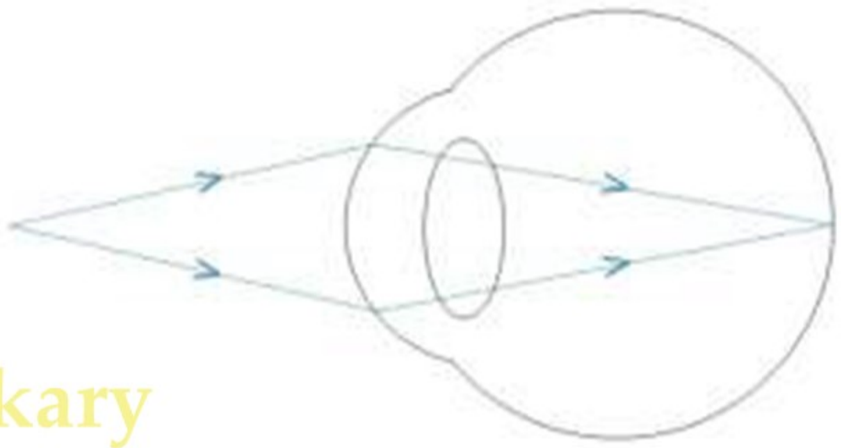
No ciliary adjustment is required

Accommodation of normal eye during far-vision



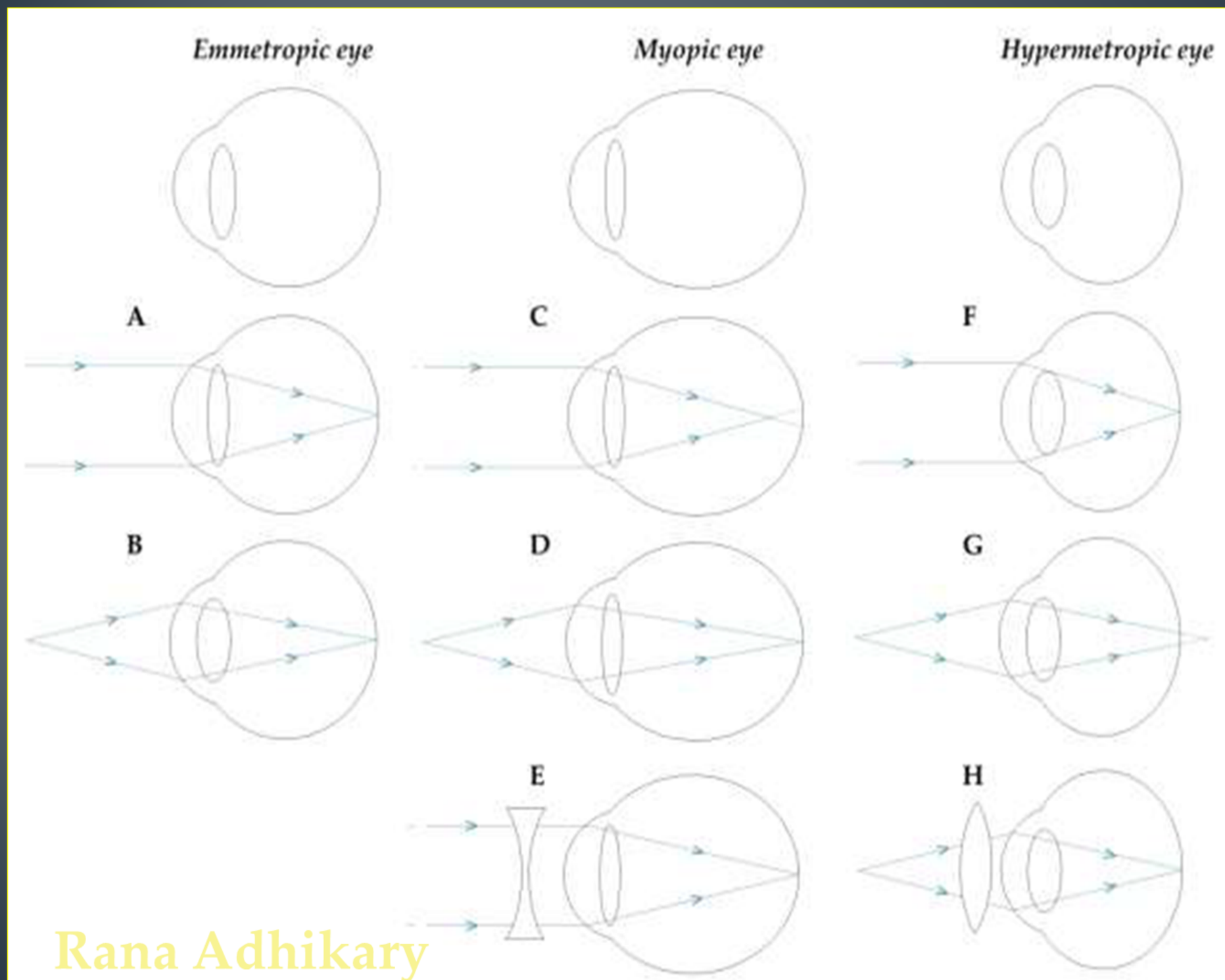
Relaxation of ciliary muscles in order to decrease the antero-posterior thickness of the lens

Accommodation of normal eye during near-vision



Contraction of ciliary muscles in order to increase the antero-posterior thickness of the lens

ERRORS OF REFRACTION



The errors of refraction and their corrections: adjustments of emmetropic eye to far vision (A) and near vision (B), changes in myopic eye during far vision (C) and near vision (D) and its correction (E); changes in hypermetropic eye during far vision (F) and near vision (G) and its correction (H).

… thank you !