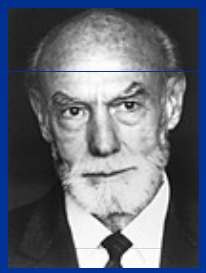
Fotorecepce

The Nobel Prize in Physiology or Medicine 1981

"for his discoveries concerning the functional specialization of the cerebral hemispheres"

"for their discoveries concerning information processing in the visual system"



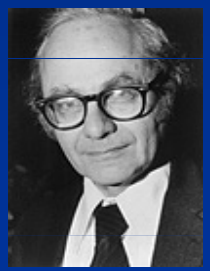
Roger W. Sperry

1/2 of the prize

USA

California Institute of Technology
Pasadena, CA, USA

b. 1913
d. 1994



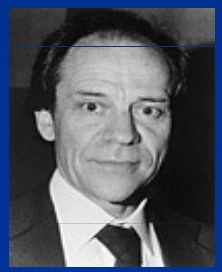
David H. Hubel

1/4 of the prize

USA

Harvard Medical School
Boston, MA, USA

b. 1926
(in Windsor, ON, Canada)



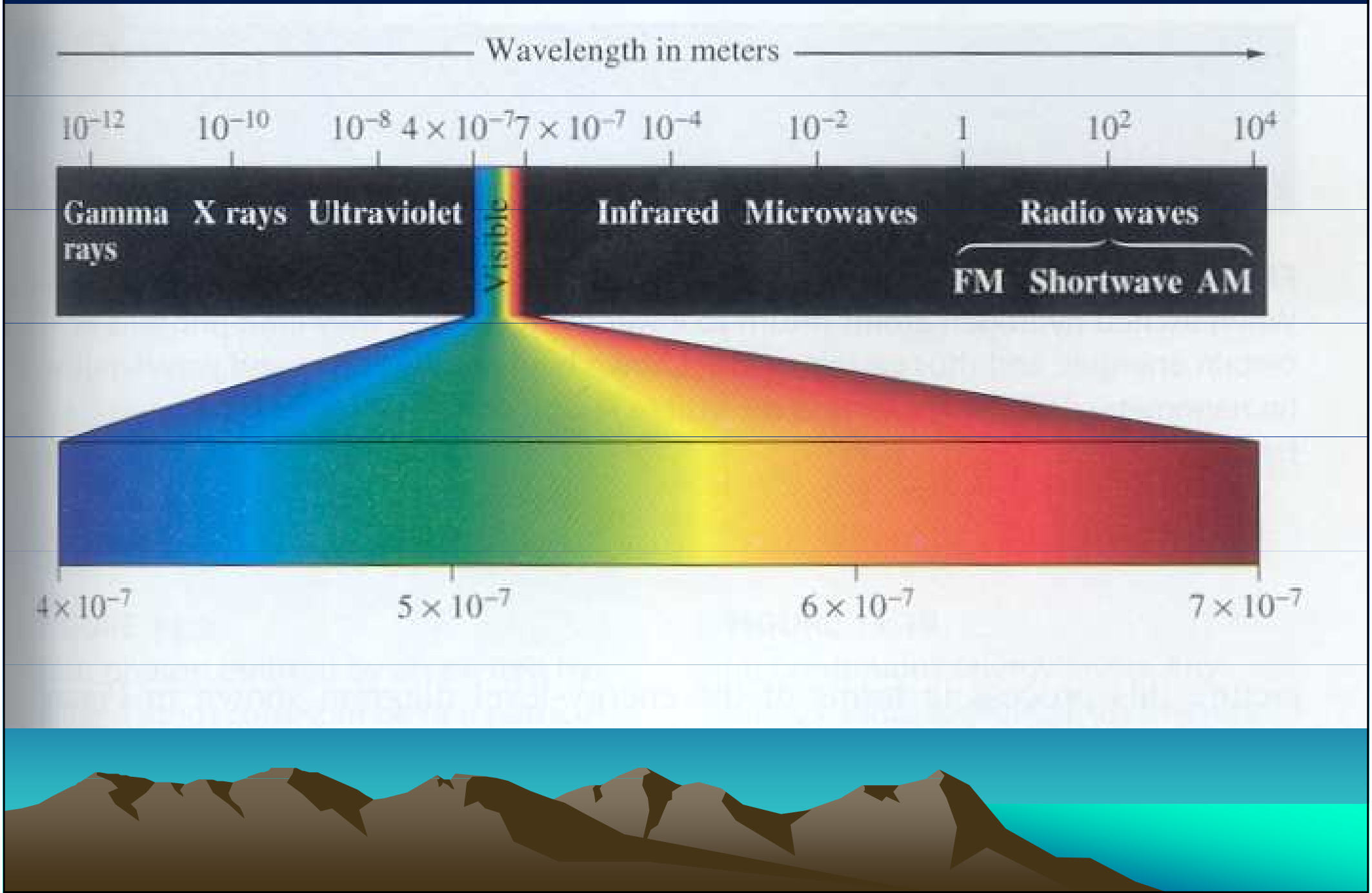
Torsten N. Wiesel

1/4 of the prize

Sweden

Harvard Medical School
Boston, MA, USA

b. 1924


Wavelength in meters
10^{-12}
10^{-10}
10^{-8}
4×10^{-7}
7×10^{-7}
10^{-4}
10^{-2}
1
10^{2}
10^{4}
Gamma rays
X rays
Ultraviolet
Visible
Infrared
Microwaves
Radio waves
FM
Shortwave
AM
4×10^{-7}
5×10^{-7}
6×10^{-7}
7×10^{-7}

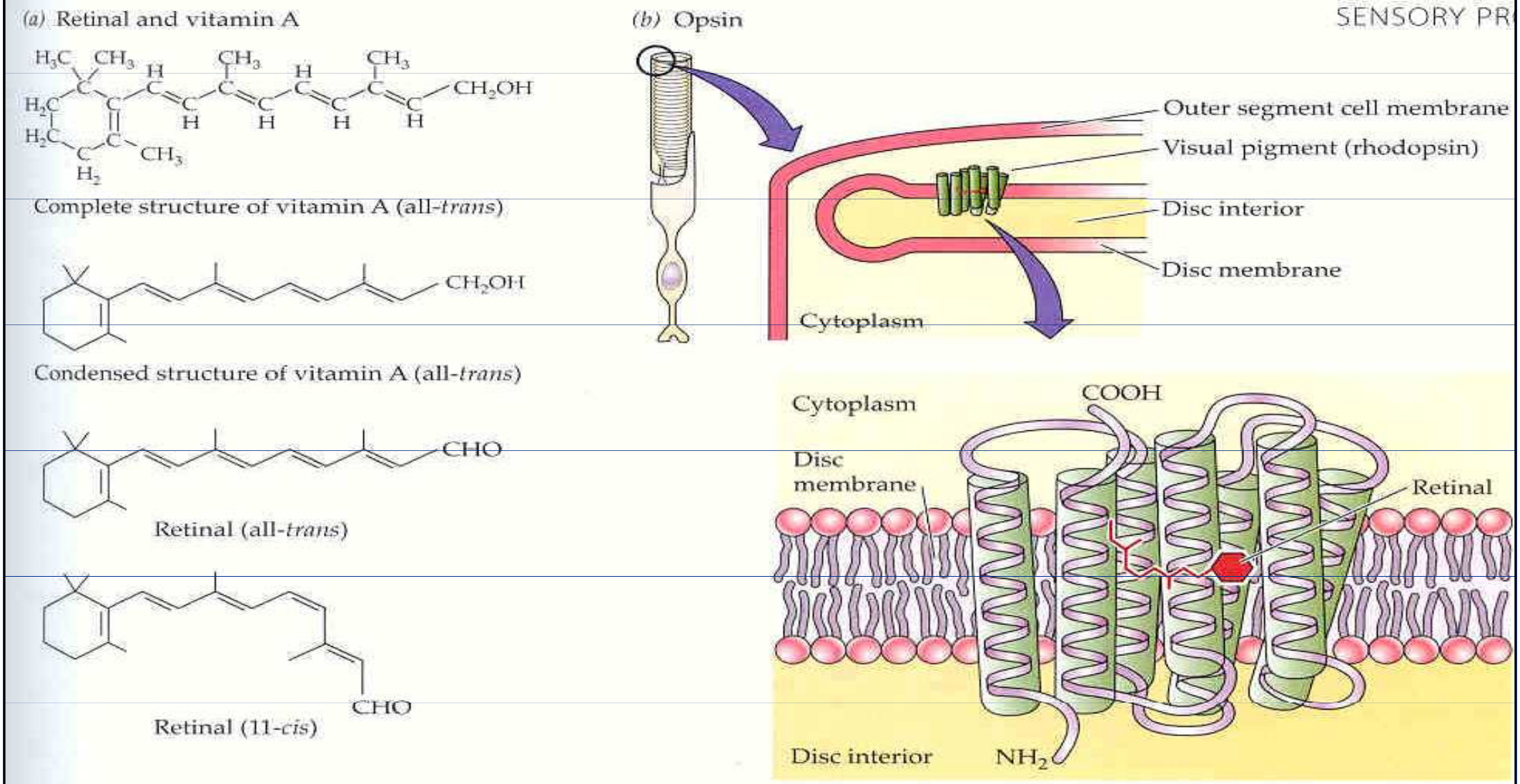
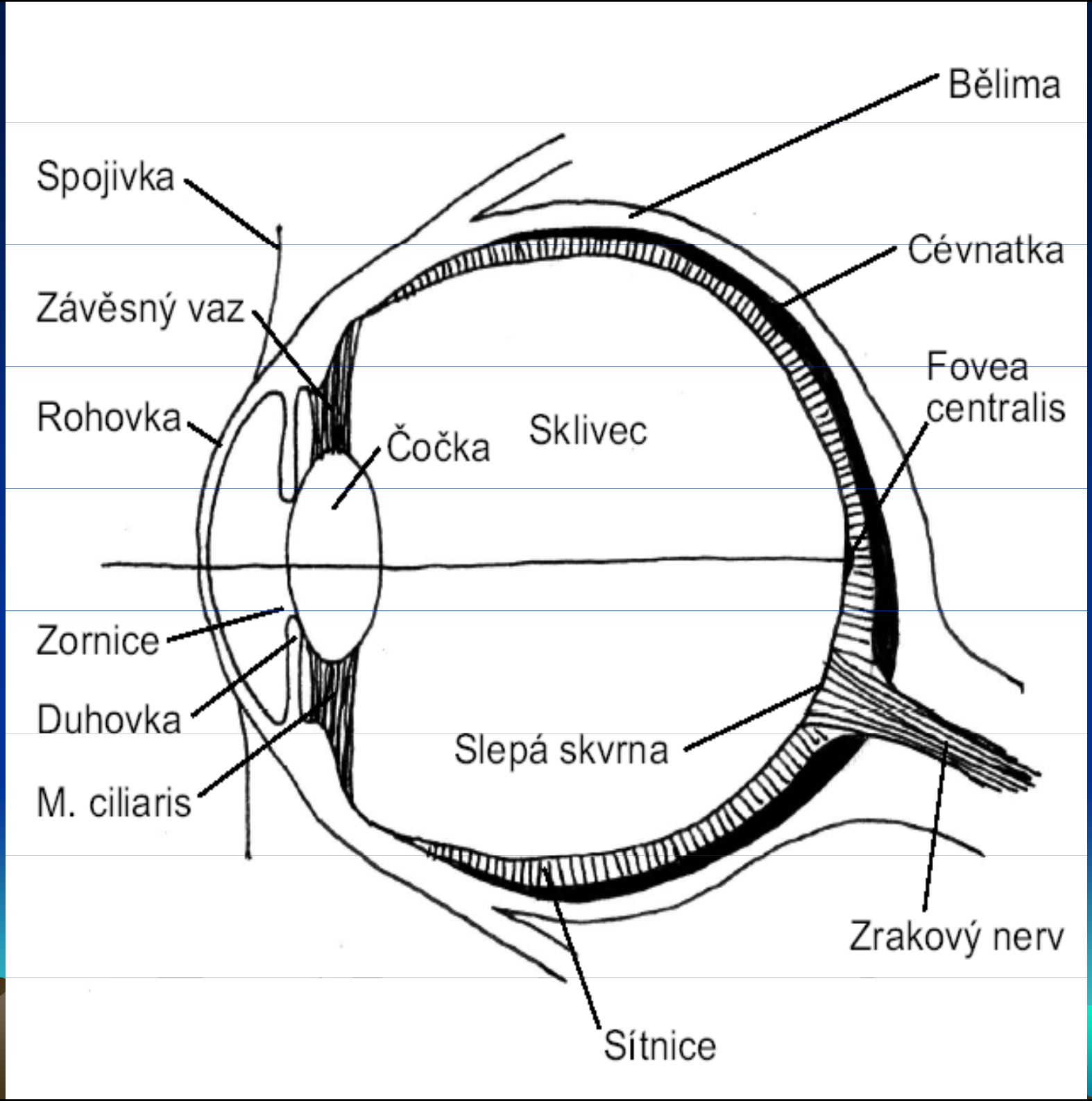
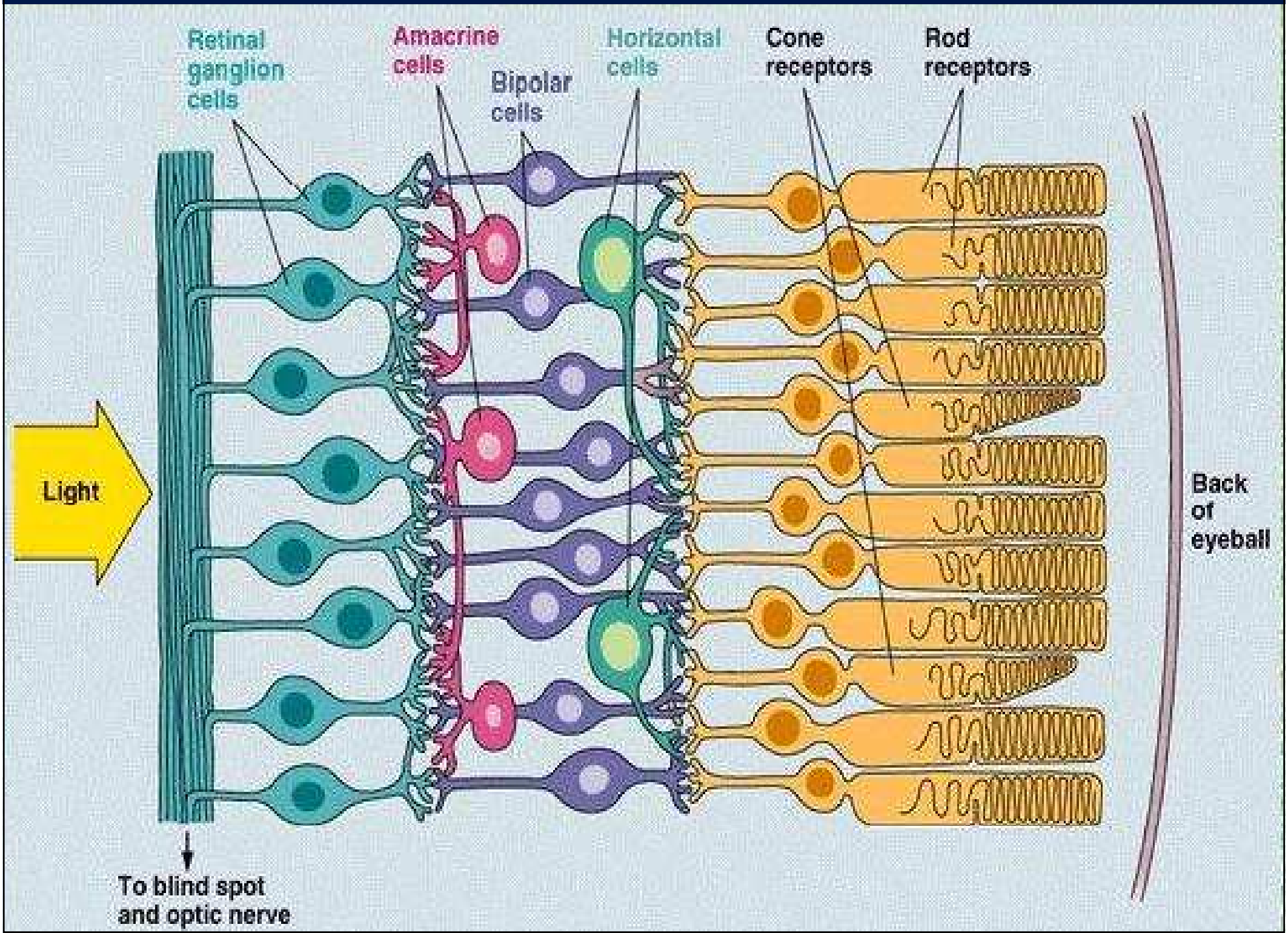


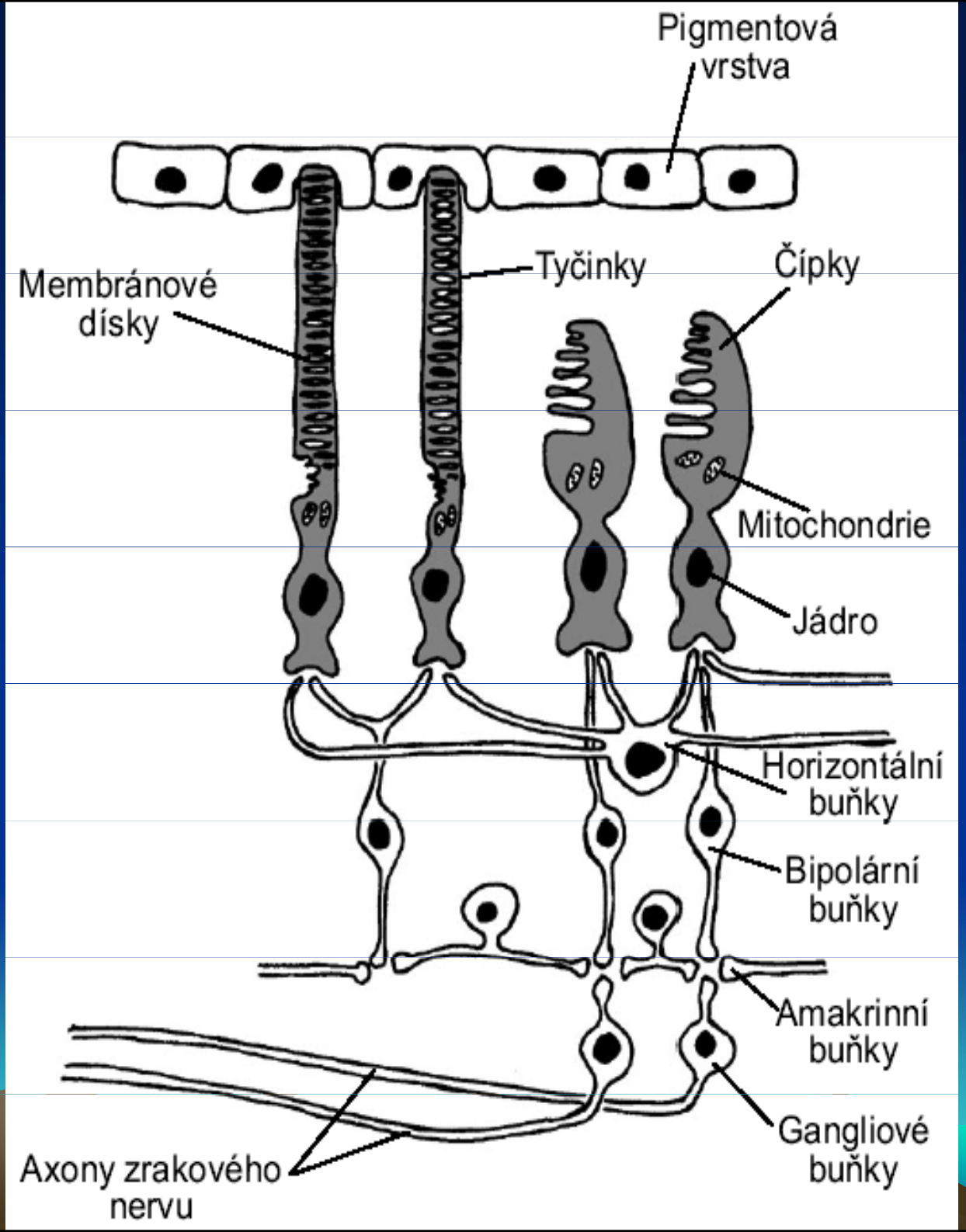
Figure 13.13 Rhodopsin is a photopigment composed of two parts: retinal and opsin
(a) Chemical structures of vitamin A and of retinal. Vitamin A is shown both as a complete structure (top) and as a skeleton structure (middle). Vitamin A is converted to retinal, which has two isomers (11-*cis* and all-*trans*). *(b)* Three-dimensional structure of the protein (opsin) portion of vertebrate rhodopsin. Seven α-helical regions of the protein span the membrane; retinal is attached to an amino acid residue within the seventh membrane-spanning region.

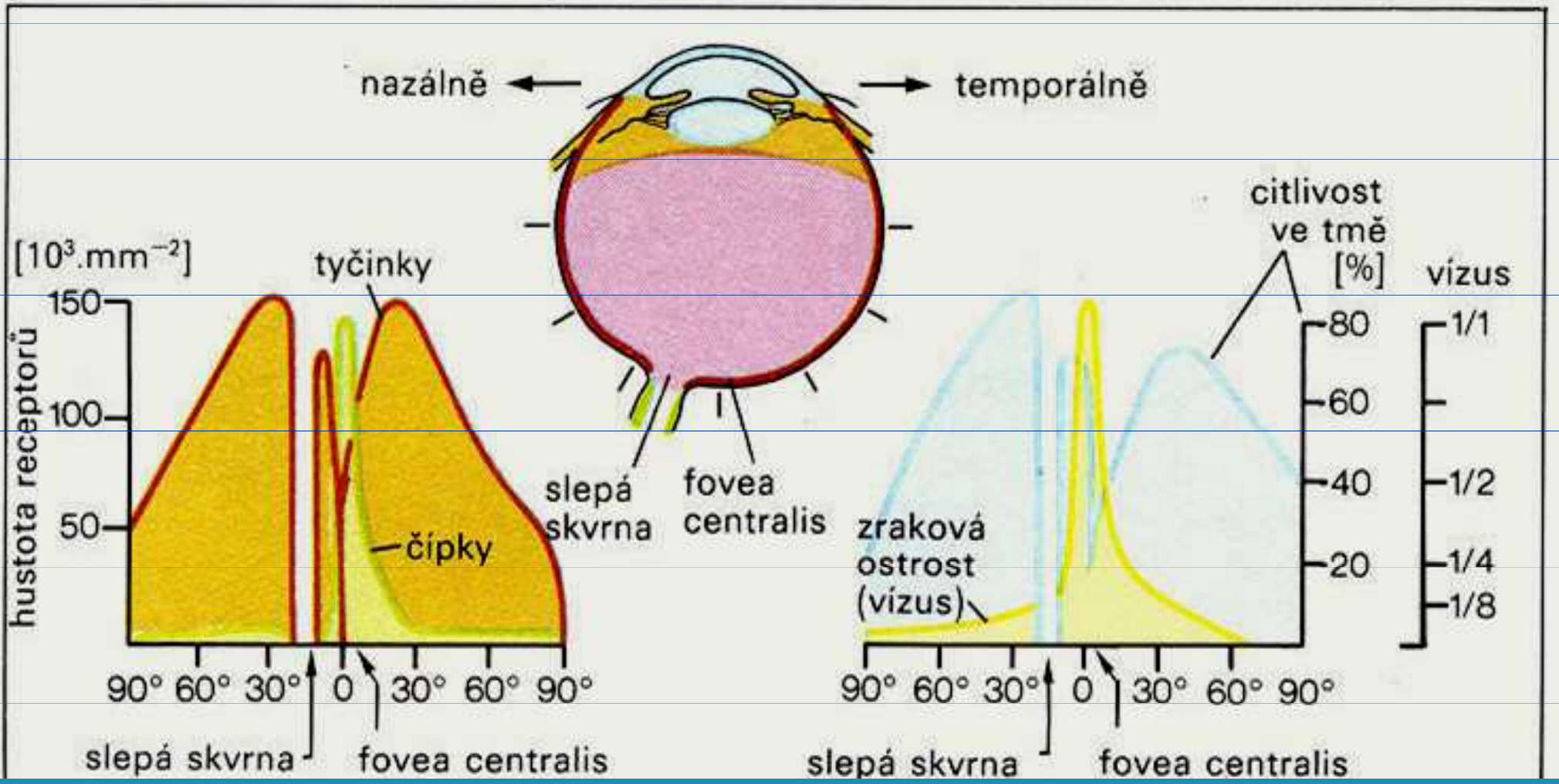
- Optický systém oka
- Fotoreceptory sítnice
- Optická dráha
- Korová zraková oblast

http://hubel.med.harvard.edu/bcontex.htm


Bělima
Spojivka
Cévnatka
Závěsný vaz
Fovea centralis
Rohovka
Čočka
Sklivec
Zornice
Duhovka
Slepá skvrna
M. ciliaris
Zrakový nerv
Sítnice


Retinal ganglion cells
Amacrine cells
Bipolar cells
Horizontal cells
Cone receptors
Rod receptors
Light
Back of eyeball
To blind spot and optic nerve


Pigmentová vrstva
Tyčinky
Čípky
Membránové disky
Mitochondrie
Jádro
Horizontální buňky
Bipolární buňky
Amakrinní buňky
Gangliové buňky
Axony zrakového nervu


nazálně
temporálně
[10³.mm⁻²]
hustota receptorů
150
100
50
tyčinky
čípky
slepá skvrna
fovea centralis
90° 60° 30° 0 30° 60° 90°
slepá skvrna
fovea centralis
citlivost ve tmě [%]
vízus
80
60
40
20
1/1
1/2
1/4
1/8
zraková ostrost (vízus)
90° 60° 30° 0 30° 60° 90°
slepá skvrna
fovea centralis

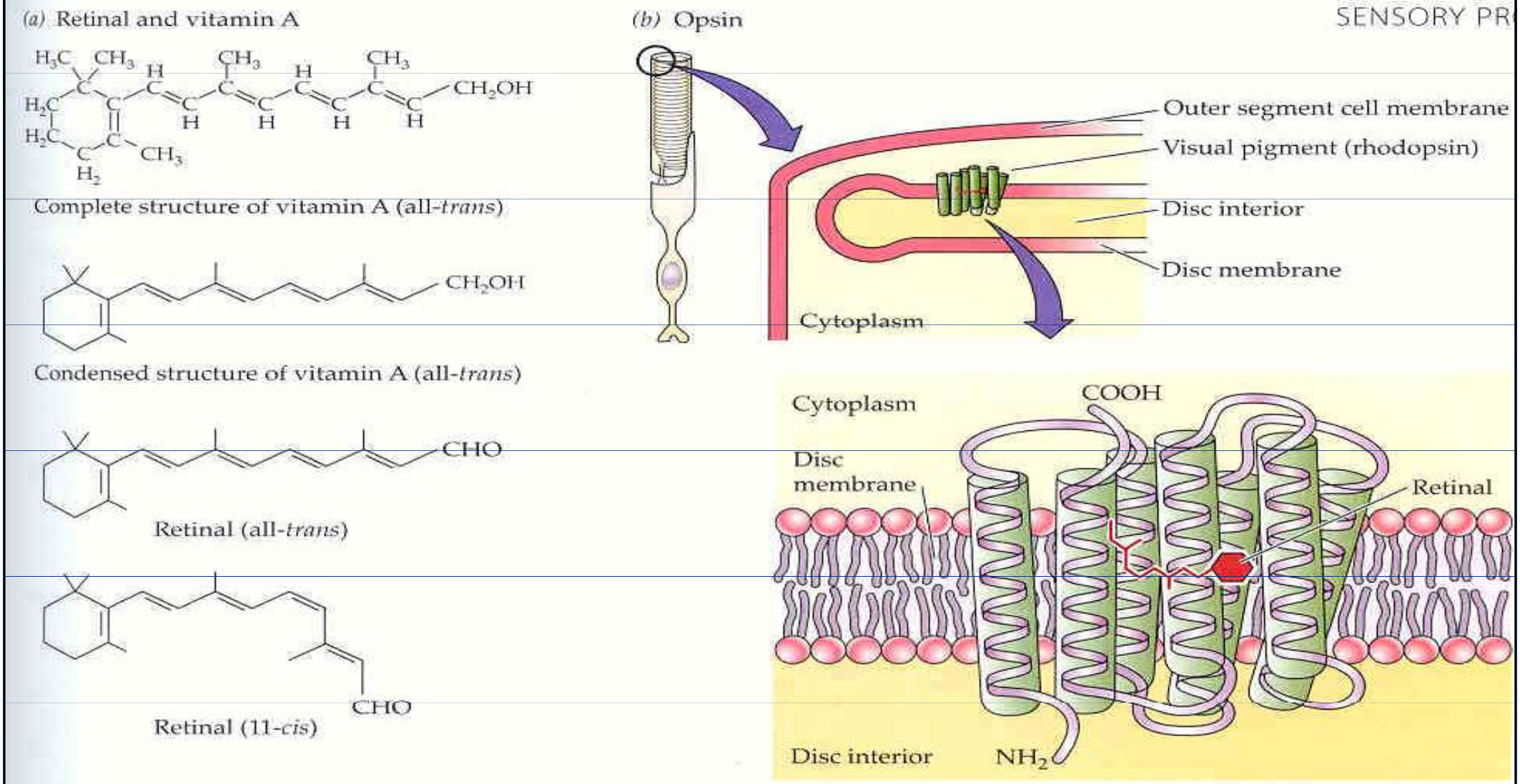
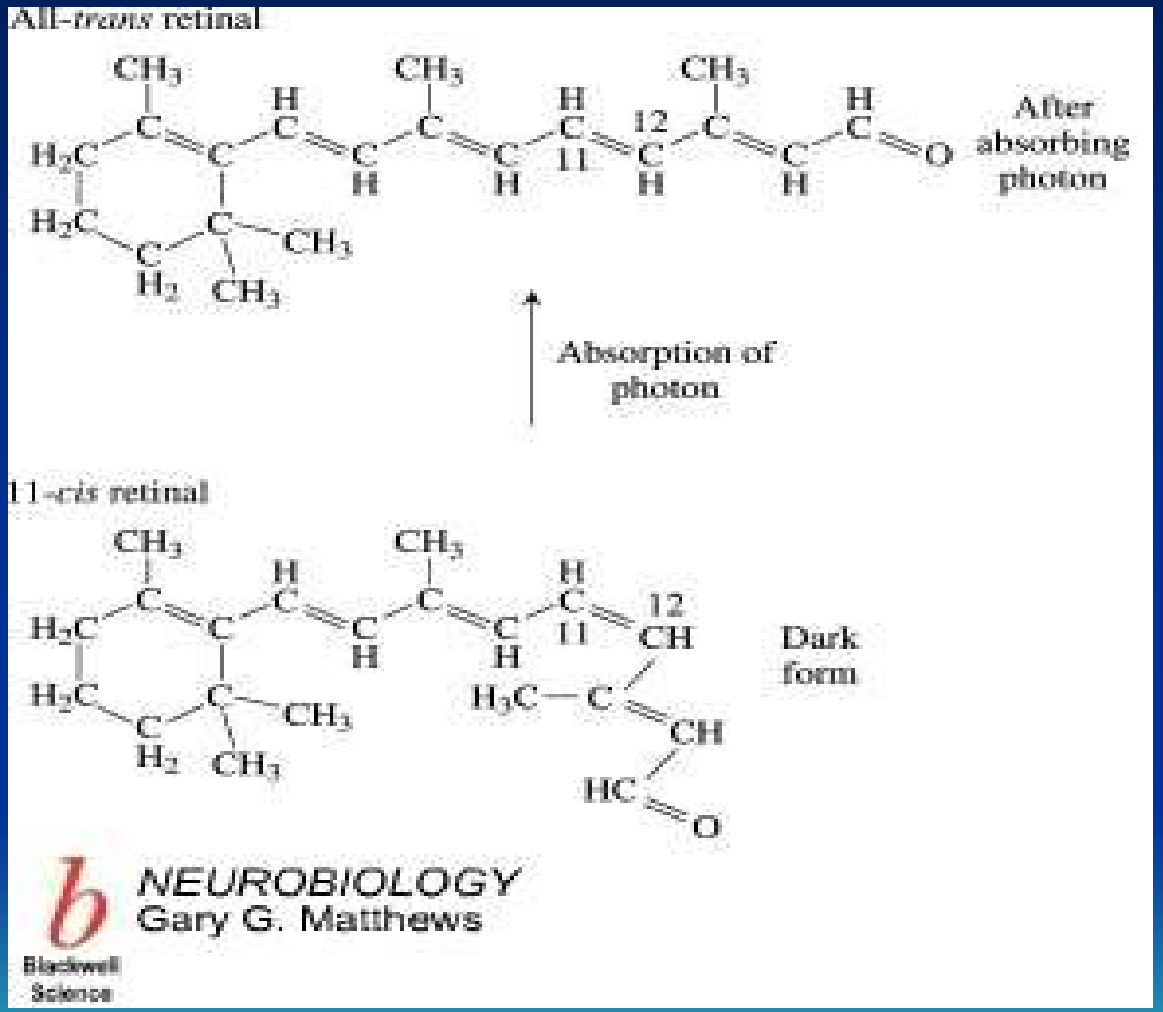
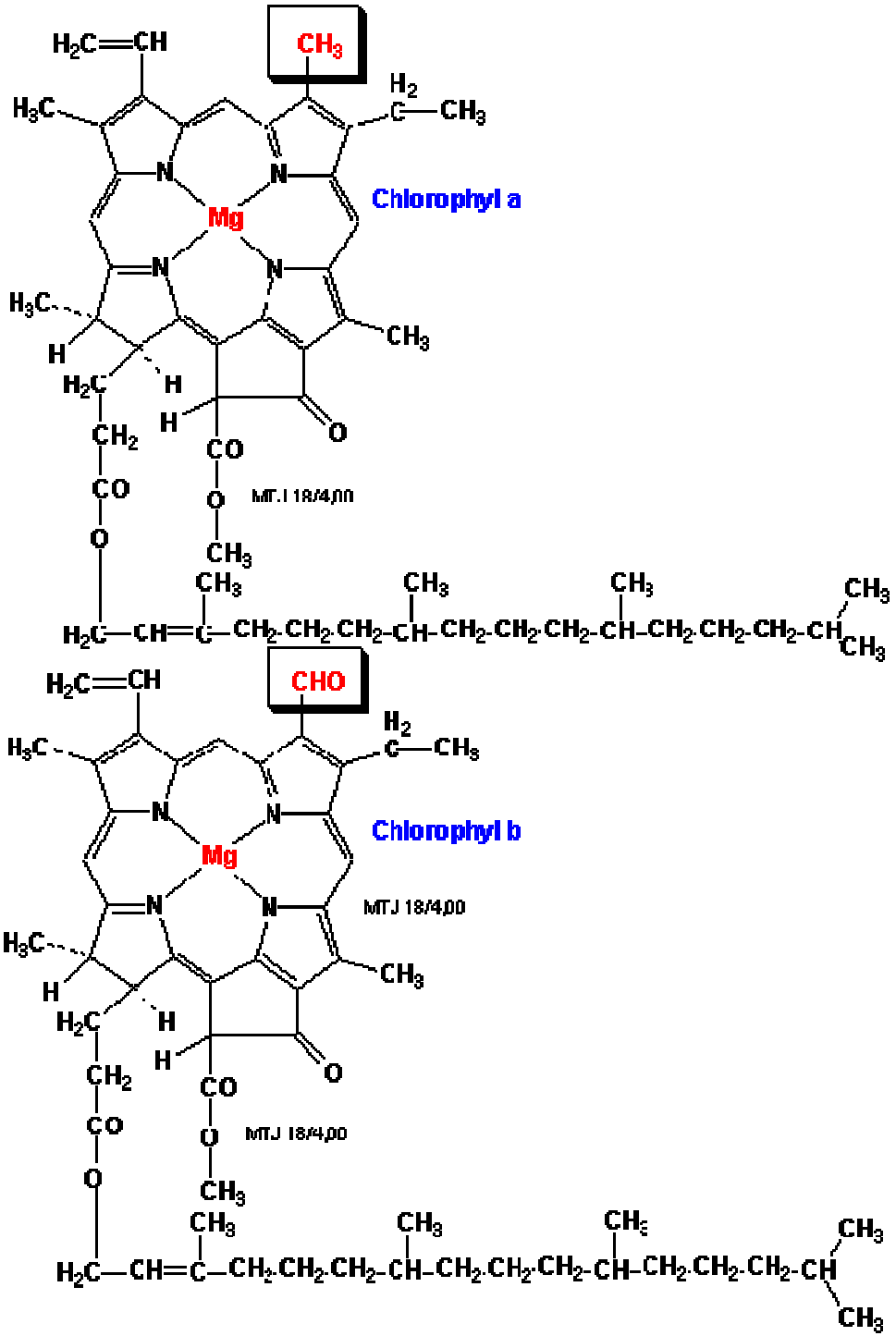
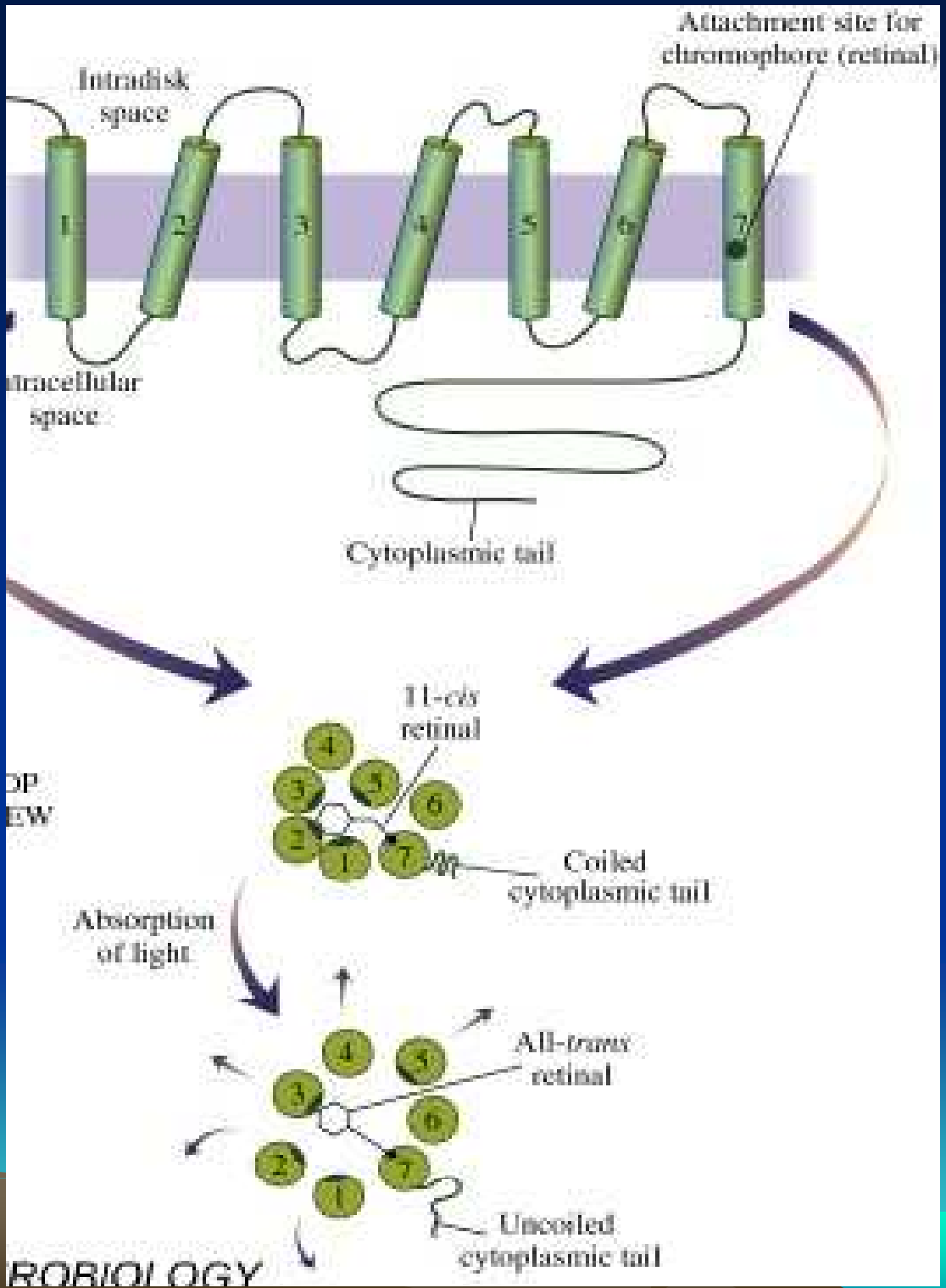


Figure 13.13 Rhodopsin is a photopigment composed of two parts: retinal and opsin
(a) Chemical structures of vitamin A and of retinal. Vitamin A is shown both as a complete structure (top) and as a skeleton structure (middle). Vitamin A is converted to retinal, which has two isomers (11-*cis* and all-*trans*). *(b)* Three-dimensional structure of the protein (opsin) portion of vertebrate rhodopsin. Seven α-helical regions of the protein span the membrane; retinal is attached to an amino acid residue within the seventh membrane-spanning region.

Video cis - trans




Chlorophyl a
MT.I 18/4,00
Chlorophyl b
MTJ 18/4,00
MTJ 18/4,00


Attachment site for chromophore (retinal)
Intradisk space
1
2
3
4
5
6
7
Cytoplasmic tail
11-cis retinal
Coiled cytoplasmic tail
Absorption of light
All-trans retinal
Uncoiled cytoplasmic tail

Video aktivace rhodopsinu

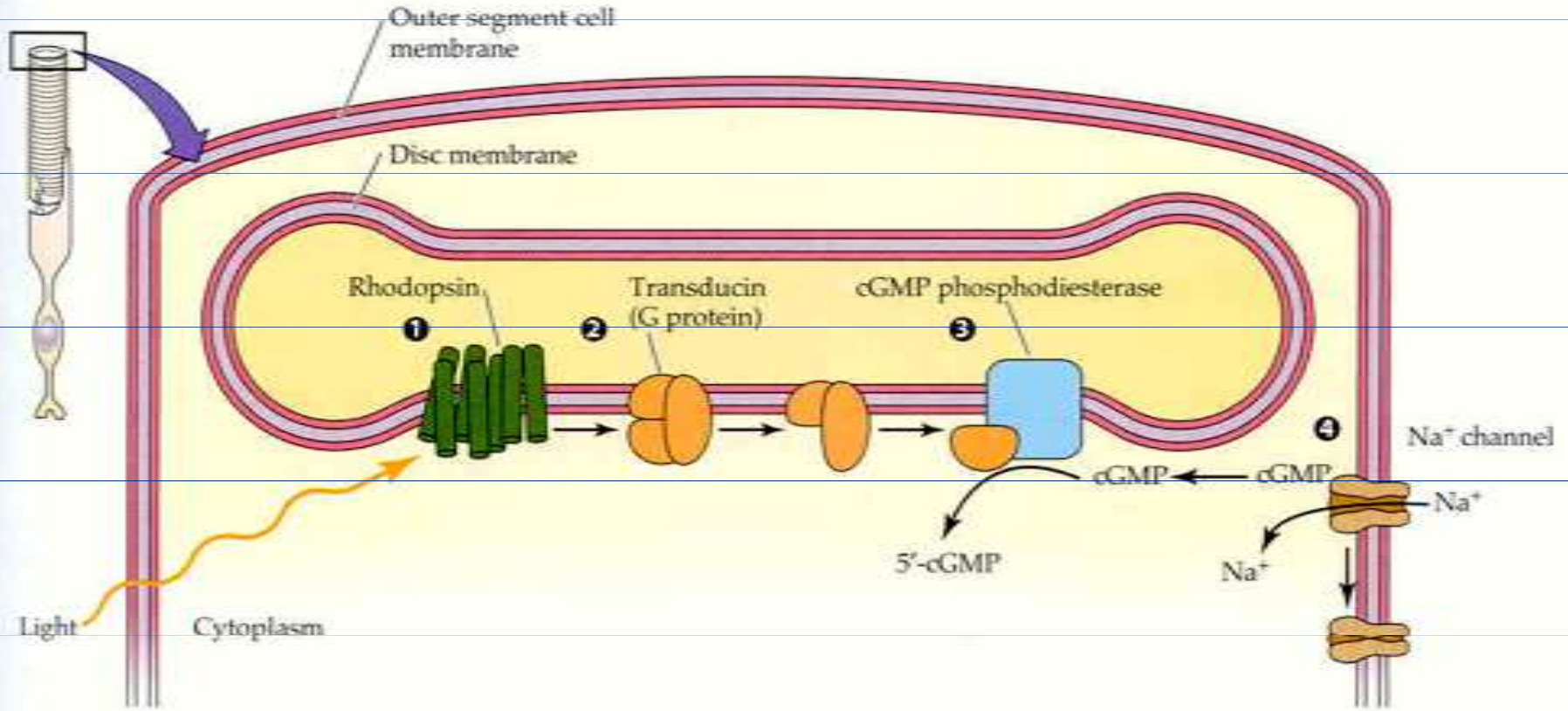
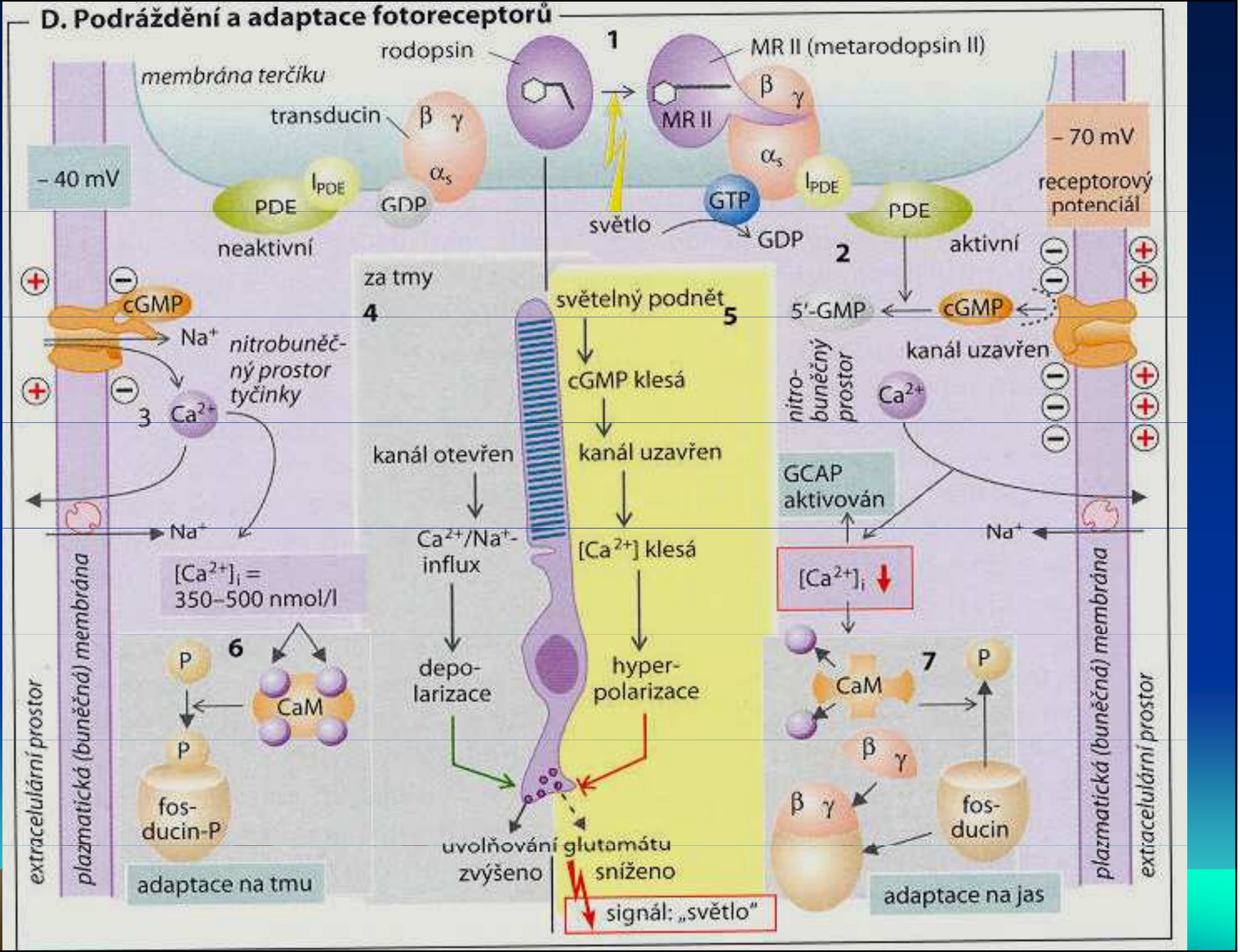


Figure 13.14 Phototransduction closes cation channels in the outer segment of the photoreceptor membrane In the dark, the cation channels are kept open by intracellular cGMP and conduct an inward current, carried largely by Na^+. When light strikes the photoreceptor, these channels are closed by a G protein–coupled mechanism. ❶ Rhodopsin molecules in the disc membrane absorb light and are activated. ❷ The activated rhodopsin stimulates a G protein (transducin in rods), which in turn activates cGMP phosphodiesterase. ❸ The phosphodiesterase catalyzes the breakdown of cGMP to 5′-GMP. ❹ As the cGMP concentration decreases, cGMP detaches from the cation channels, which close.


D. Podráždění a adaptace fotoreceptorů
membrána terčíku
rodopsin
1
MR II (metarodopsin II)
MR II
transducin
β γ
α_s
I_{PDE}
PDE
GDP
GTP
světlo
– 40 mV
– 70 mV
receptorový potenciál
neaktivní
aktivní
2
za tmy
4
světelný podnět
5
cGMP
5'-GMP
kanál uzavřen
Na^+
nitrobuněčný prostor tyčinky
3
Ca^{2+}
nitro-buněčný prostor
cGMP klesá
kanál otevřen
kanál uzavřen
GCAP aktivován
Ca^{2+}/Na^+-influx
$[Ca^{2+}]$ klesá
$[Ca^{2+}]_i$ =
350–500 nmol/l
$[Ca^{2+}]_i$
6
7
P
CaM
depo-larizace
hyper-polarizace
fos-ducin-P
fos-ducin
uvolňování glutamátu
zvýšeno
sníženo
signál: „světlo"
adaptace na tmu
adaptace na jas
extracelulární prostor
plazmatická (buněčná) membrána

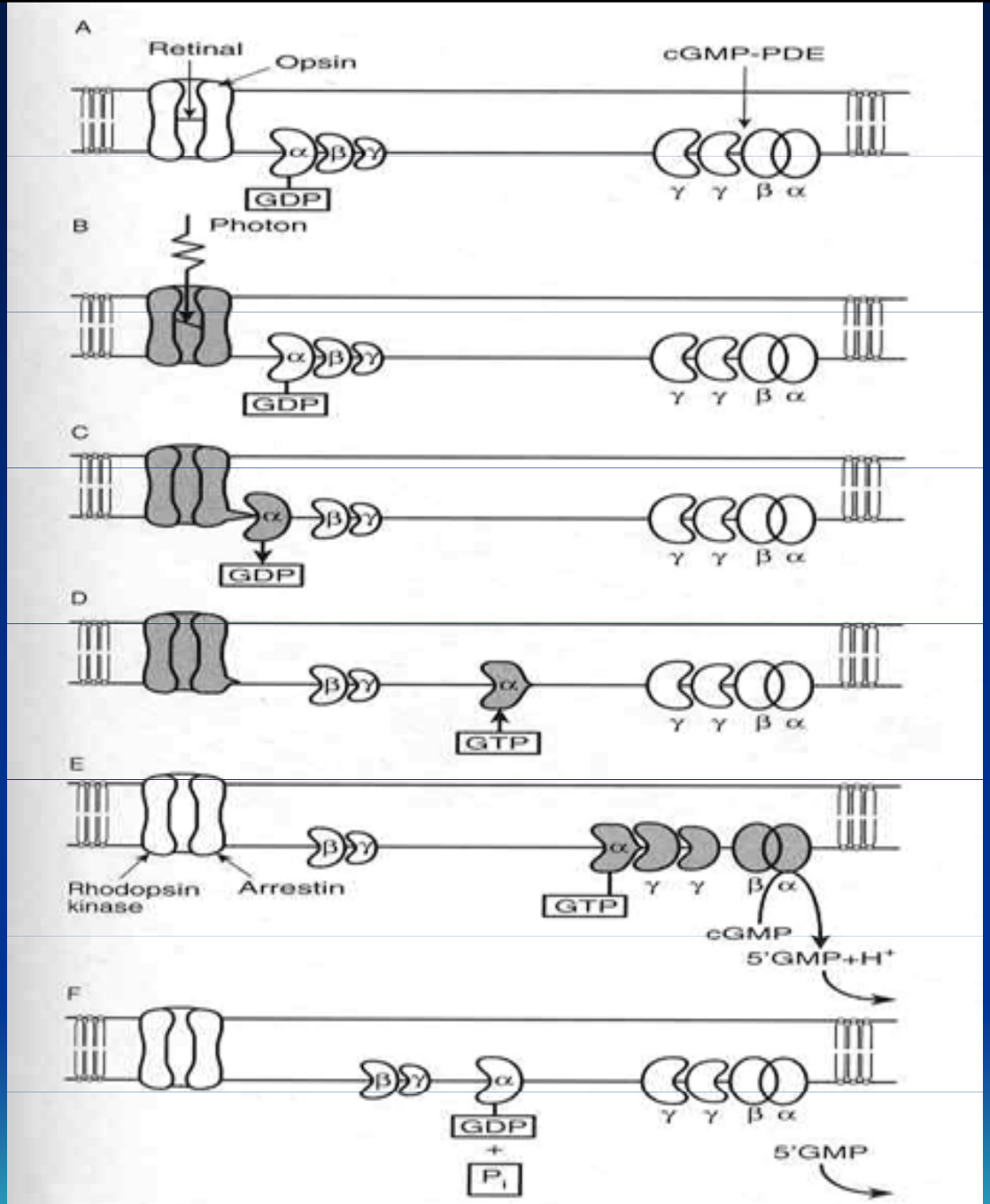
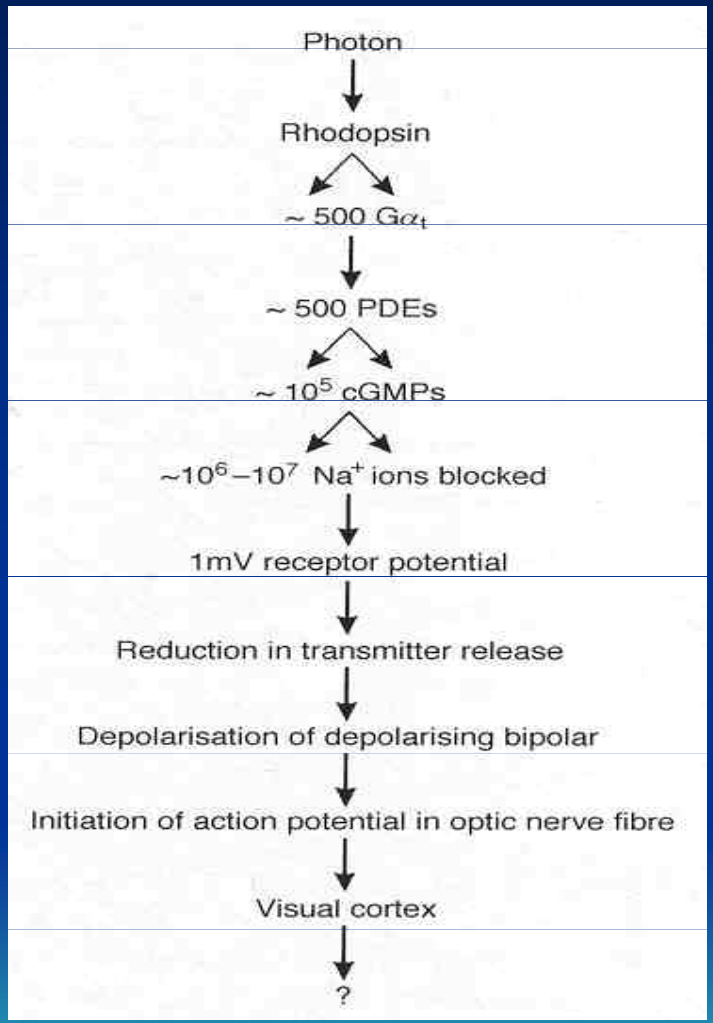
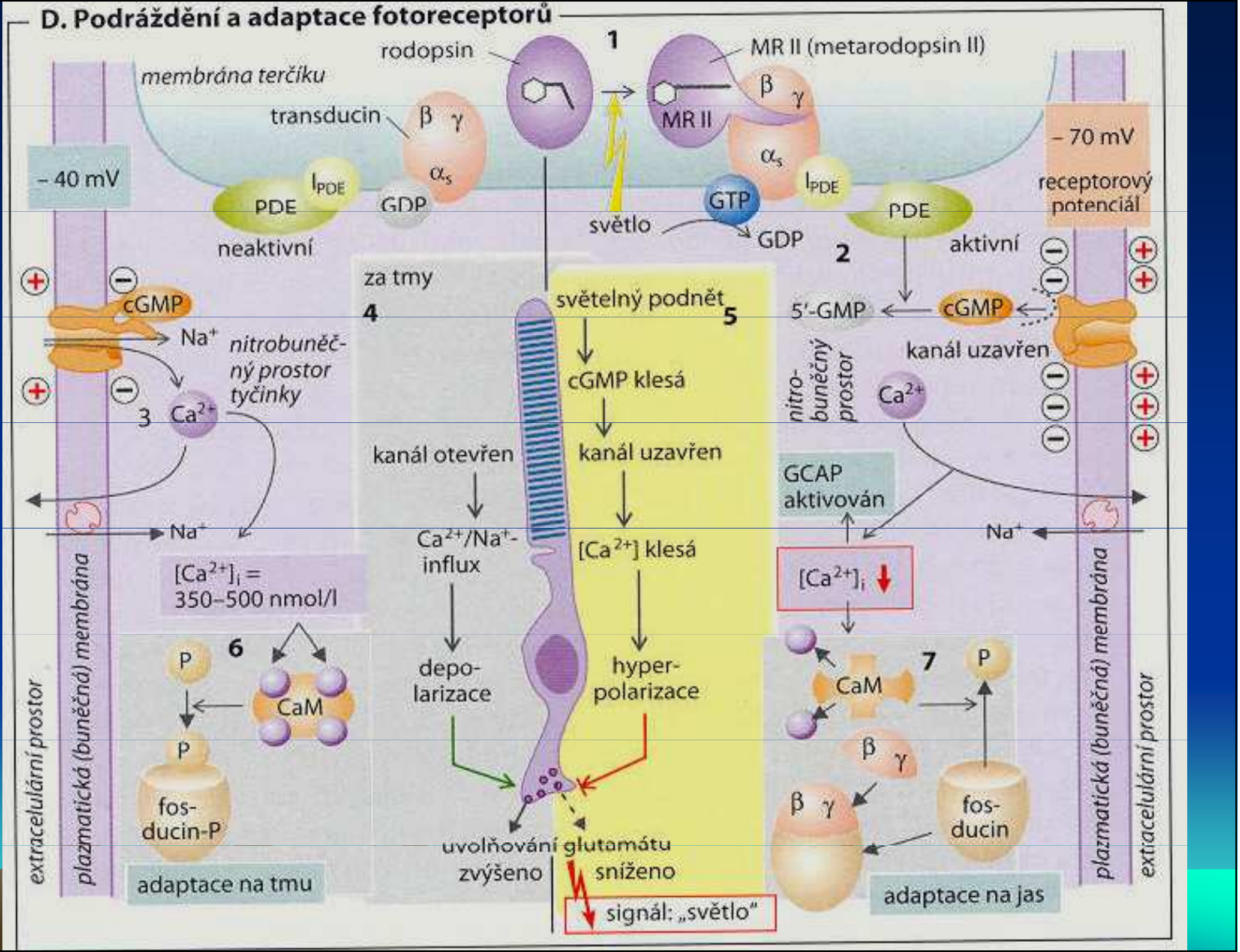
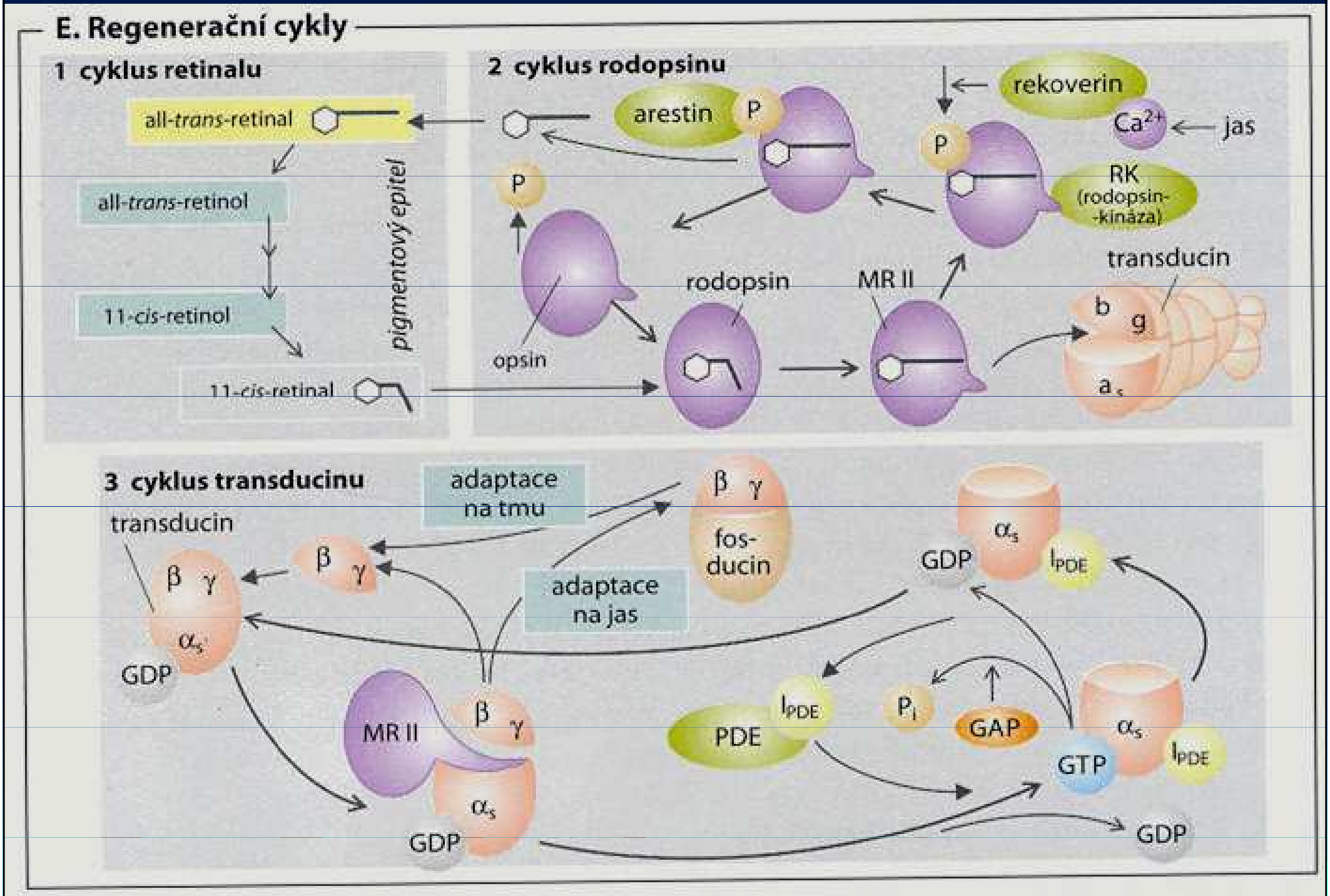


Figure 16.9 Collision coupling in disc membrane. (A) resting condition. (B) On receipt of a photon of light retinal undergoes a *cis-trans* transformation. (C) and (D) 11-*cis* retinal diffuses out of the 'activated' opsin and the α-subunit of T-protein is freed to accept GTP. (E) T_a-GTP activates cGMP-PDE and arrestin and rhodopsin kinase inactivate opsin. (F) GTP is dephosphorylated and the action of T_a on cGMP-PDE is terminated. The system returns to rest. Stipple = activated



- Vypnutí – Arestin v G-prot. Signalizaci, Ca
- Adaptace – úloha Ca iontů (čich, sluch)
- Regenerace


D. Podráždění a adaptace fotoreceptorů
membrána terčíku
rodopsin
1
MR II (metarodopsin II)
MR II
transducin
β γ
α_s
I_{PDE}
PDE
GDP
GTP
světlo
– 40 mV
– 70 mV
receptorový potenciál
neaktivní
aktivní
2
za tmy
4
světelný podnět
5
cGMP
5'-GMP
kanál uzavřen
Na^+
nitrobuněčný prostor tyčinky
3
Ca^{2+}
nitro-buněčný prostor
cGMP klesá
kanál otevřen
kanál uzavřen
GCAP aktivován
Ca^{2+}/Na^+-influx
$[Ca^{2+}]$ klesá
$[Ca^{2+}]_i$ =
350–500 nmol/l
$[Ca^{2+}]_i$
6
7
P
CaM
depo-larizace
hyper-polarizace
fos-ducin-P
fos-ducin
uvolňování glutamátu
zvýšeno
sníženo
signál: „světlo"
adaptace na tmu
adaptace na jas
extracelulární prostor
plazmatická (buněčná) membrána


E. Regenerační cykly
1 cyklus retinalu
all-trans-retinal
all-trans-retinol
11-cis-retinol
11-cis-retinal
pigmentový epitel
2 cyklus rodopsinu
arestin
P
rekoverin
Ca2+
jas
RK
(rodopsin-
-kináza)
opsin
rodopsin
MR II
transducin
b
g
as
3 cyklus transducinu
transducin
adaptace
na tmu
adaptace
na jas
fos-
ducin
GDP
GTP
MR II
PDE
lPDE
PI
GAP

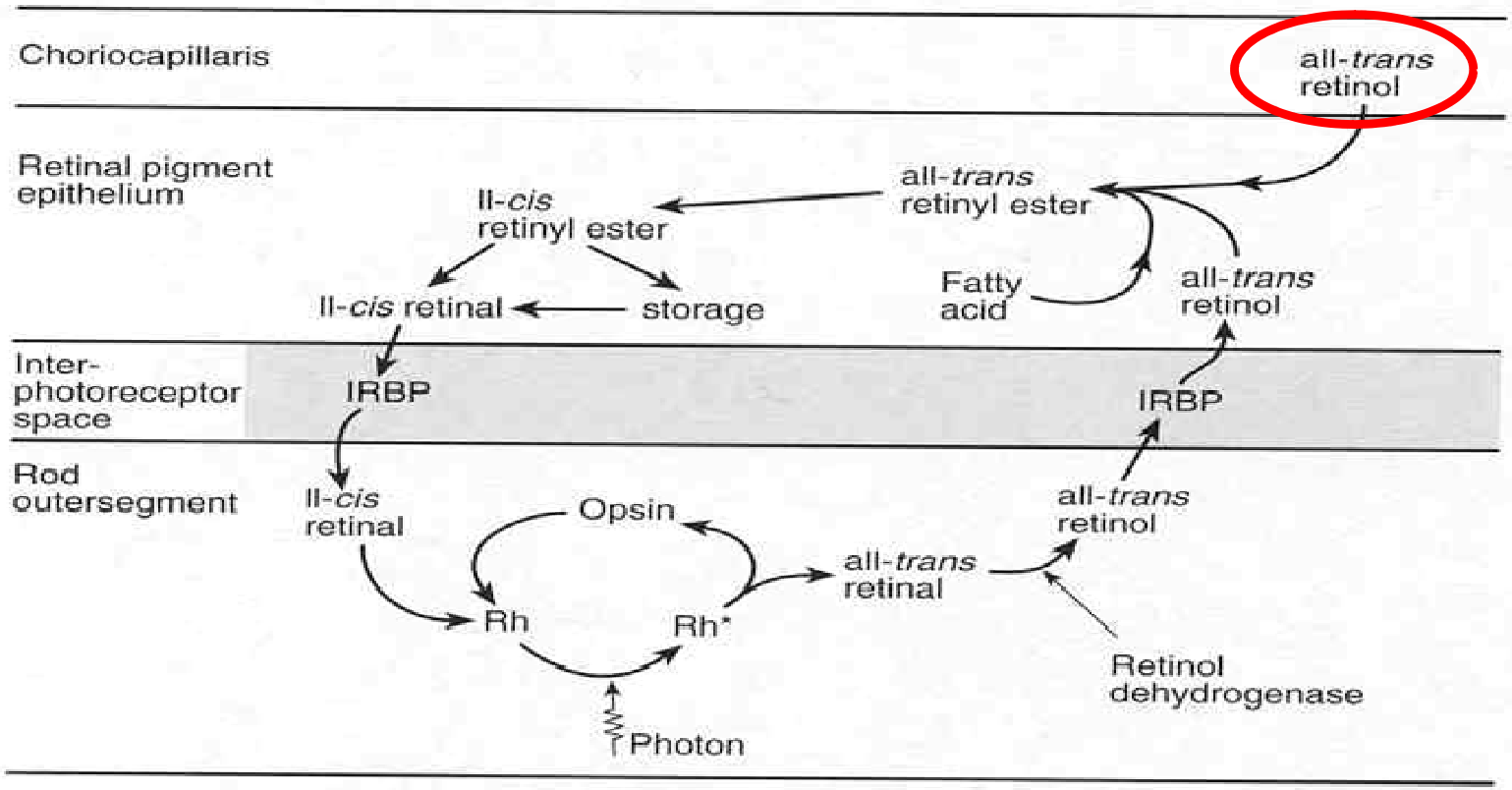
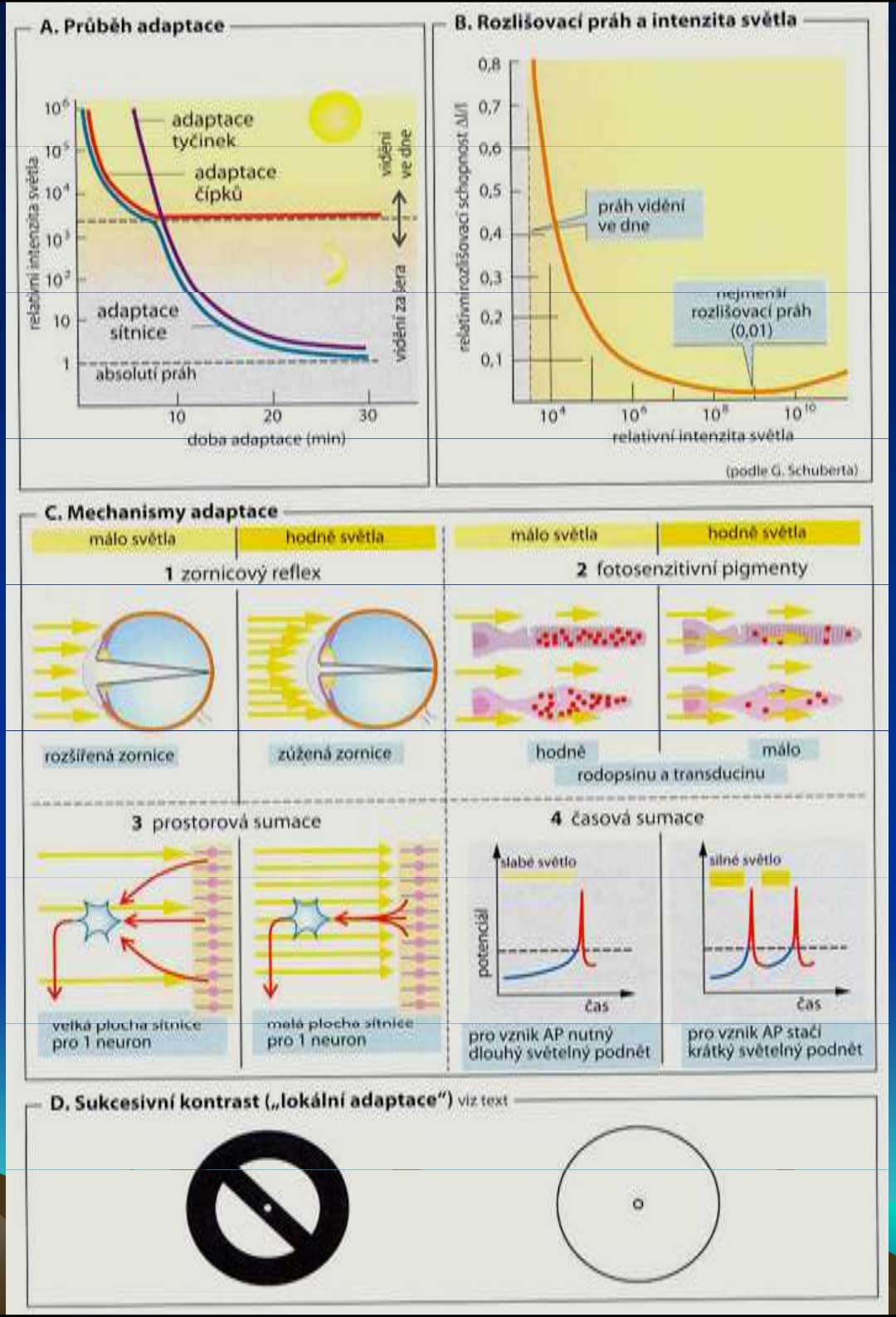
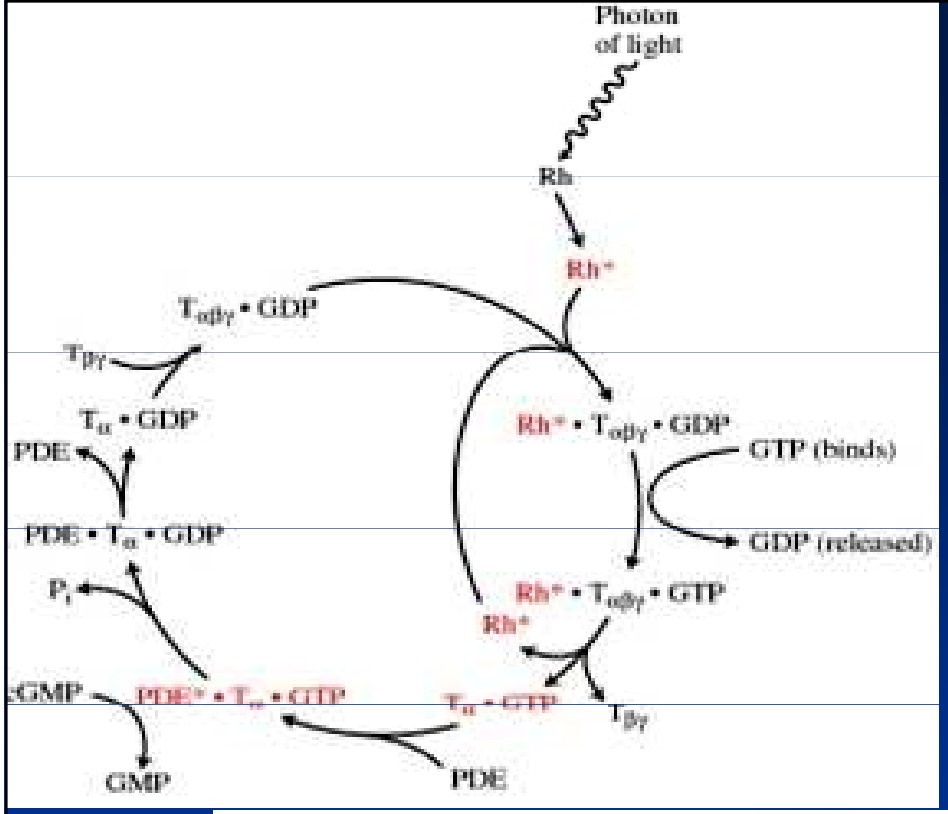
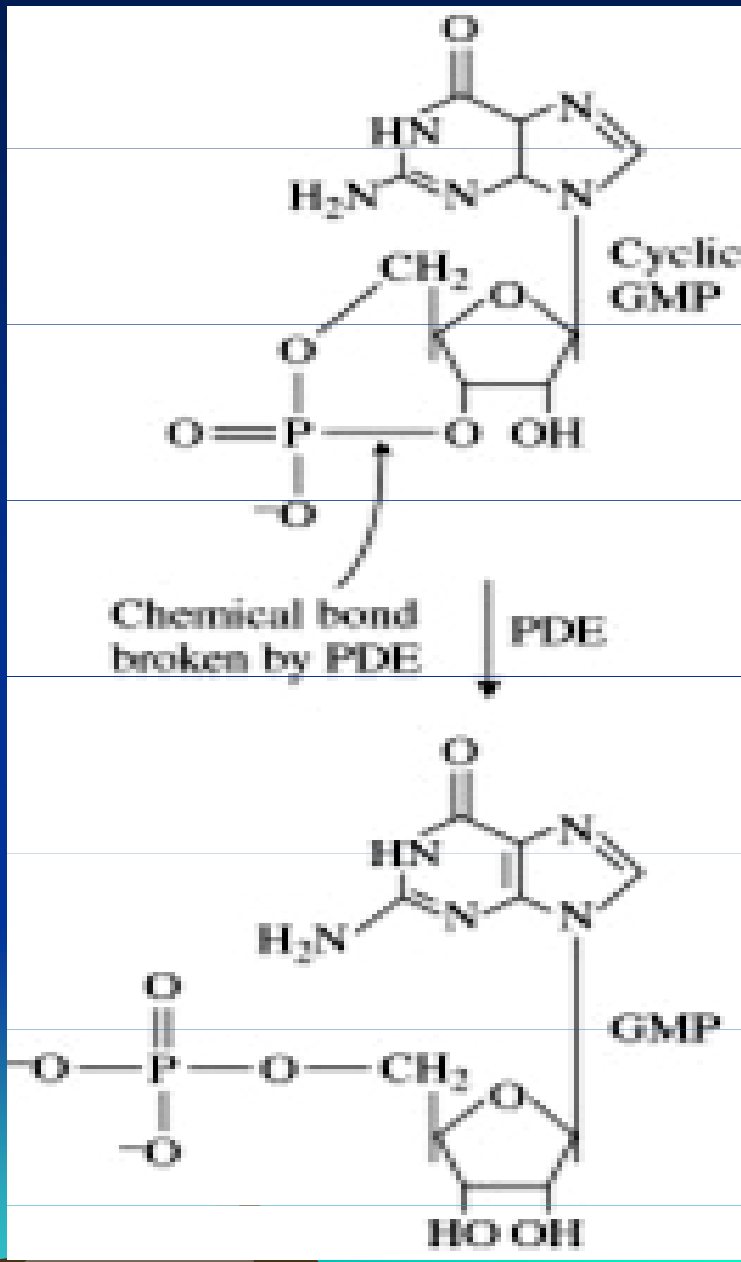
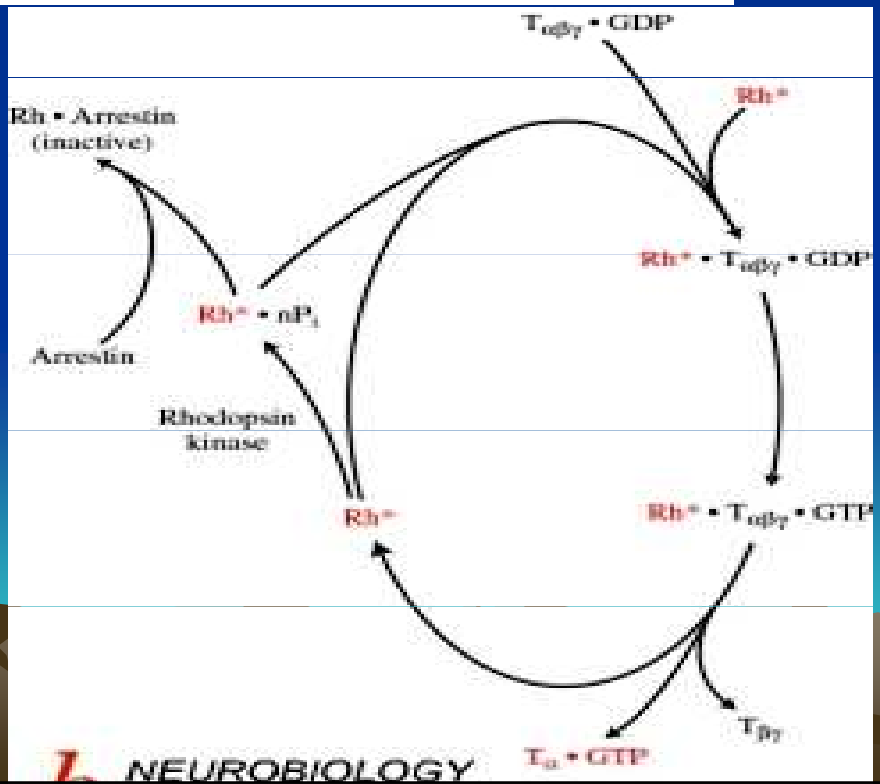


Figure 16.13 Regeneration of 11-*cis* retinal. Explanation in text. IRBP = interphotoreceptor retinoid binding protein; Rh = rhodopsin; Rh* = activated rhodopsin. Simplified from Harding, 1997


A. Průběh adaptace
relativní intenzita světla
adaptace tyčinek
adaptace čípků
adaptace sítnice
absolutní práh
vidění ve dne
vidění za šera
doba adaptace (min)
B. Rozlišovací práh a intenzita světla
relativní rozlišovací schopnost ΔI/I
práh vidění ve dne
nejmenší rozlišovací práh (0,01)
relativní intenzita světla
(podle G. Schuberta)
C. Mechanismy adaptace
málo světla
hodně světla
1 zornicový reflex
rozšířená zornice
zúžená zornice
2 fotosenzitivní pigmenty
hodně
málo
rodopsinu a transducinu
3 prostorová sumace
velká plocha sítnice pro 1 neuron
malá plocha sítnice pro 1 neuron
4 časová sumace
slabé světlo
silné světlo
potenciál
čas
pro vznik AP nutný dlouhý světelný podnět
pro vznik AP stačí krátký světelný podnět
D. Sukcesivní kontrast („lokální adaptace“) viz text


Photon of light
Rh
Rh*
$T_{\alpha\beta\gamma}$ • GDP
$T_{\beta\gamma}$
T_α • GDP
PDE
PDE • T_α • GDP
P_i
Rh* • $T_{\alpha\beta\gamma}$ • GDP
GTP (binds)
GDP (released)
Rh* • $T_{\alpha\beta\gamma}$ • GTP
Rh*
T_α • GTP
$T_{\beta\gamma}$
PDE* • T_α • GDP
GMP
PDE

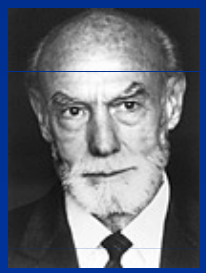

Cyclic GMP
Chemical bond broken by PDE
PDE
GMP

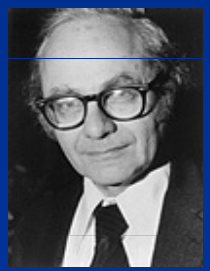

$T_{\alpha\beta\gamma}$ • GDP
Rh*
Rh • Arrestin (inactive)
Rh* • $T_{\alpha\beta\gamma}$ • GDP
Rh* • nP_i
Arrestin
Rhodopsin kinase
Rh*
Rh* • $T_{\alpha\beta\gamma}$ • GTP
$T_{\beta\gamma}$
T_α • GTP

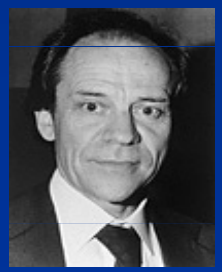
The Nobel Prize in Physiology or Medicine 1981

"for his discoveries concerning the functional specialization of the cerebral hemispheres"

"for their discoveries concerning information processing in the visual system"







Roger W. Sperry

1/2 of the prize

USA

California Institute of Technology
Pasadena, CA, USA

b. 1913
d. 1994

David H. Hubel

1/4 of the prize

USA

Harvard Medical School
Boston, MA, USA

b. 1926
(in Windsor, ON, Canada)

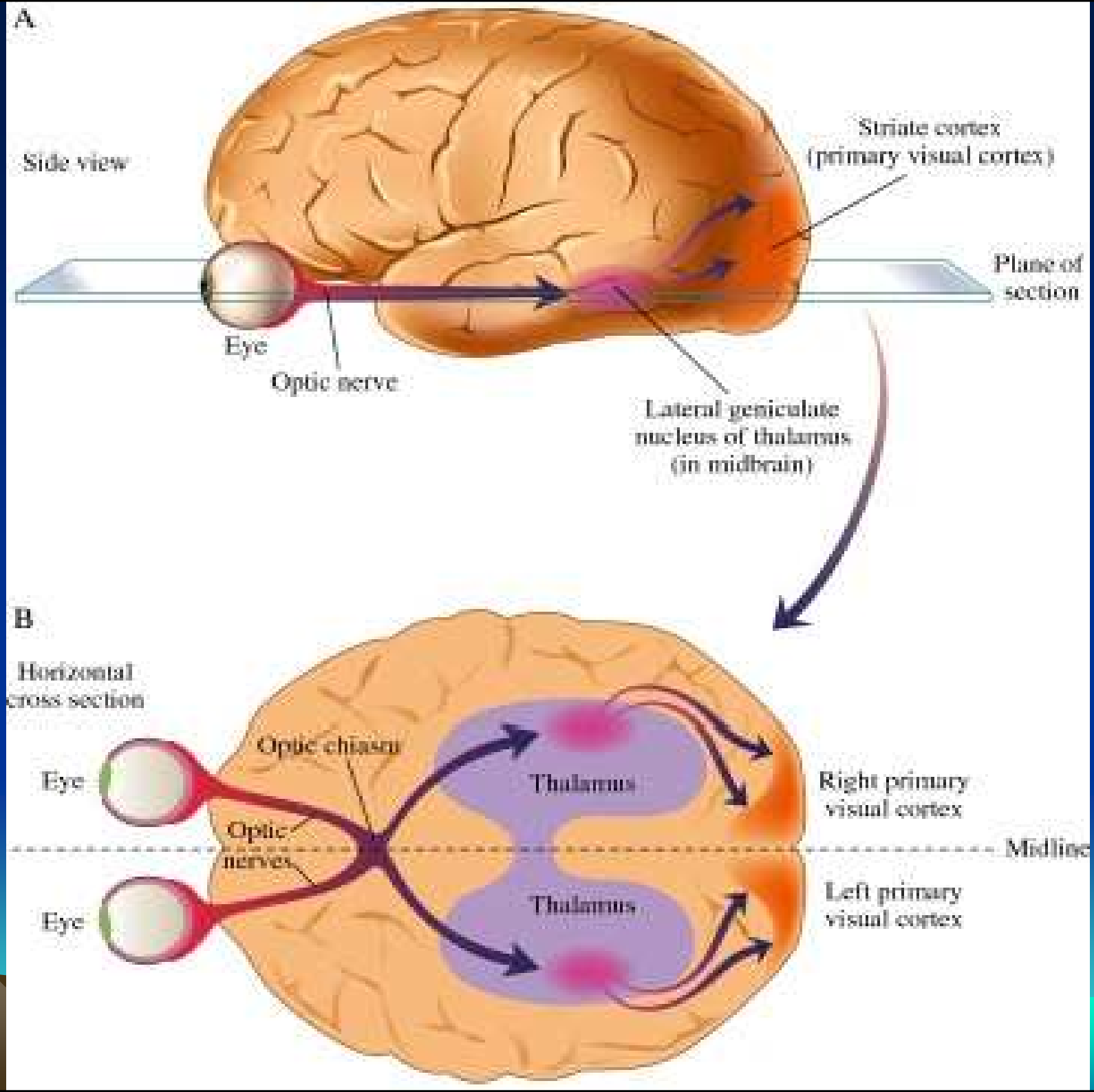
Torsten N. Wiesel

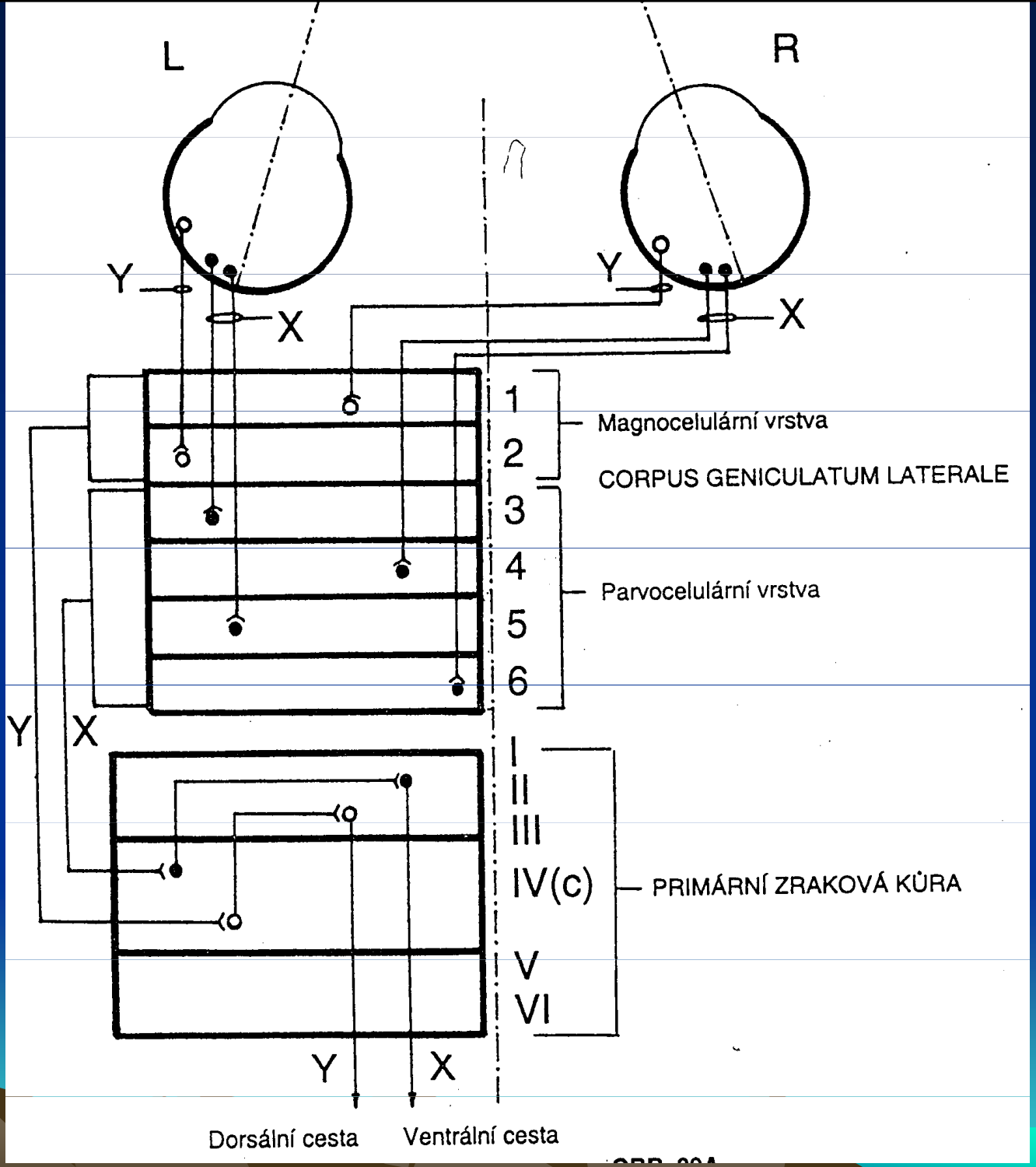
1/4 of the prize

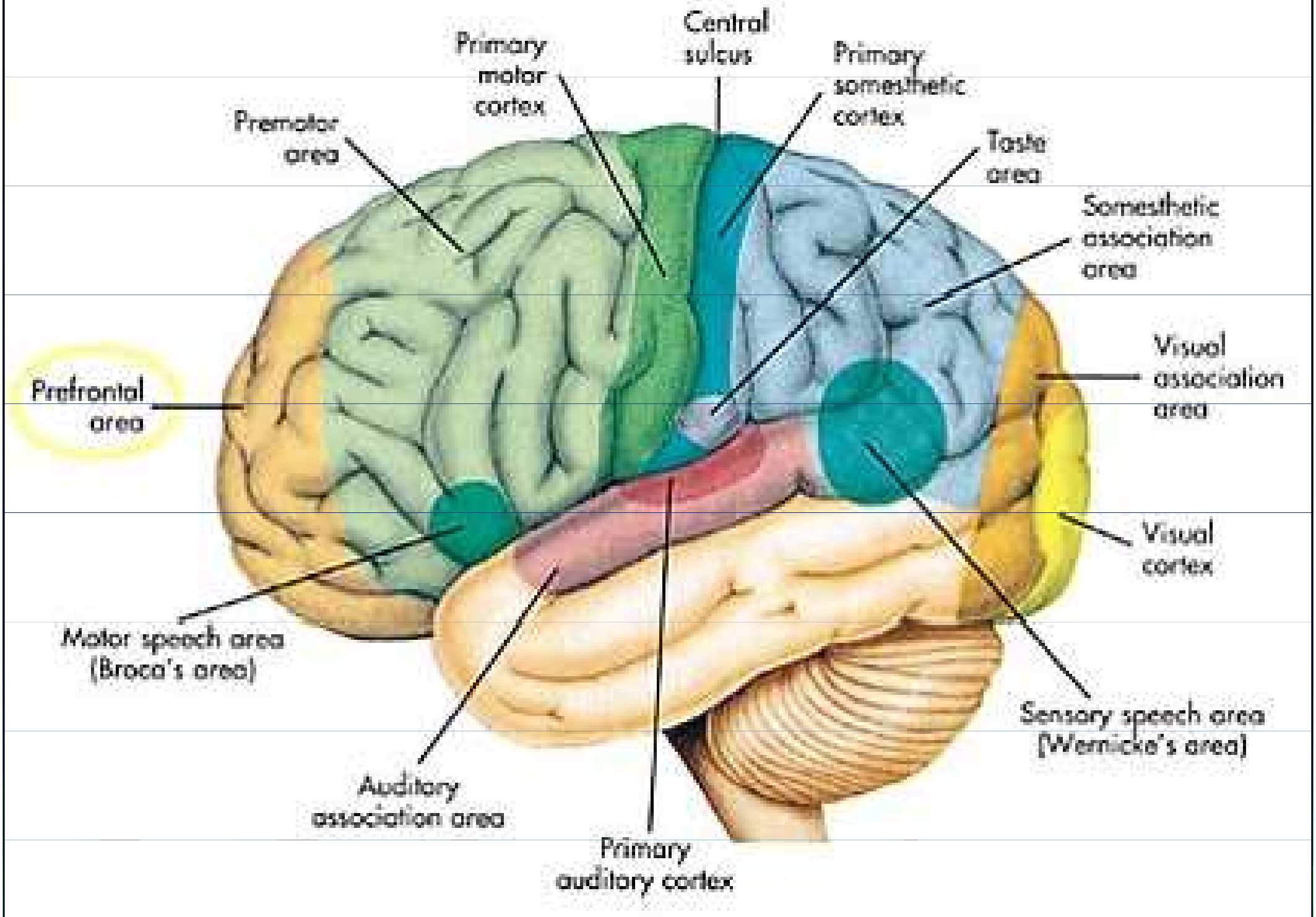
Sweden

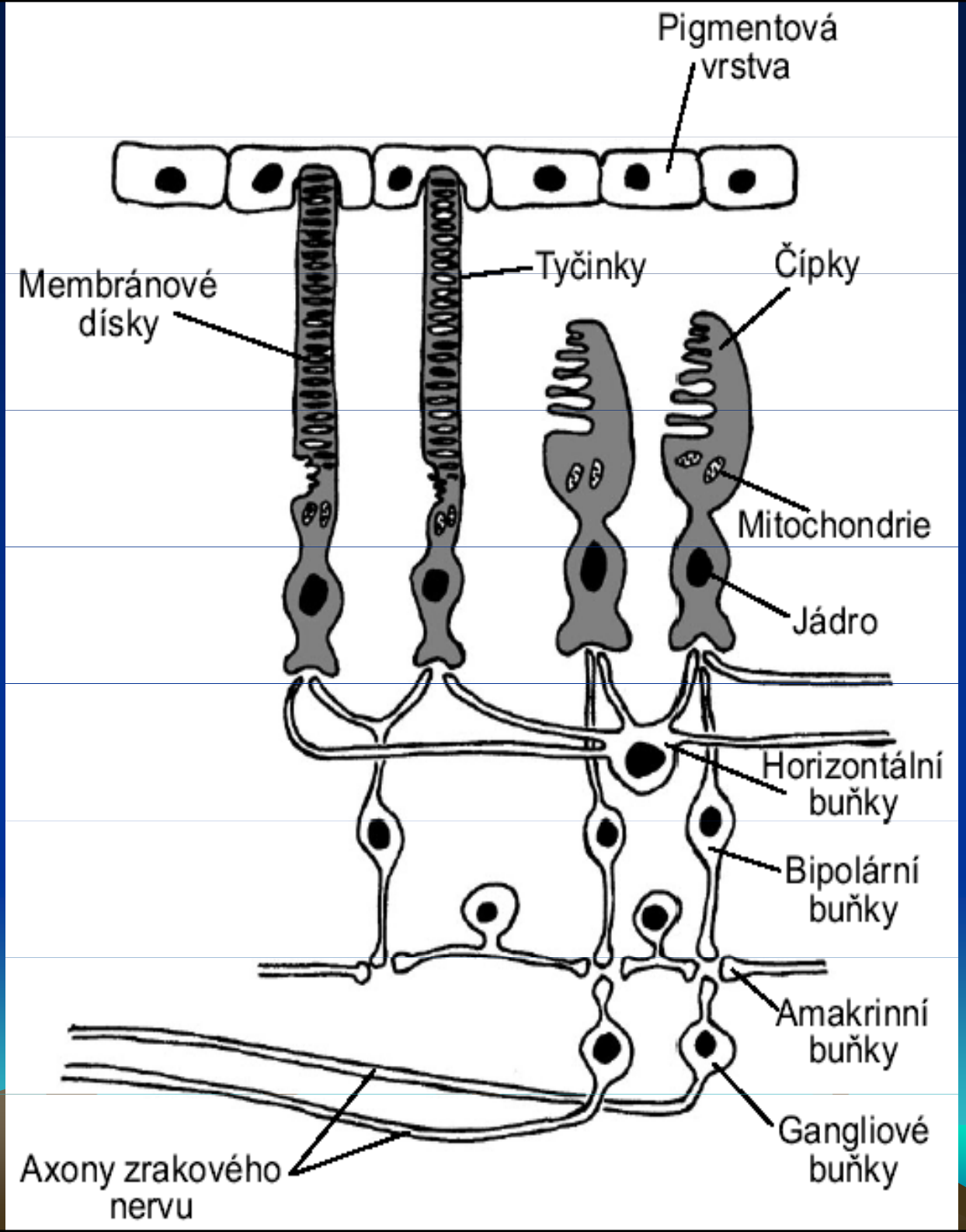
Harvard Medical School
Boston, MA, USA

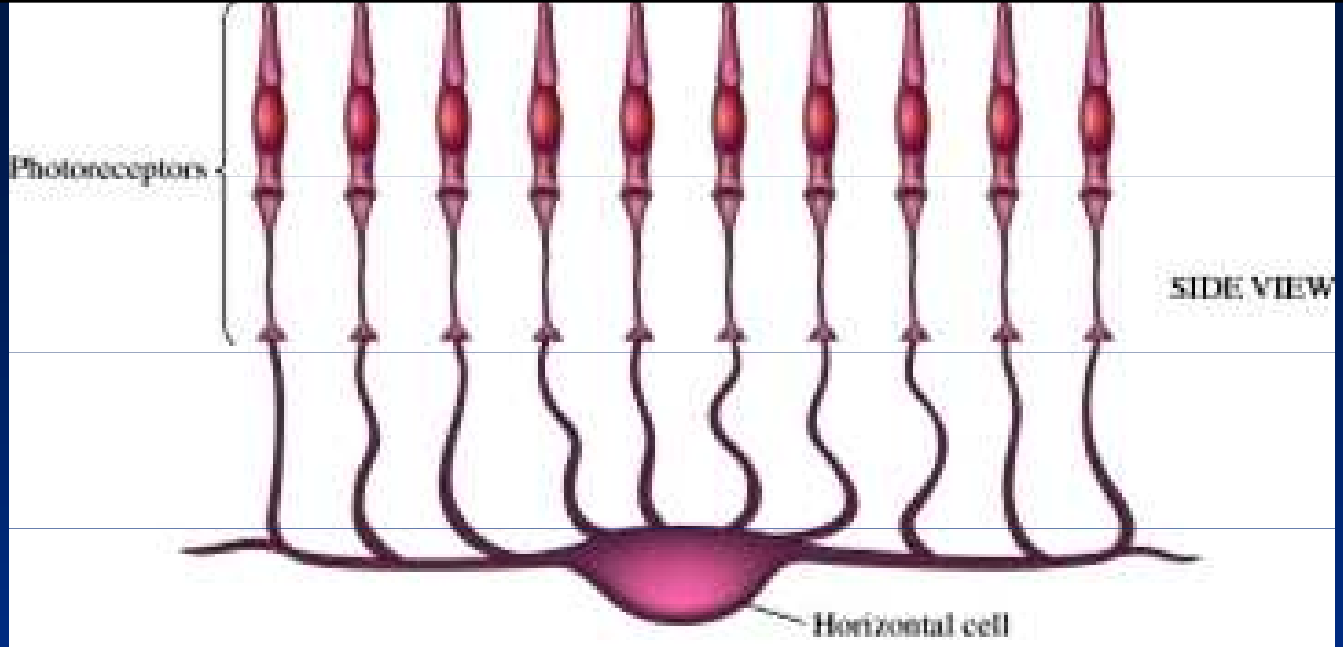
b. 1924


A
Side view
Striate cortex
(primary visual cortex)
Plane of
section
Eye
Optic nerve
Lateral geniculate
nucleus of thalamus
(in midbrain)
B
Horizontal
cross section
Optic chiasm
Eye
Thalamus
Right primary
visual cortex
Optic
nerves
Midline
Eye
Thalamus
Left primary
visual cortex

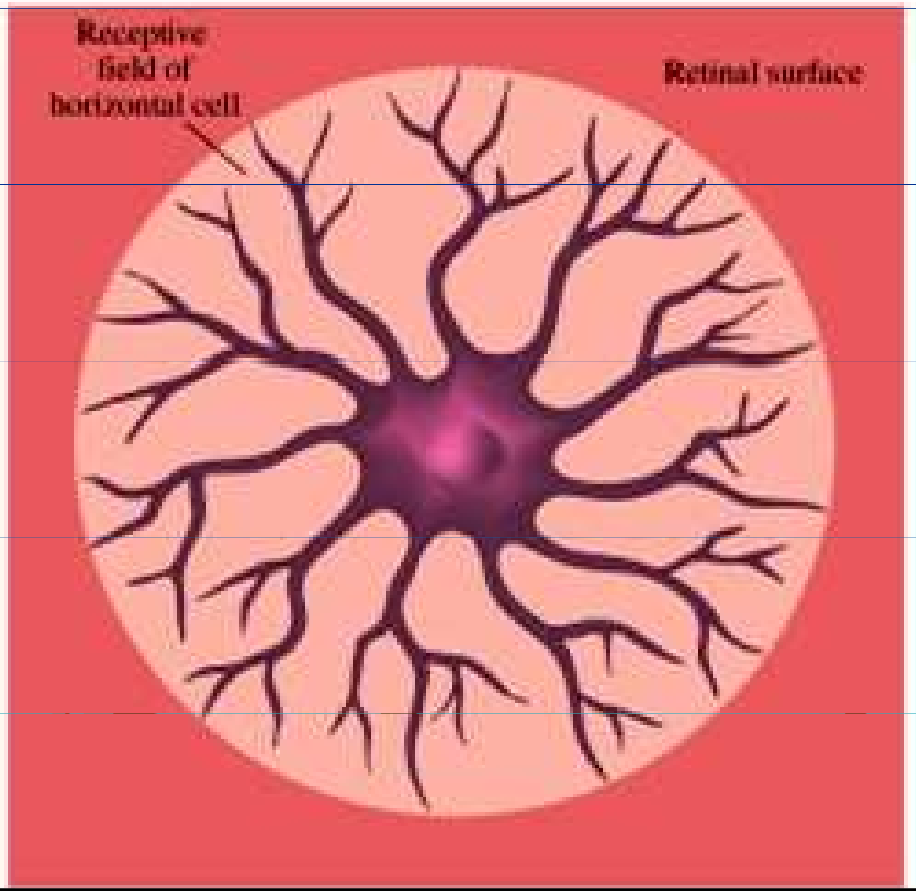

L
R
Y
X
Y
X
1
2
3
4
5
6
Magnocelulární vrstva
CORPUS GENICULATUM LATERALE
Parvocelulární vrstva
Y
X
I
II
III
IV(c)
V
VI
PRIMÁRNÍ ZRAKOVÁ KŮRA
Y
X
Dorsální cesta
Ventrální cesta


Central sulcus
Primary motor cortex
Primary somesthetic cortex
Premotor area
Taste area
Somesthetic association area
Visual association area
Prefrontal area
Visual cortex
Motor speech area (Broca's area)
Sensory speech area (Wernicke's area)
Auditory association area
Primary auditory cortex

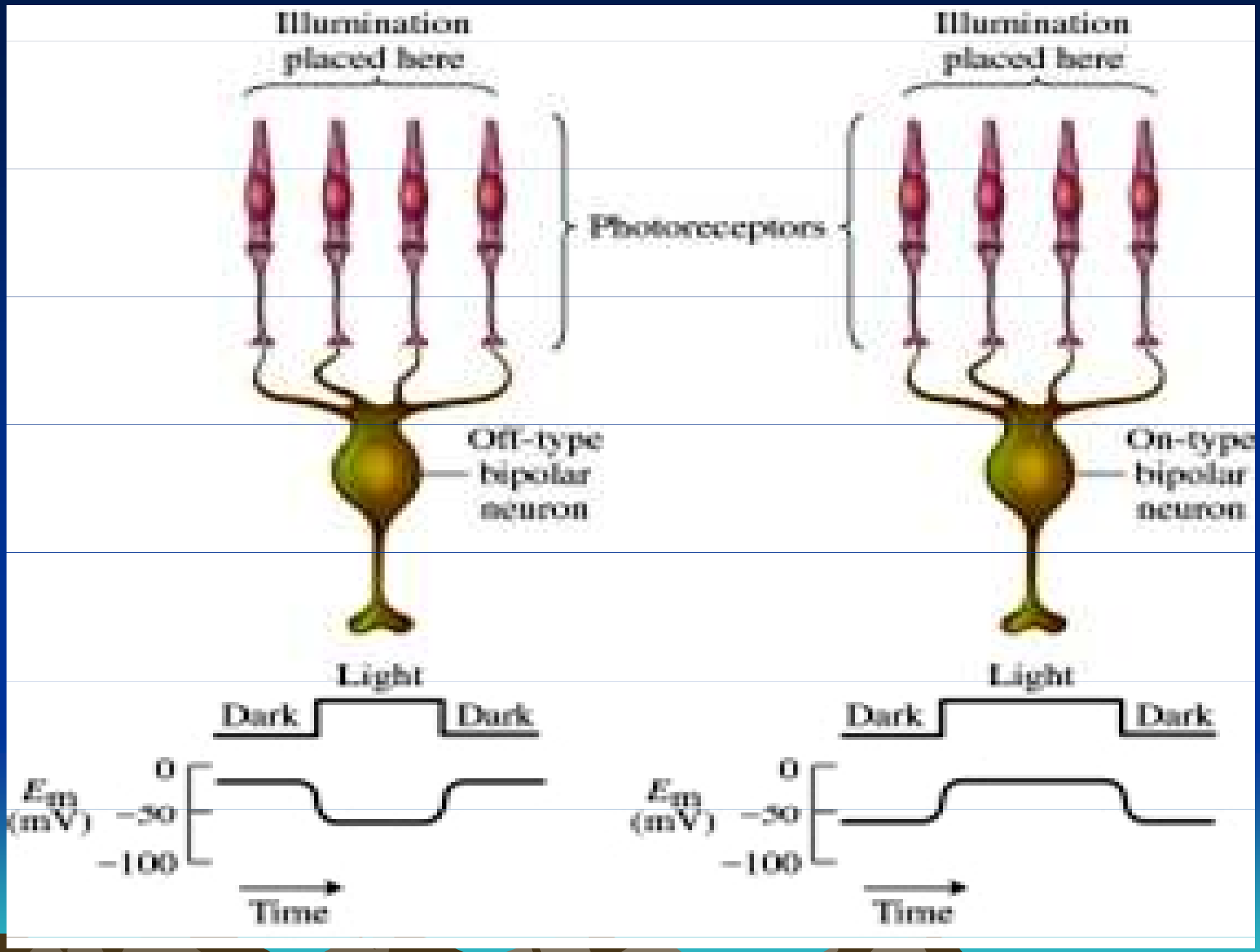

Pigmentová vrstva
Tyčinky
Čípky
Membránové disky
Mitochondrie
Jádro
Horizontální buňky
Bipolární buňky
Amakrinní buňky
Gangliové buňky
Axony zrakového nervu

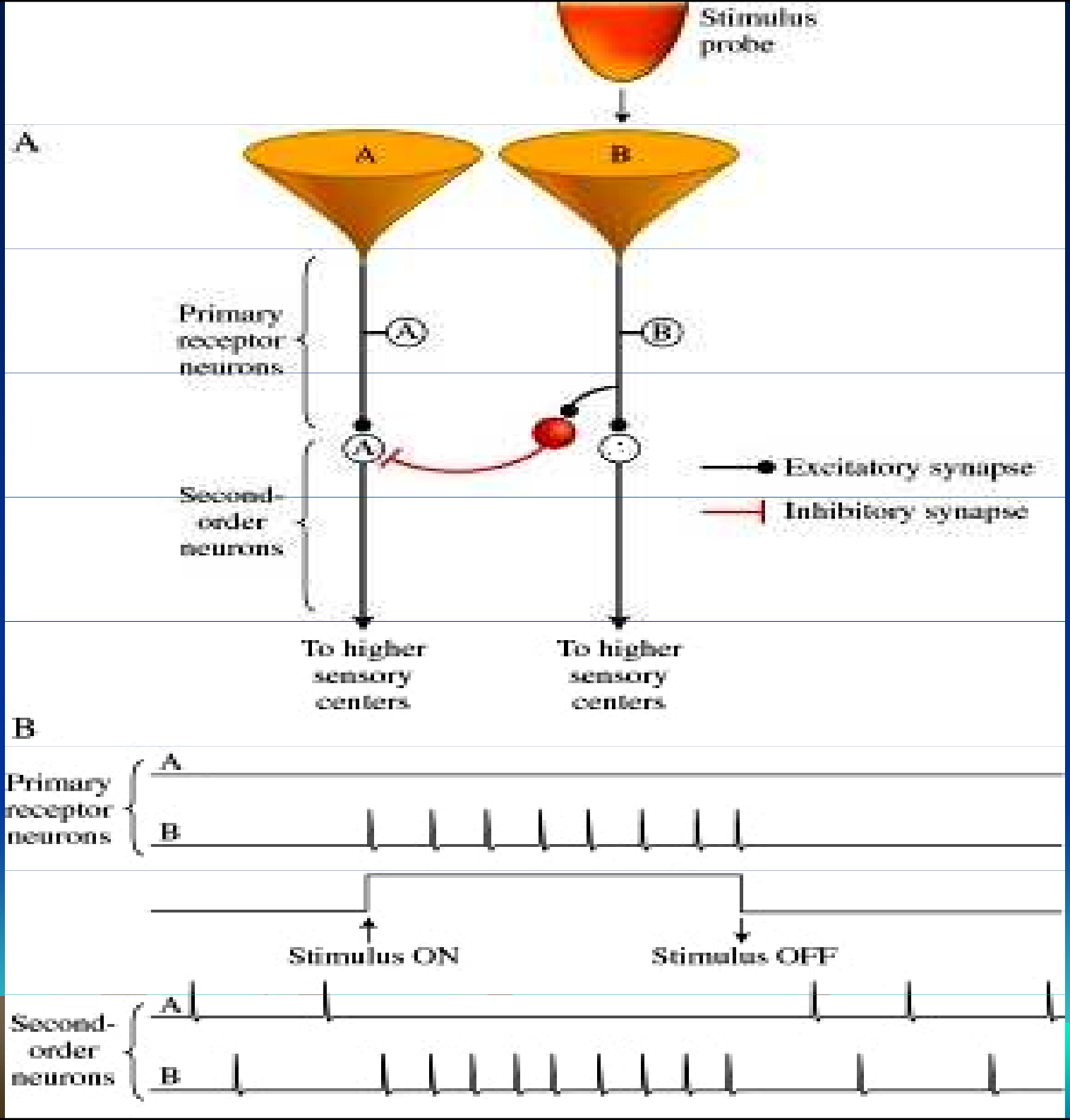


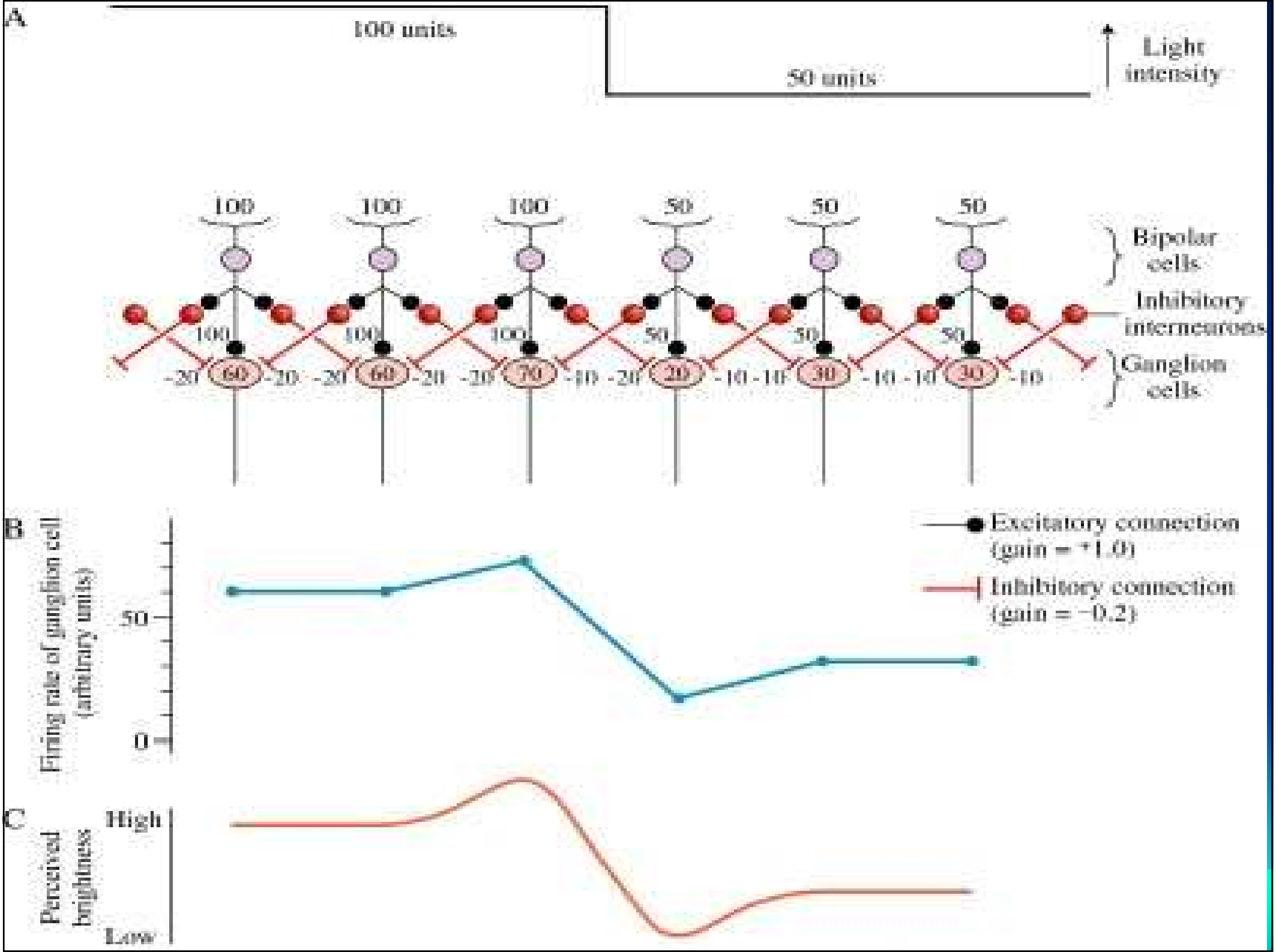
SIDE VIEW

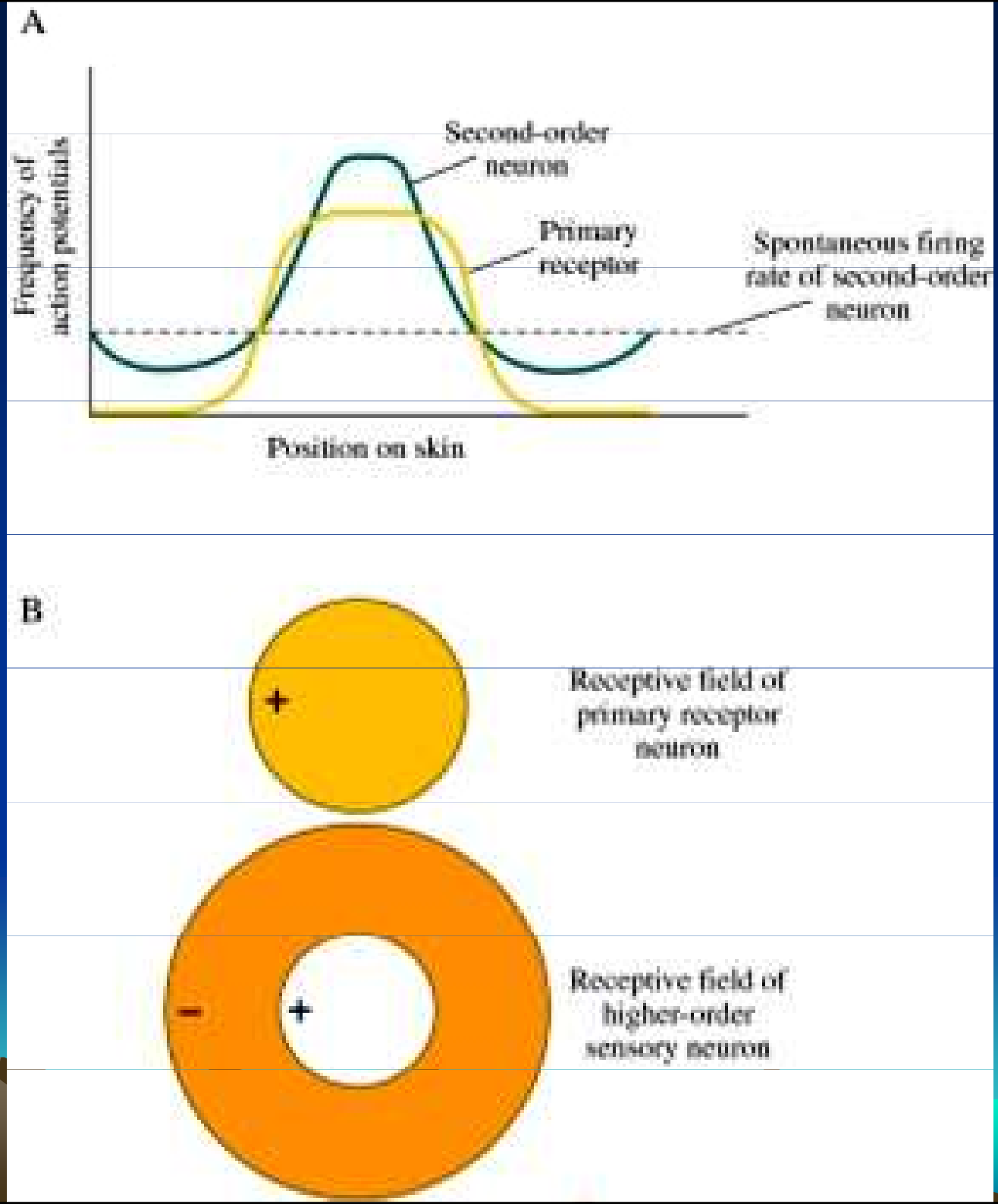


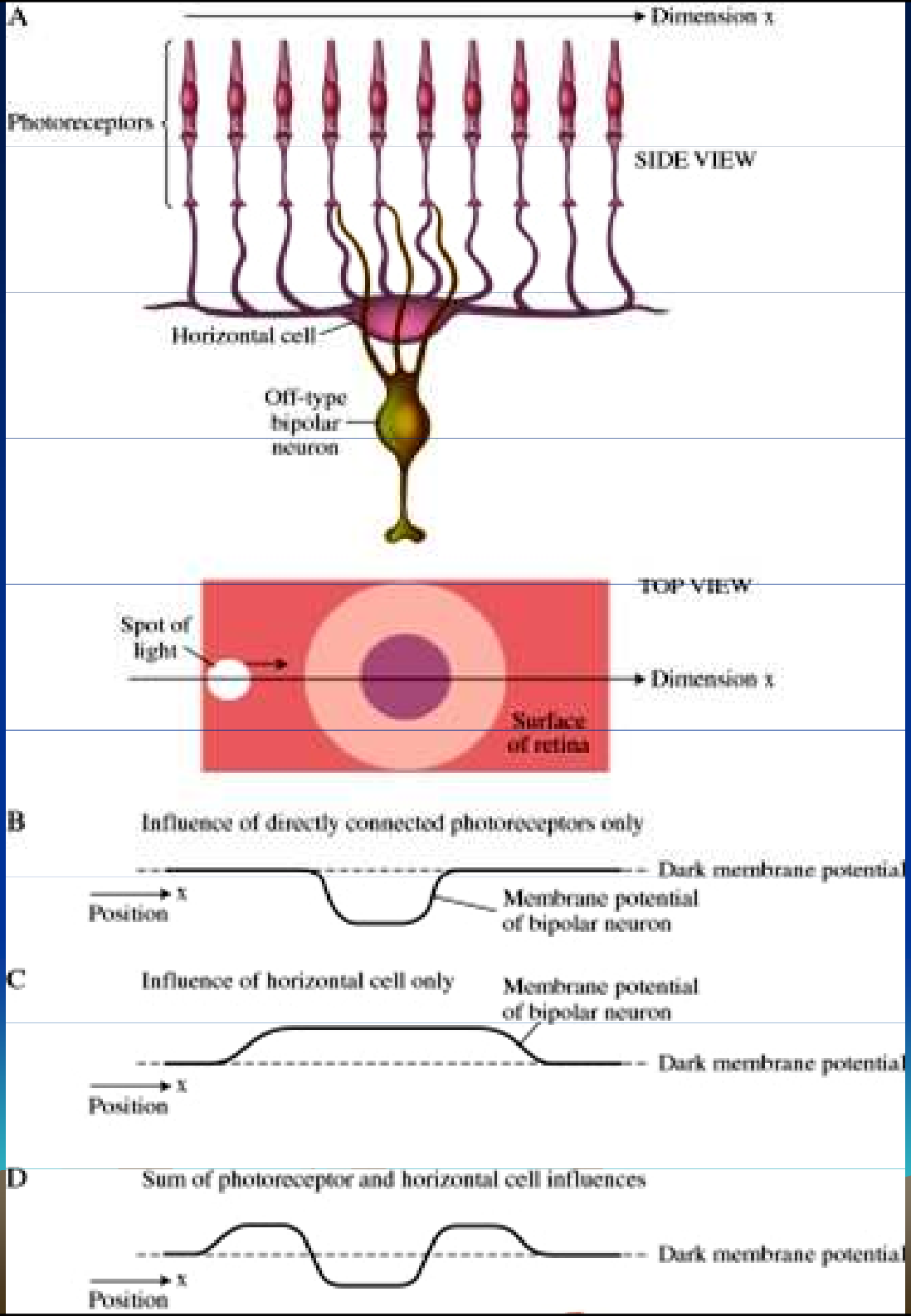
TOP VIEW


Illumination placed here
Illumination placed here
Photoreceptors
Off-type bipolar neuron
On-type bipolar neuron
Light
Dark
Dark
Light
Dark
Dark
E_m (mV)
0
−50
−100
E_m (mV)
0
−50
−100
Time
Time

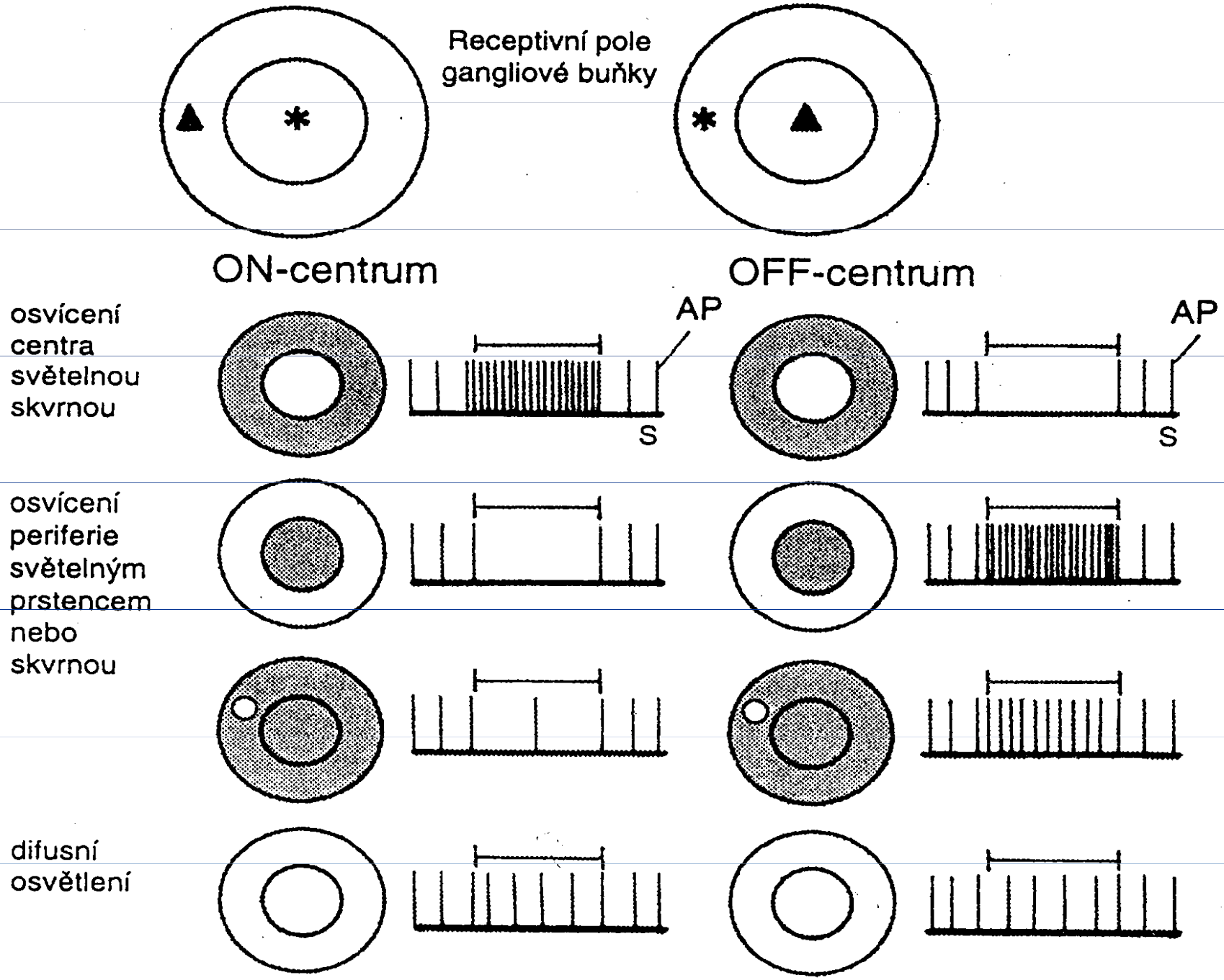

Stimulus probe
A
A
B
Primary receptor neurons
A
B
Second-order neurons
A
Excitatory synapse
Inhibitory synapse
To higher sensory centers
To higher sensory centers
B
Primary receptor neurons
A
B
Stimulus ON
Stimulus OFF
Second-order neurons
A
B


A
100 units
50 units
Light intensity
100
100
100
50
50
50
Bipolar cells
Inhibitory interneurons
Ganglion cells
100
100
100
50
50
50
-20 60 -20 -20 60 -20 -20 70 -10 -20 20 -10 -10 30 -10 -10 30 -10
B
Firing rate of ganglion cell (arbitrary units)
50
0
Excitatory connection (gain = +1.0)
Inhibitory connection (gain = −0.2)
C
Perceived brightness
High
Low

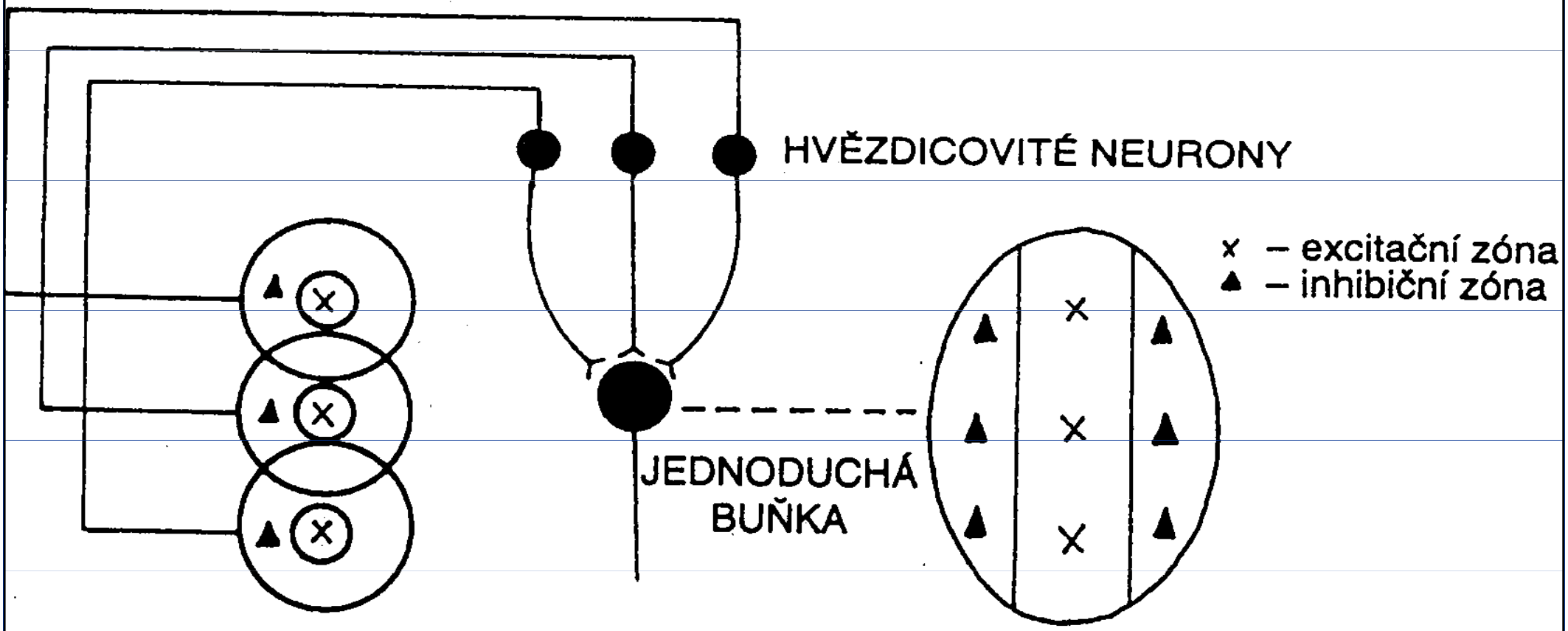

A
Frequency of action potentials
Second-order neuron
Primary receptor
Spontaneous firing rate of second-order neuron
Position on skin
B
+
Receptive field of primary receptor neuron
−
+
Receptive field of higher-order sensory neuron



[Video receptivní pole]

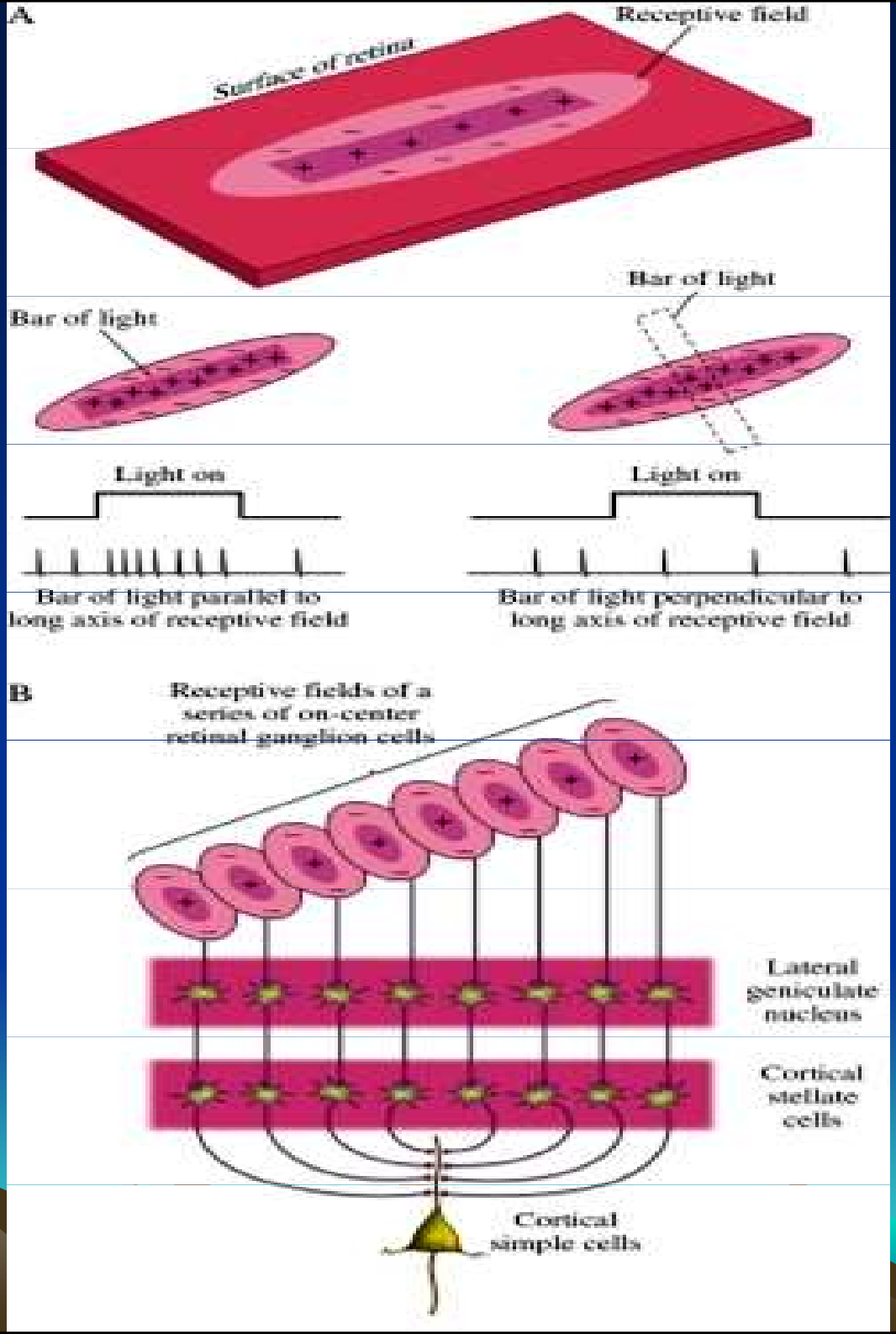


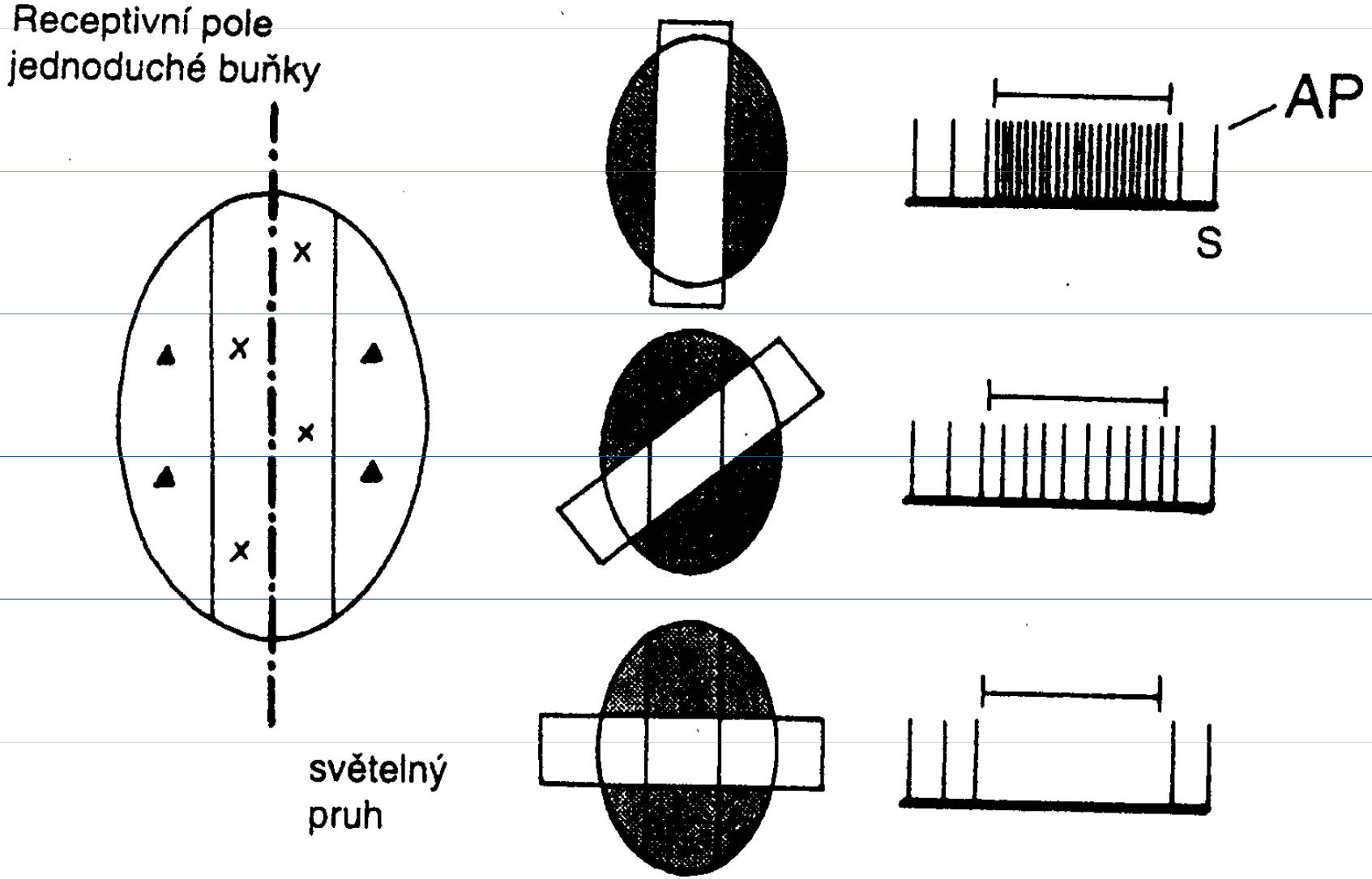
Záznam elektrické aktivity gangliových buněk sítnice s ON a OFF centrem při osvícení jednotlivých částí jejich receptivního pole. Úsečka nad záznamem elektrické aktivity značí trvání osvětlení v sekundách.
AP – potenciál. ✻ – excitační zóna ▲ – inhibiční zóna



receptivní pole hvězdicovitých buněk

receptivní pole jednoduché buňky

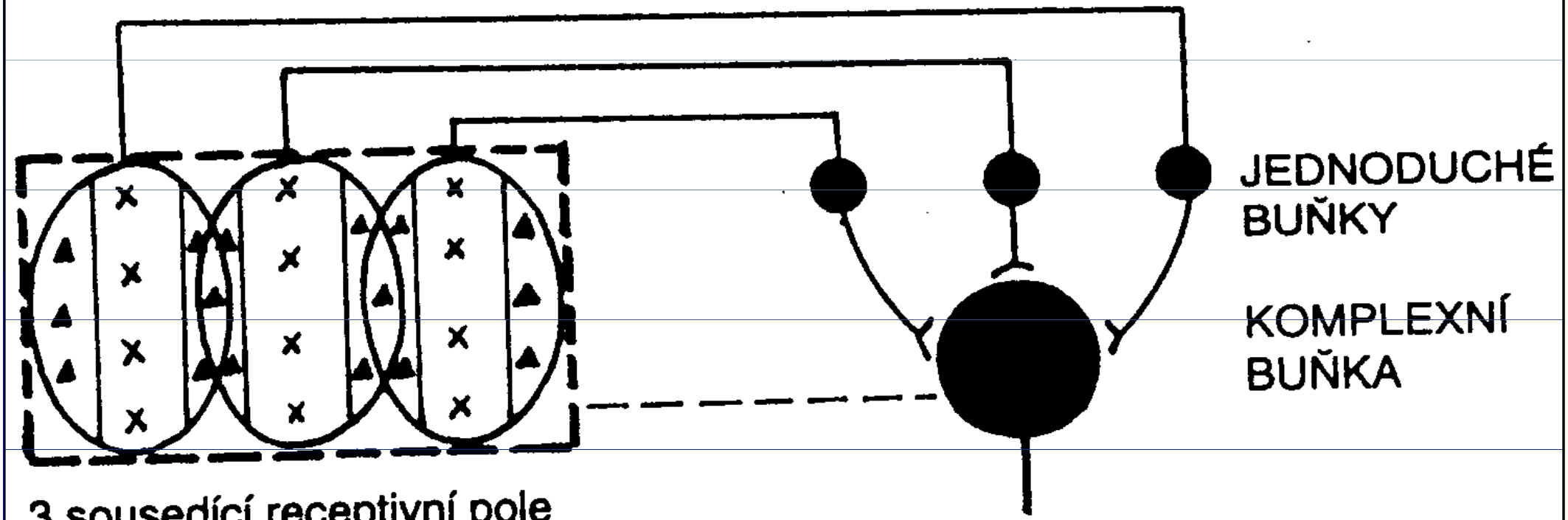

A
Receptive field
Surface of retina
Bar of light
Bar of light
Light on
Light on
Bar of light parallel to long axis of receptive field
Bar of light perpendicular to long axis of receptive field
B
Receptive fields of a series of on-center retinal ganglion cells
Lateral geniculate nucleus
Cortical stellate cells
Cortical simple cells



Vliv orientace vizuálního podnětu na elektrickou aktivitu jednoduché buňky. Úsečka nad záznamem elektrické aktivity značí trvání osvětlení v sekundách. AP – akční potenciál.

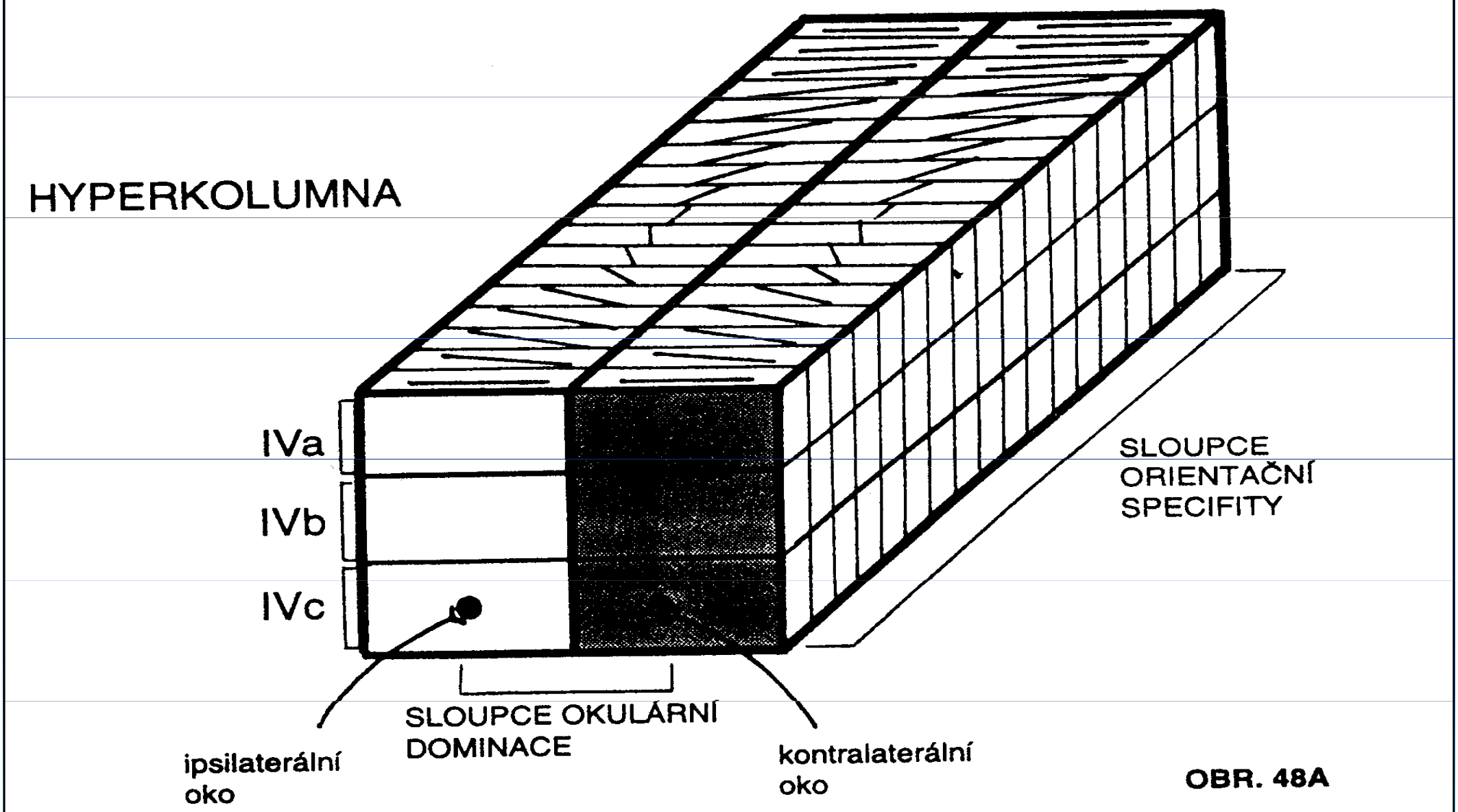
✘ – excitační zóna ▲ – inhibiční zóna

OBR. 45A

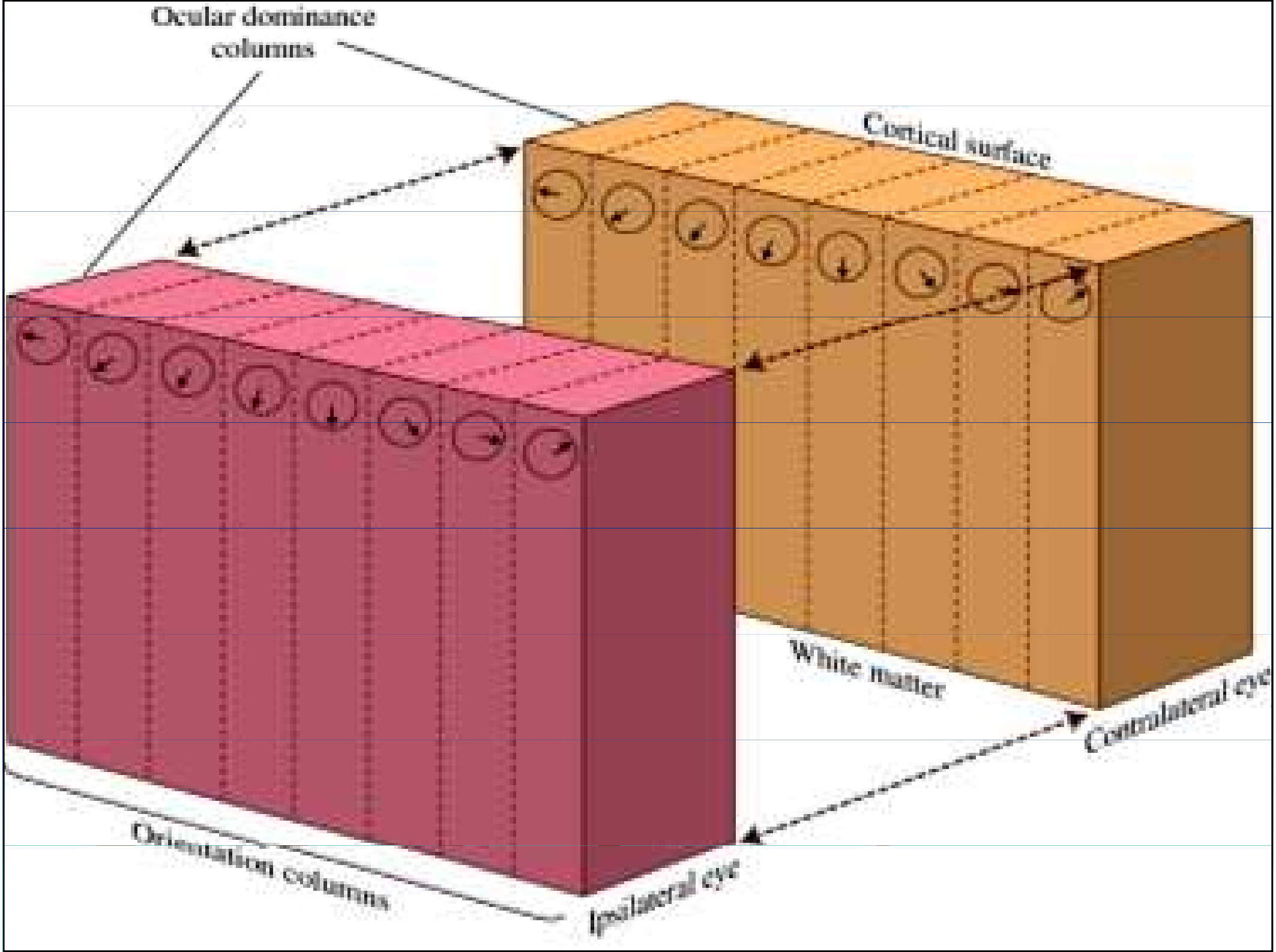


3 sousedící receptivní pole jednoduchých buněk. V rámečku zformované receptivní pole komplexní buňky.

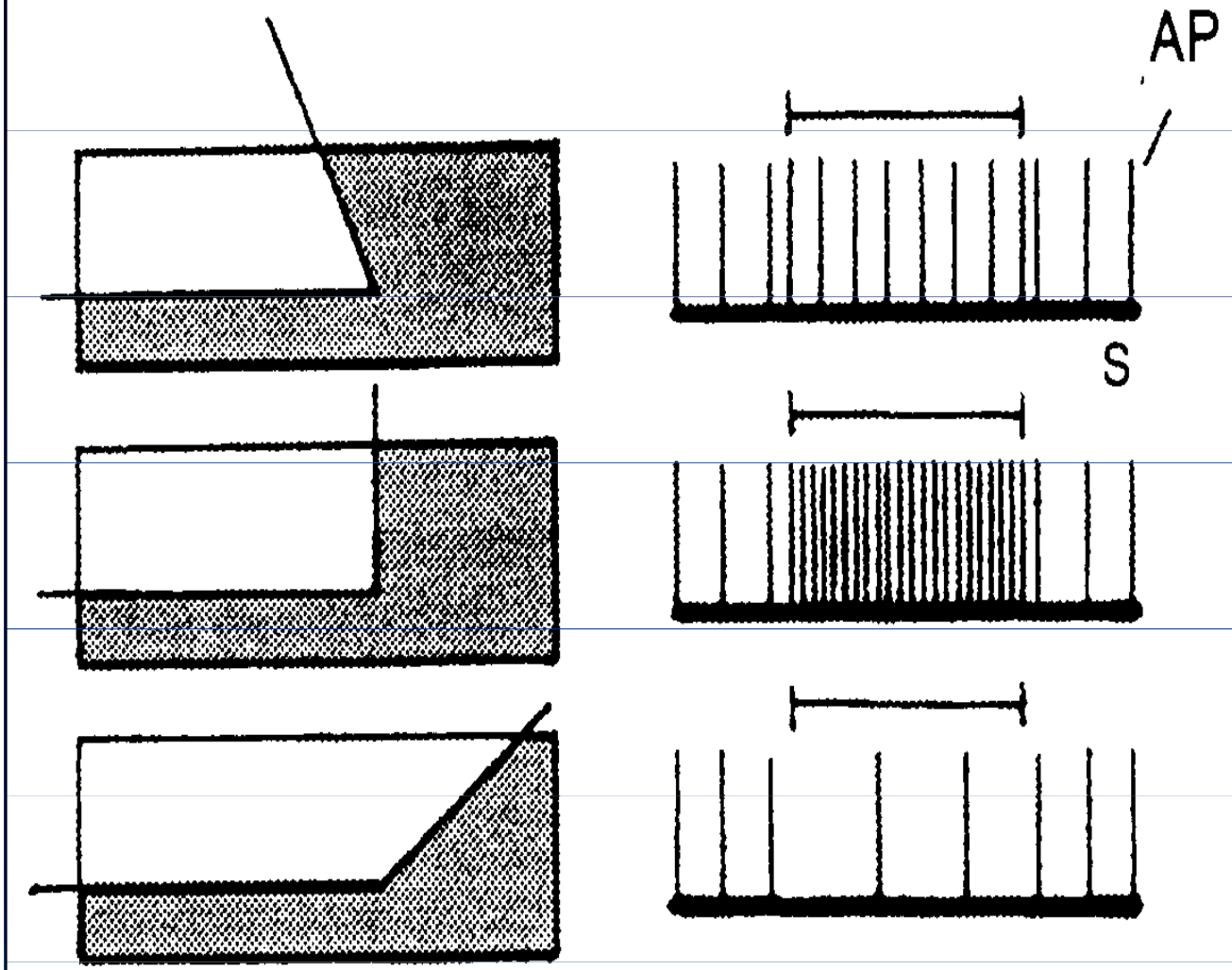
⊗ – excitační zóna ⊛ – inhibiční zóna


HYPERKOLUMNA
IVa
IVb
IVc
SLOUPCE
ORIENTAČNÍ
SPECIFITY
SLOUPCE OKULÁRNÍ
DOMINACE
ipsilaterální
oko
kontralaterální
oko

OBR. 48A

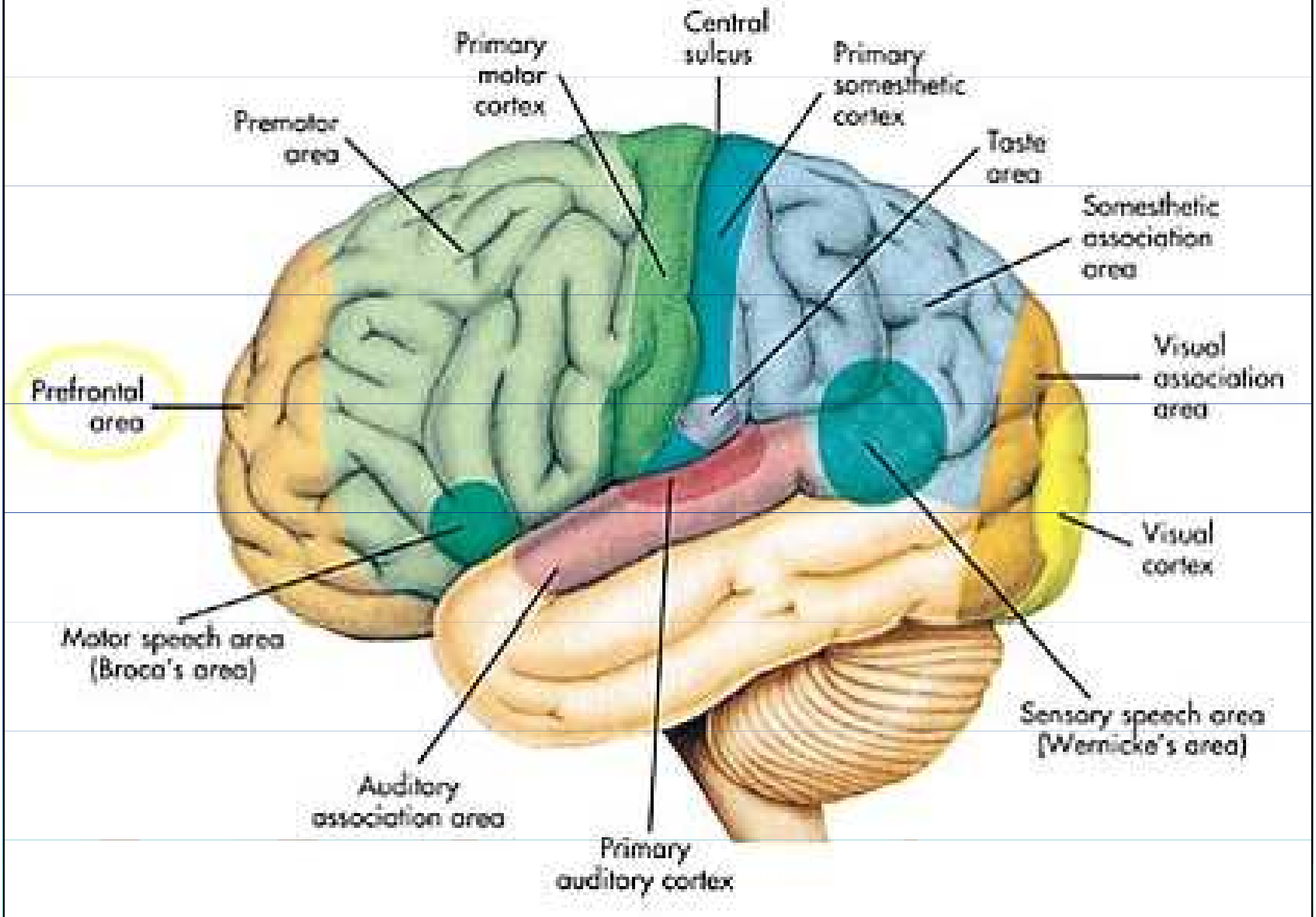

Ocular dominance columns
Cortical surface
White matter
Contralateral eye
Orientation columns
Ipsilateral eye

Sekundární kůra, hyperkomplexní buňky



Vliv různého úhlu kontrastního vizuálního podnětu na elektrickou aktivitu hyperkomplexní buňky. Úsečka nad záznamem elektrické aktivity značí trvání osvětlení v sekundách.
AP – akční potenciál.

OBR. 49A


Central sulcus
Primary motor cortex
Primary somesthetic cortex
Premotor area
Taste area
Somesthetic association area
Visual association area
Prefrontal area
Visual cortex
Motor speech area (Broca's area)
Sensory speech area (Wernicke's area)
Auditory association area
Primary auditory cortex

Barevné vidění

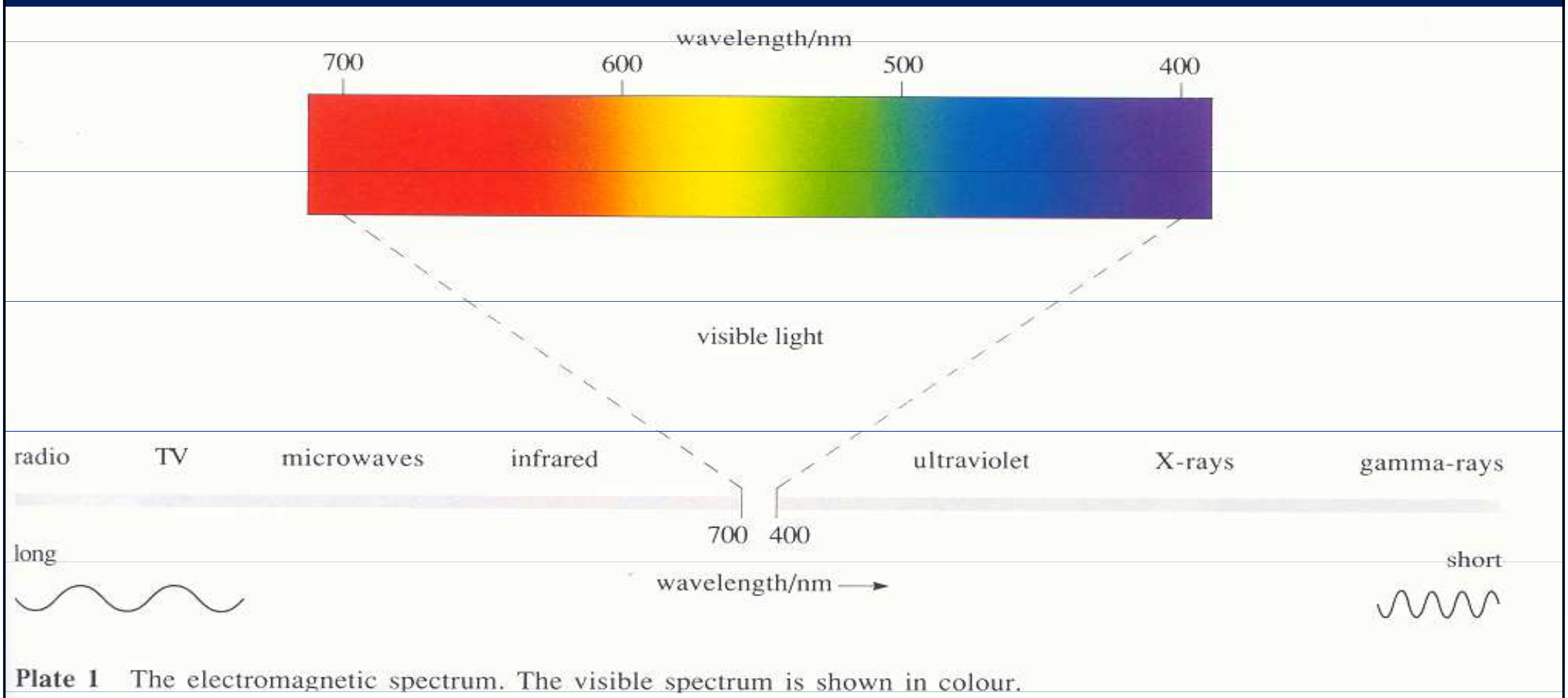
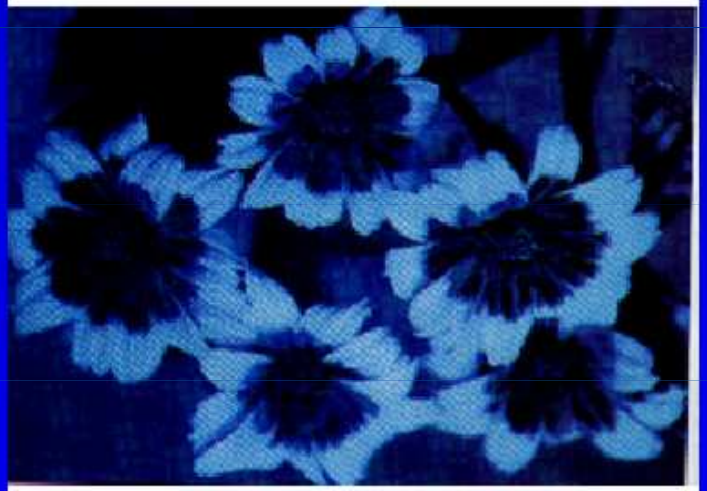


Plate 1 The electromagnetic spectrum. The visible spectrum is shown in colour.

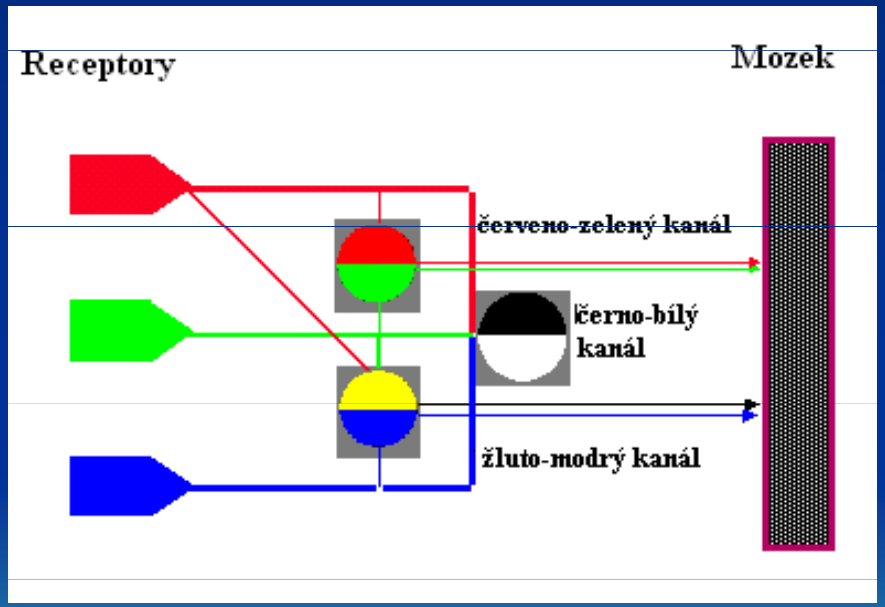
The ability to detect ultraviolet light

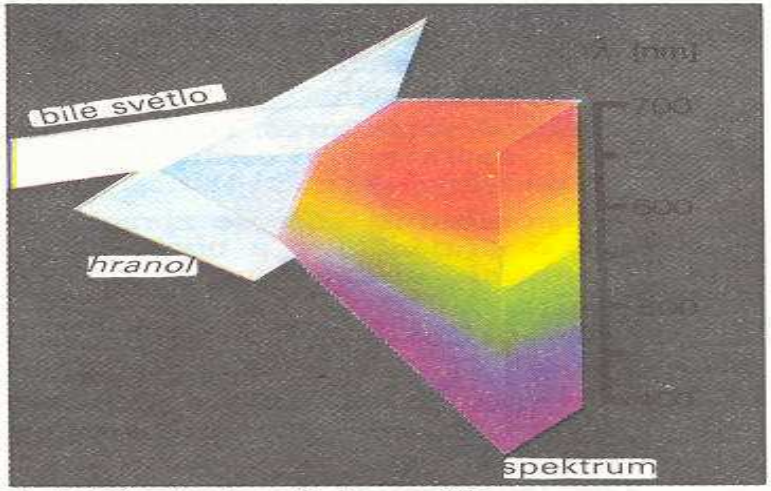
Human's view.



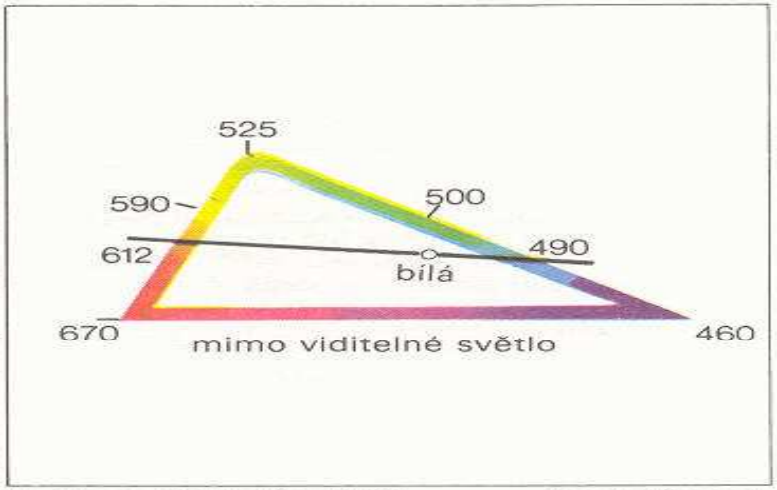
Insect's view (simulated through UV film.

Trichromatické teorie, Young-Helmhotz
Oponentní kódování, Hering

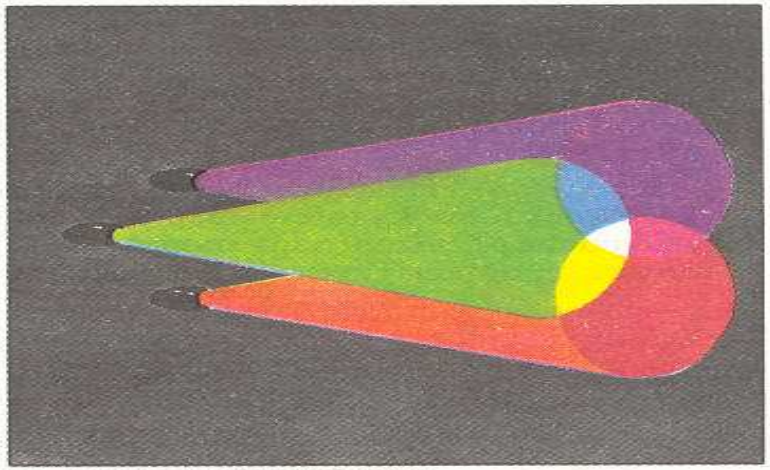




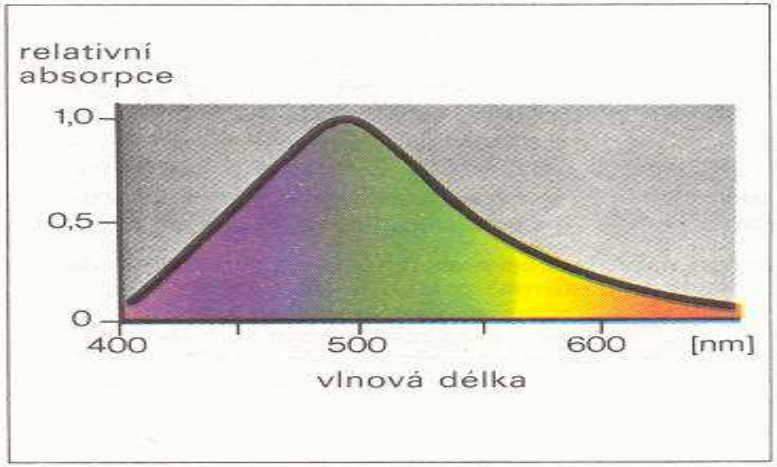
A. Složení slunečního světla



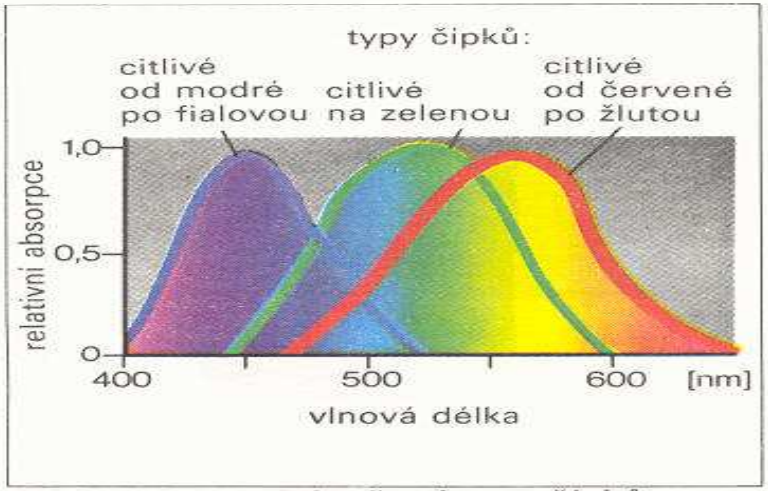
B. Barevný trojúhelník (podle Kriese)



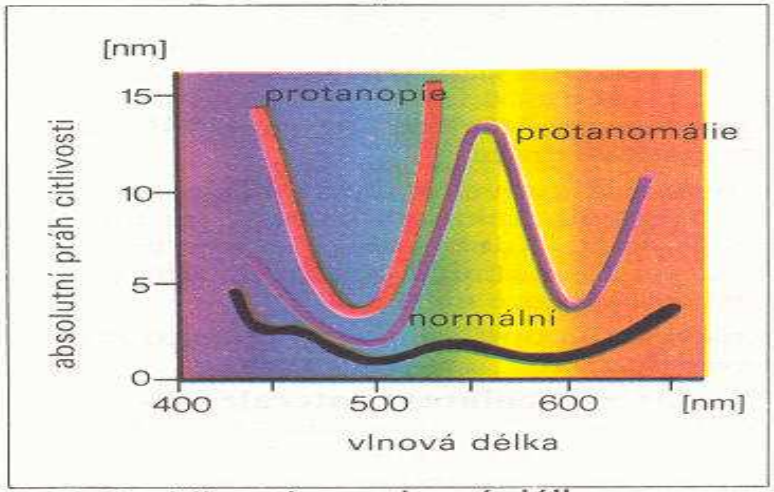
C. Aditivní míšení barev



D. Absorpce světla rodopsinem



E. Absorpce světla třemi typy čípků



F. Práh citlivosti pro vlnové délky

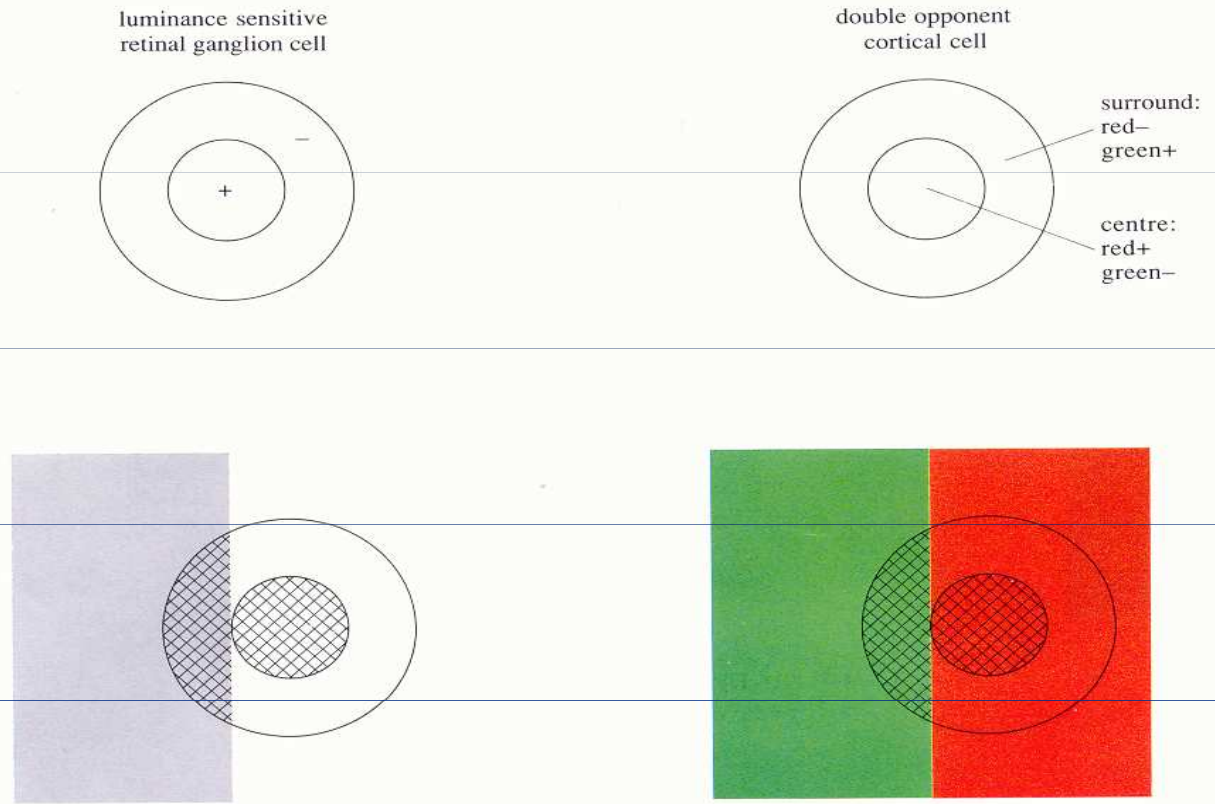


Plate 4 Double opponent receptive fields.

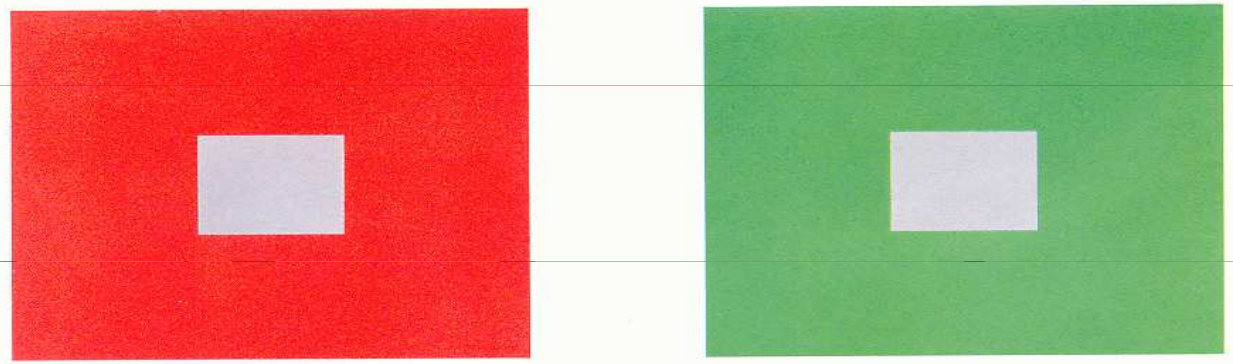
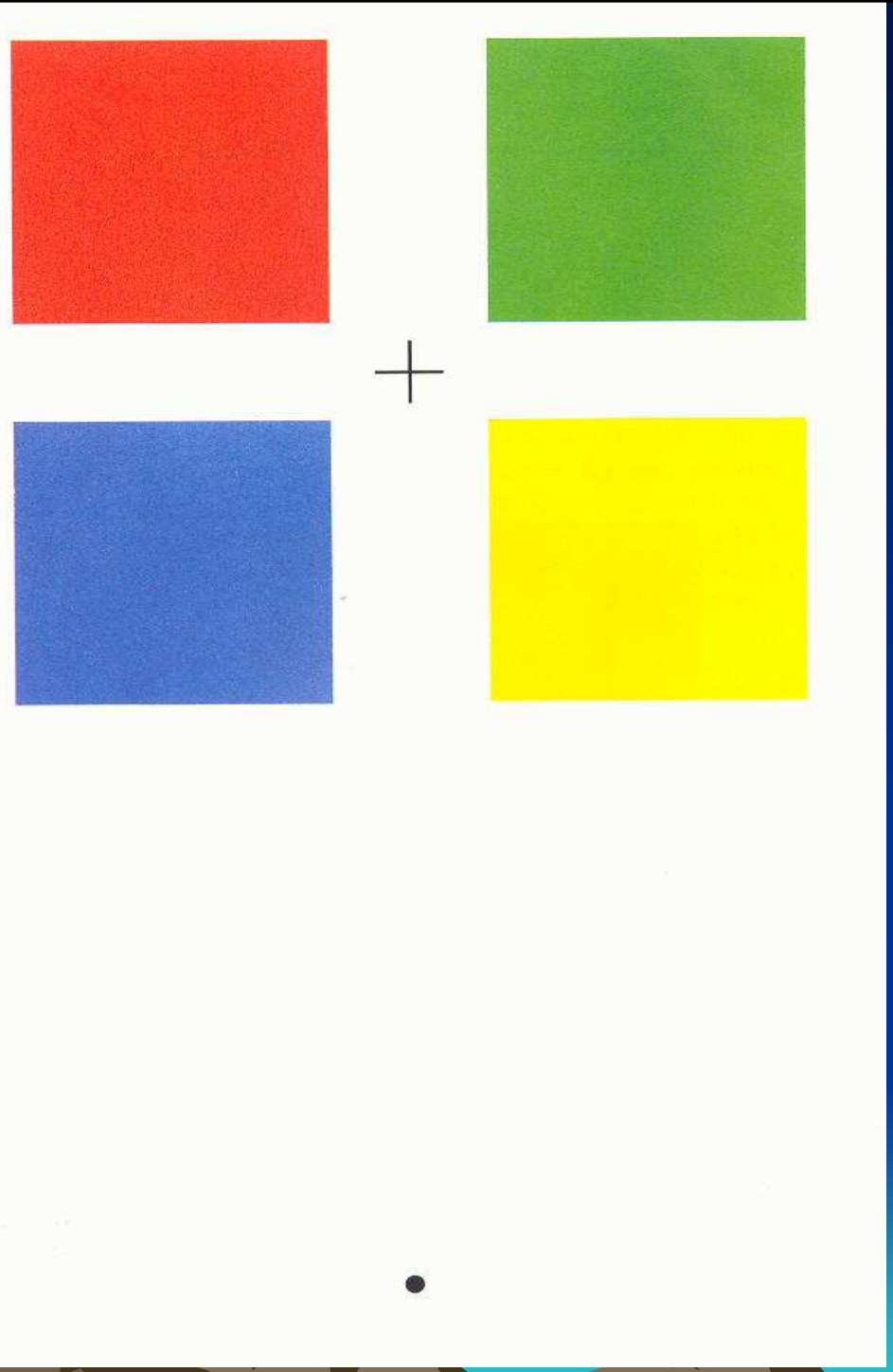
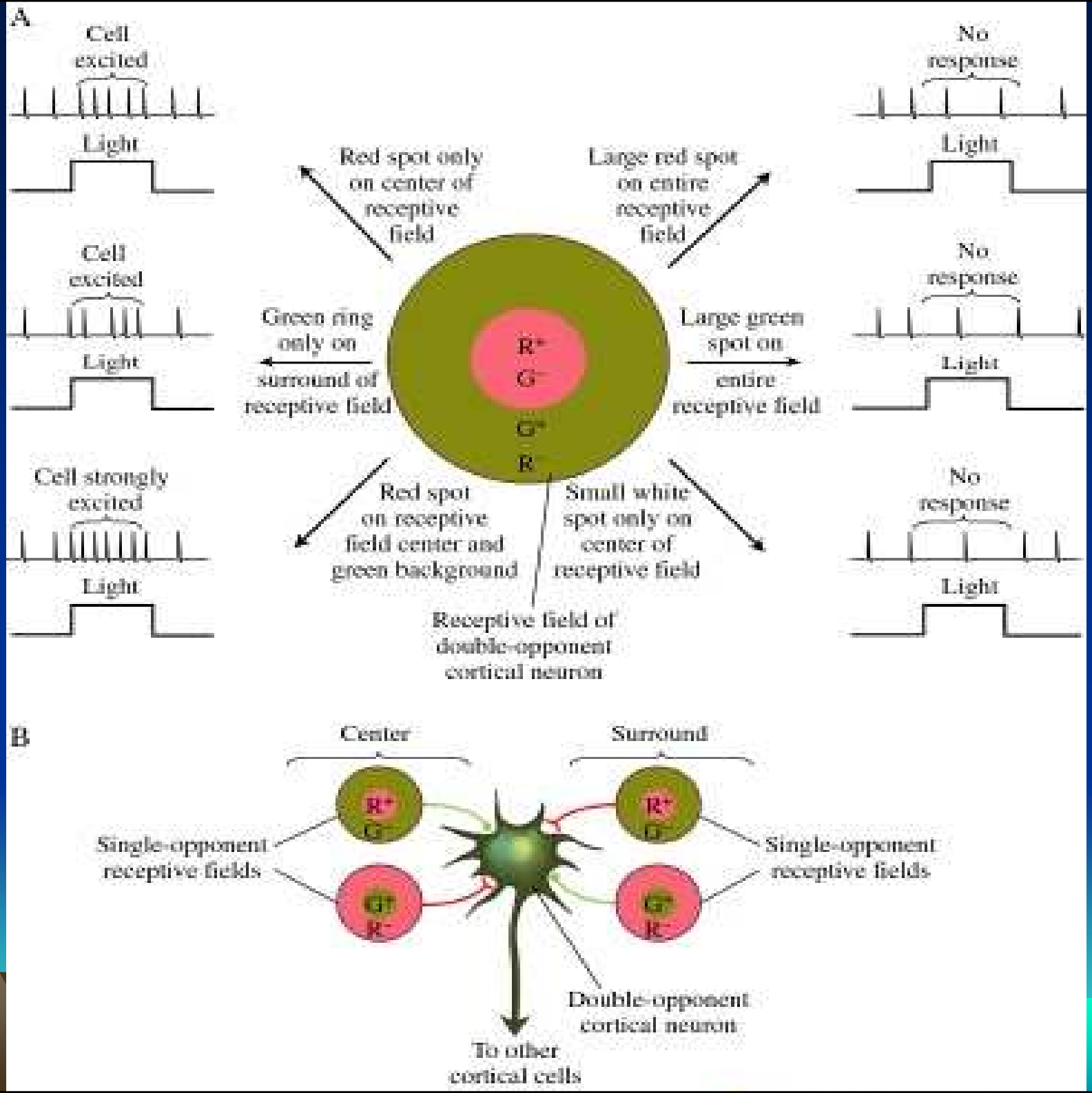


Plate 5 Simultaneous colour contrast.




A
Cell excited
Light
Red spot only on center of receptive field
Large red spot on entire receptive field
No response
Light
Cell excited
Light
Green ring only on surround of receptive field
R+ G−
G+ R−
Large green spot on entire receptive field
No response
Light
Cell strongly excited
Light
Red spot on receptive field center and green background
Small white spot only on center of receptive field
No response
Light
Receptive field of double-opponent cortical neuron
B
Center
Surround
R+ G−
G+ R−
R+ G−
G+ R−
Single-opponent receptive fields
Single-opponent receptive fields
Double-opponent cortical neuron
To other cortical cells

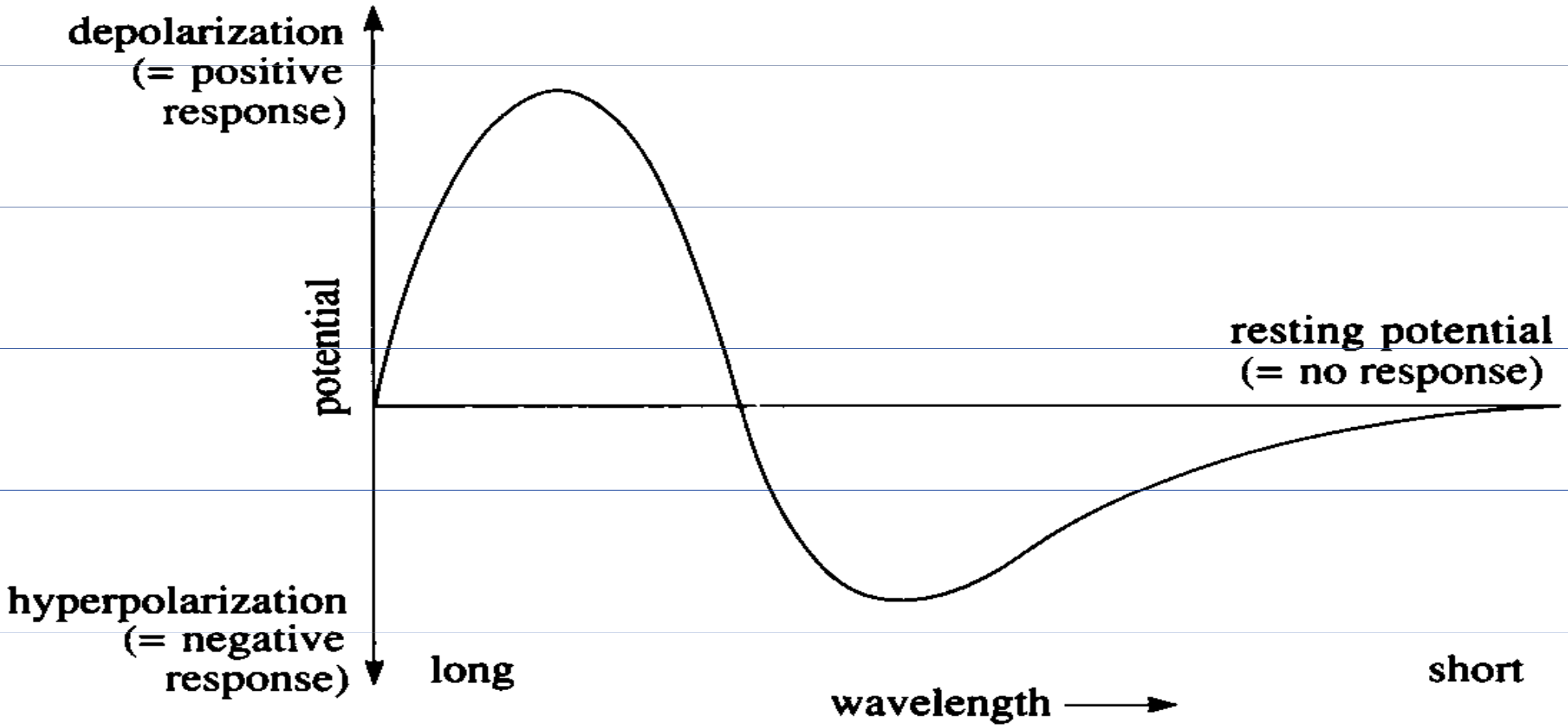
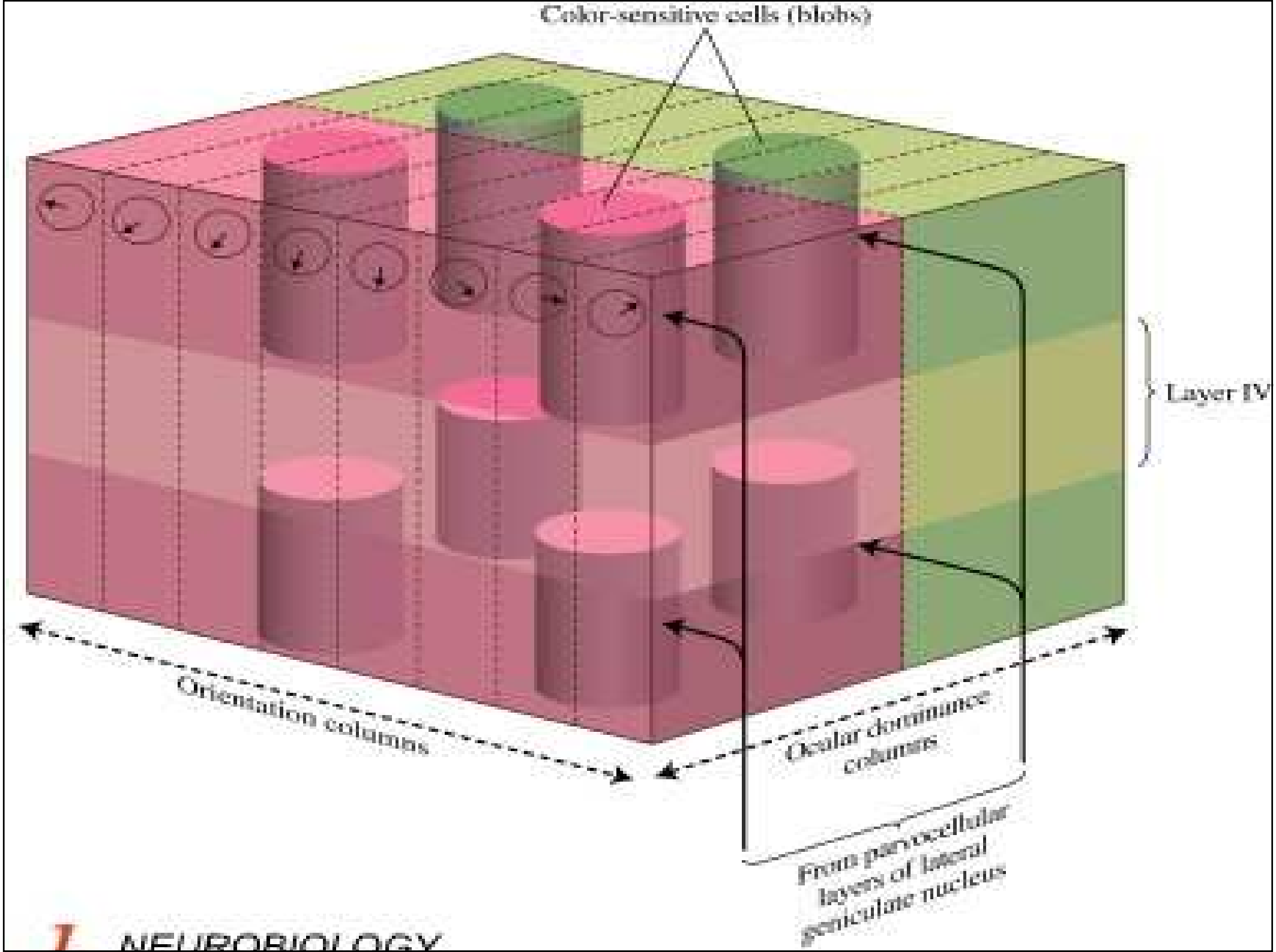
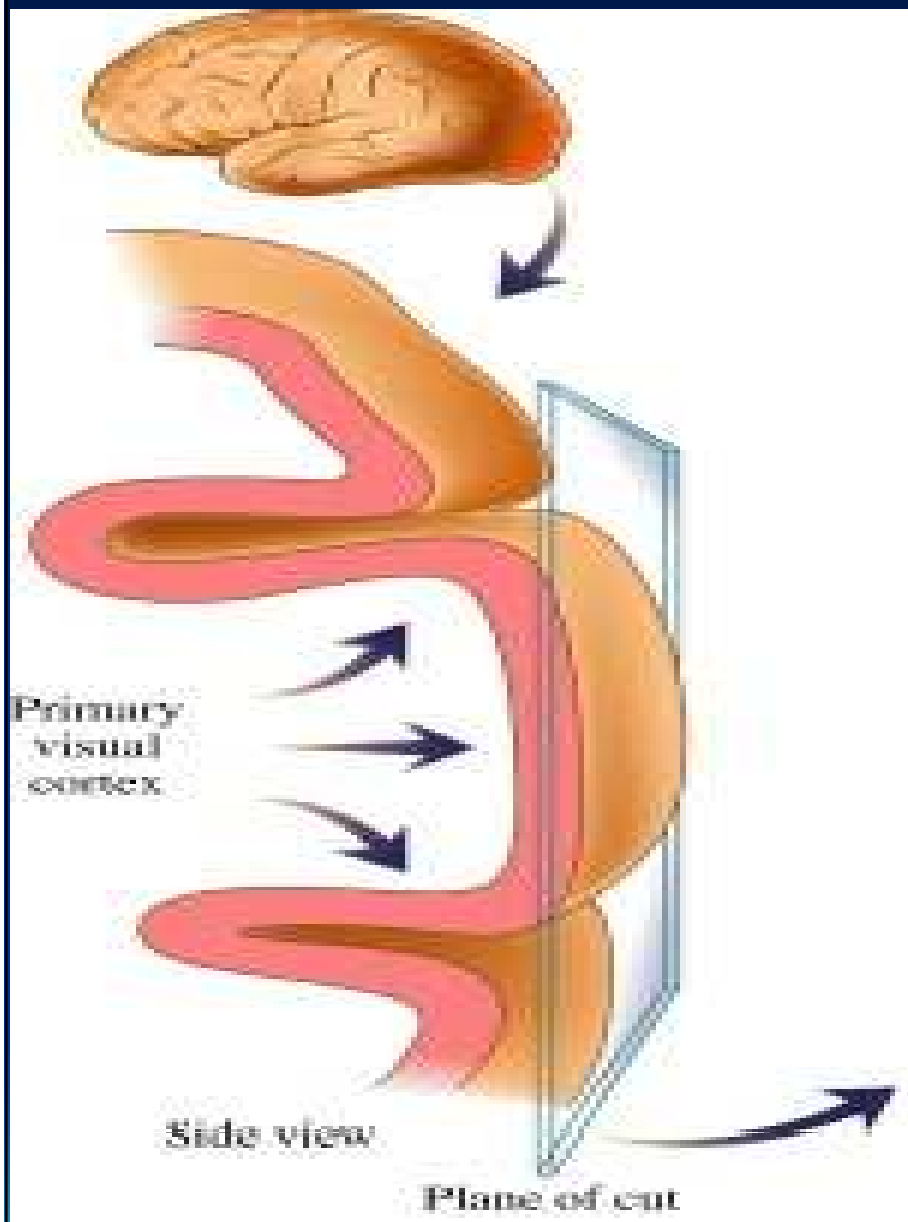
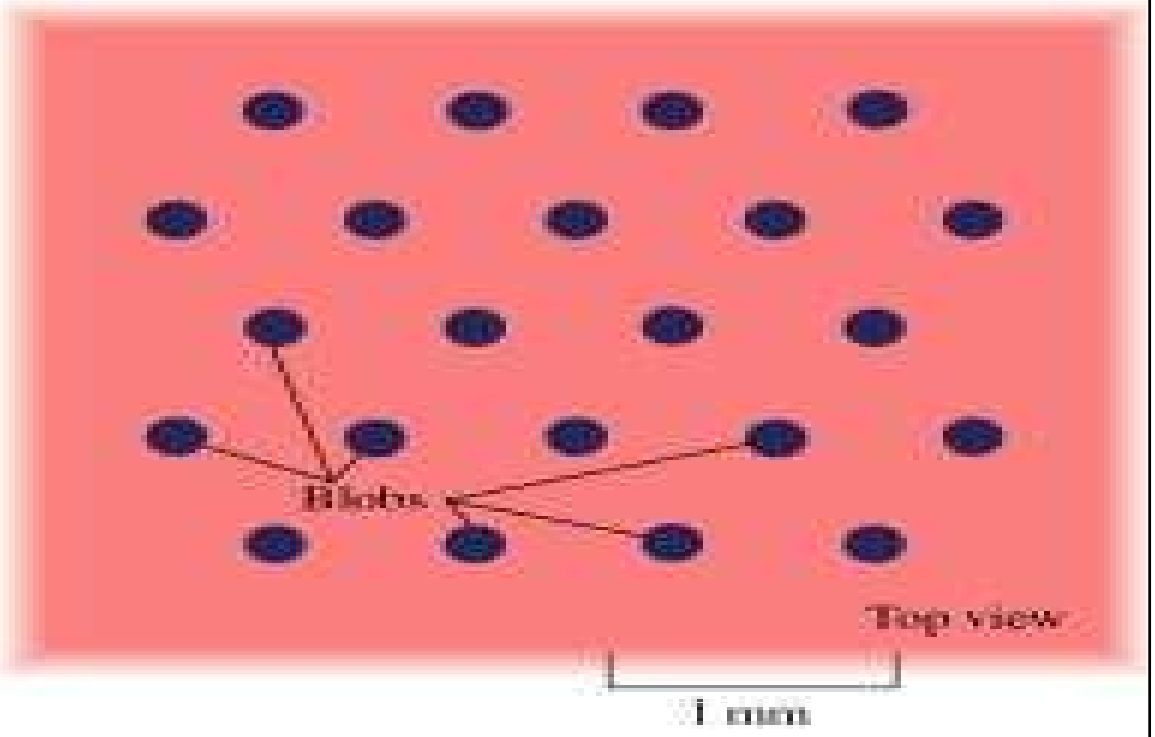


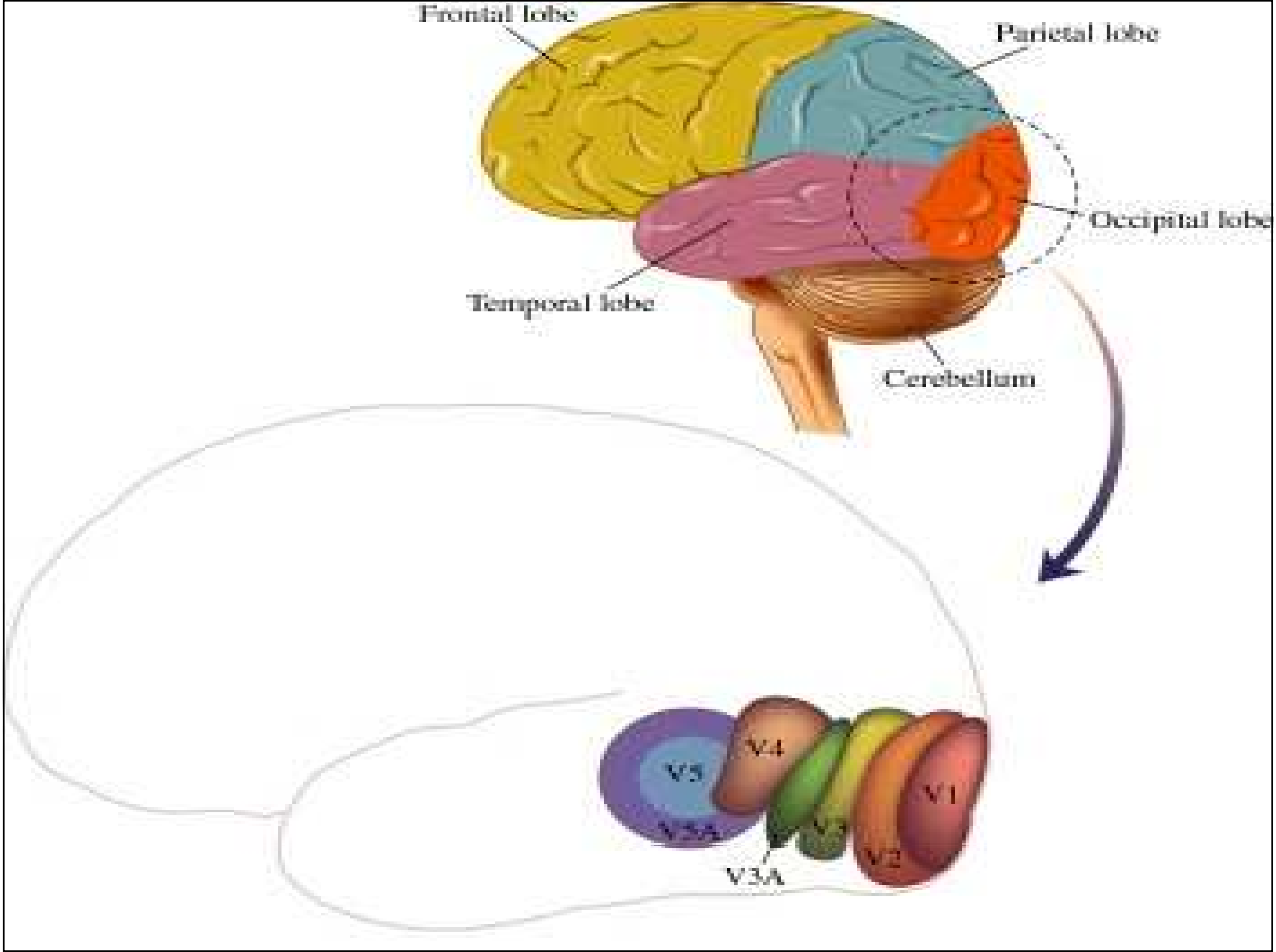
Figure 4.35 Response of a typical colour opponent bipolar cell.

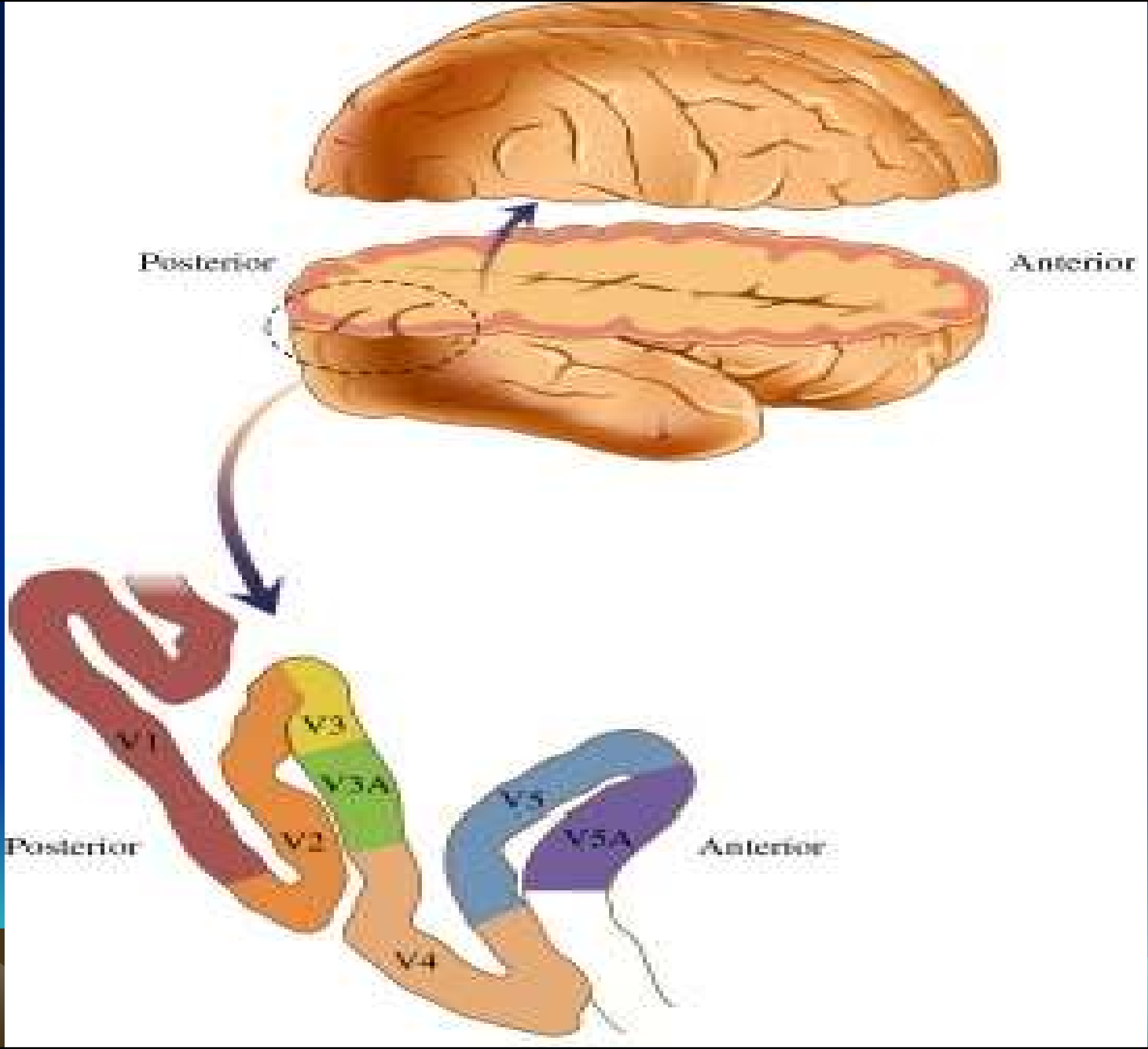

Color-sensitive cells (blobs)
Layer IV
Orientation columns
Ocular dominance columns
From parvocellular layers of lateral geniculate nucleus

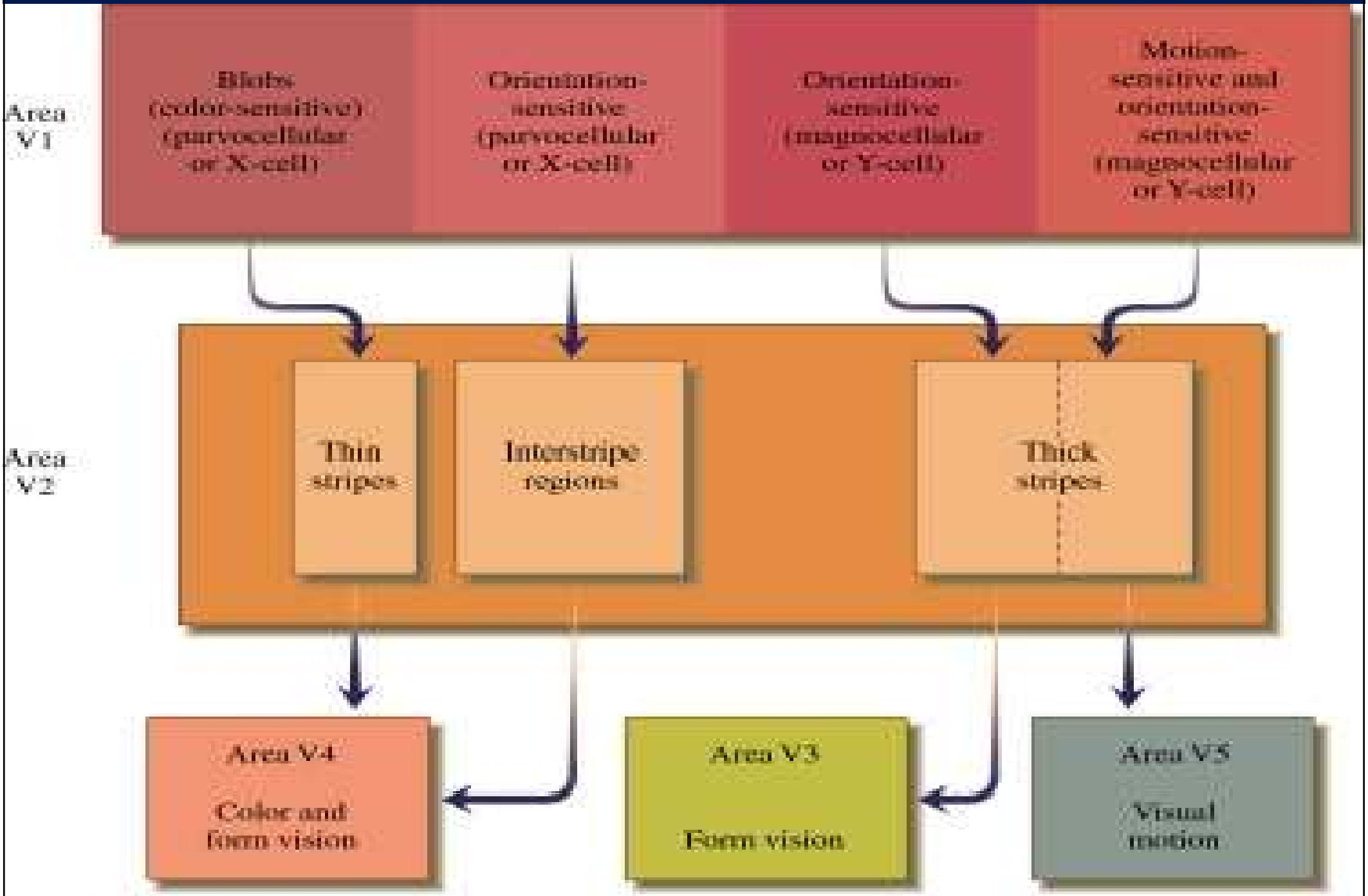


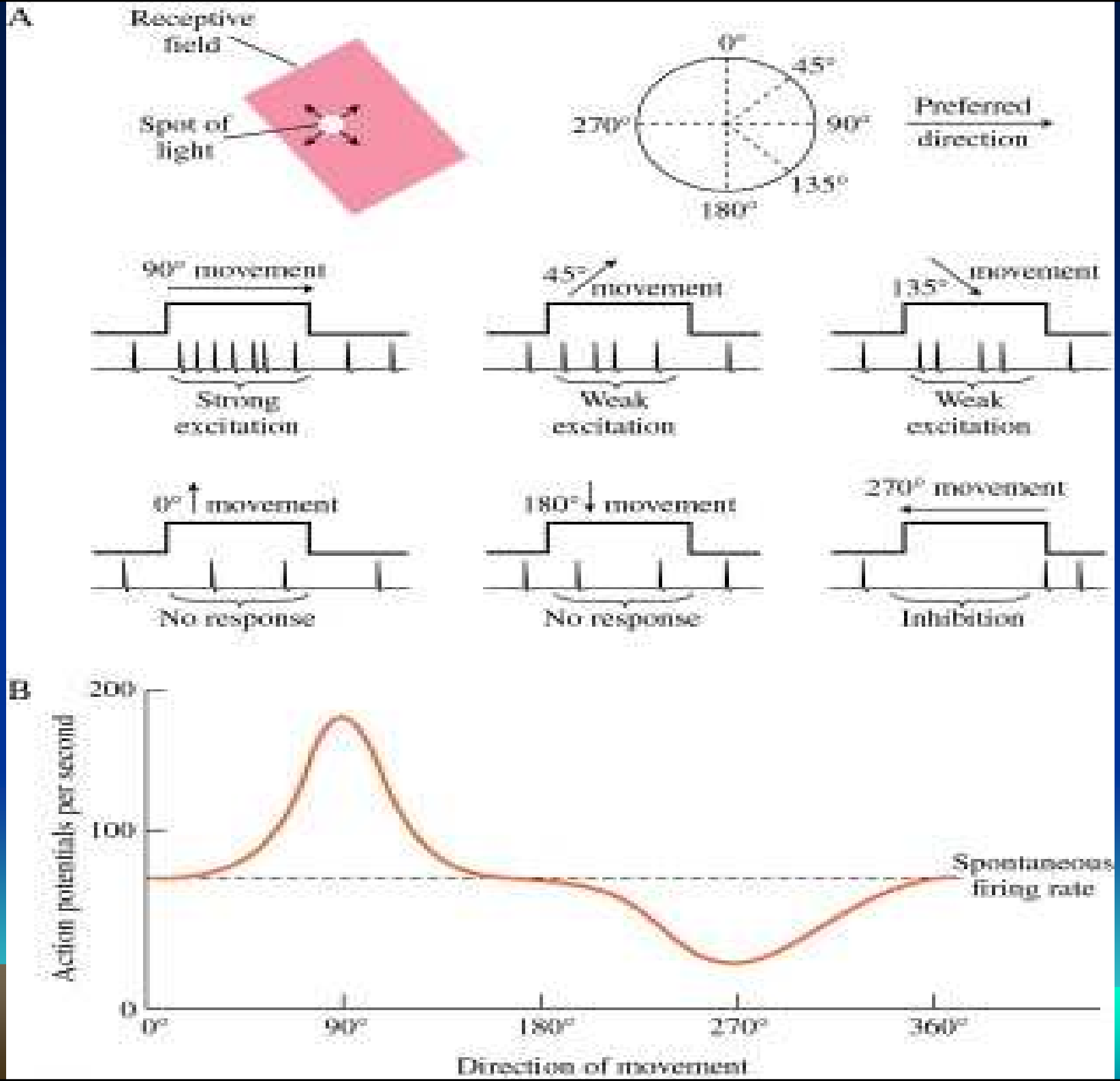


NEUROBIOLOGY
Gary G. Matthews
Blackwell Science


Frontal lobe
Parietal lobe
Occipital lobe
Temporal lobe
Cerebellum
V4
V3
V1
V3A
V2
V3A


Posterior
Anterior
V1
V3
V3A
V2
V4
V5
V5A
Posterior
Anterior


Area V1
Blobs (color-sensitive) (parvocellular or X-cell)
Orientation-sensitive (parvocellular or X-cell)
Orientation-sensitive (magnocellular or Y-cell)
Motion-sensitive and orientation-sensitive (magnocellular or Y-cell)
Area V2
Thin stripes
Interstripe regions
Thick stripes
Area V4
Color and form vision
Area V3
Form vision
Area V5
Visual motion


A
Receptive field
Spot of light
0°
45°
90°
135°
180°
270°
Preferred direction
90° movement
Strong excitation
45° movement
Weak excitation
135° movement
Weak excitation
0° movement
No response
180° movement
No response
270° movement
Inhibition
B
200
100
0
Action potentials per second
Spontaneous firing rate
0°
90°
180°
270°
360°
Direction of movement

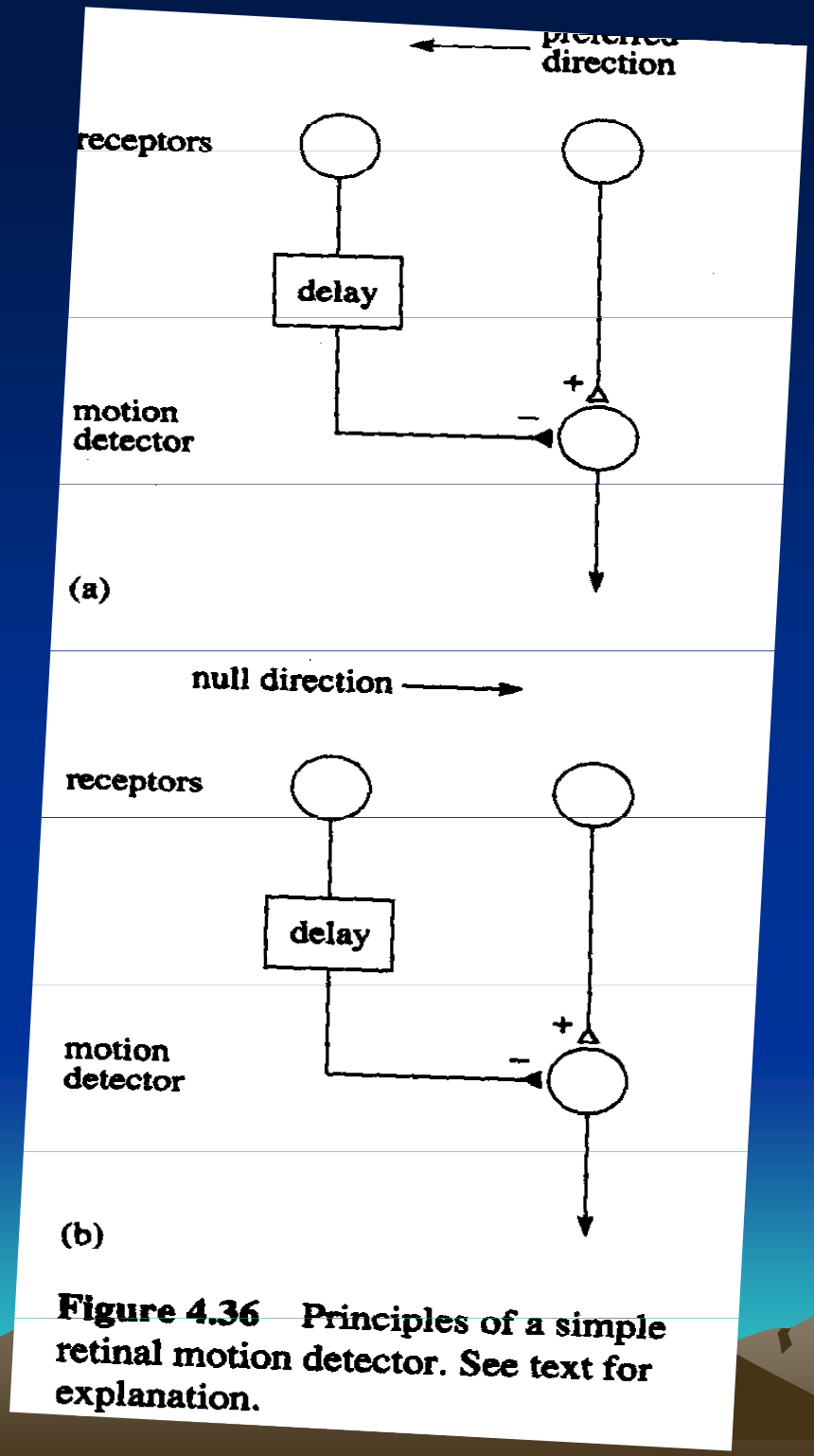
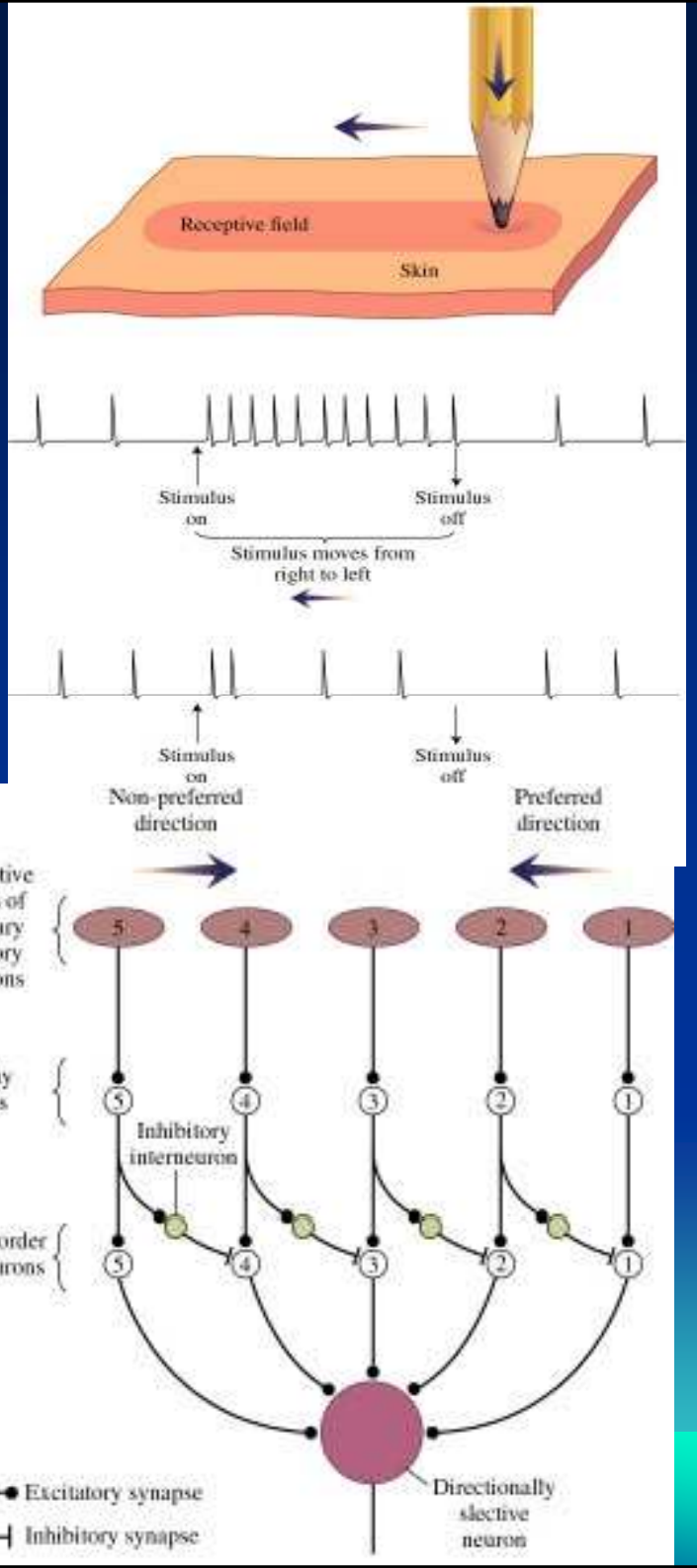


Figure 4.36 Principles of a simple retinal motion detector. See text for explanation.



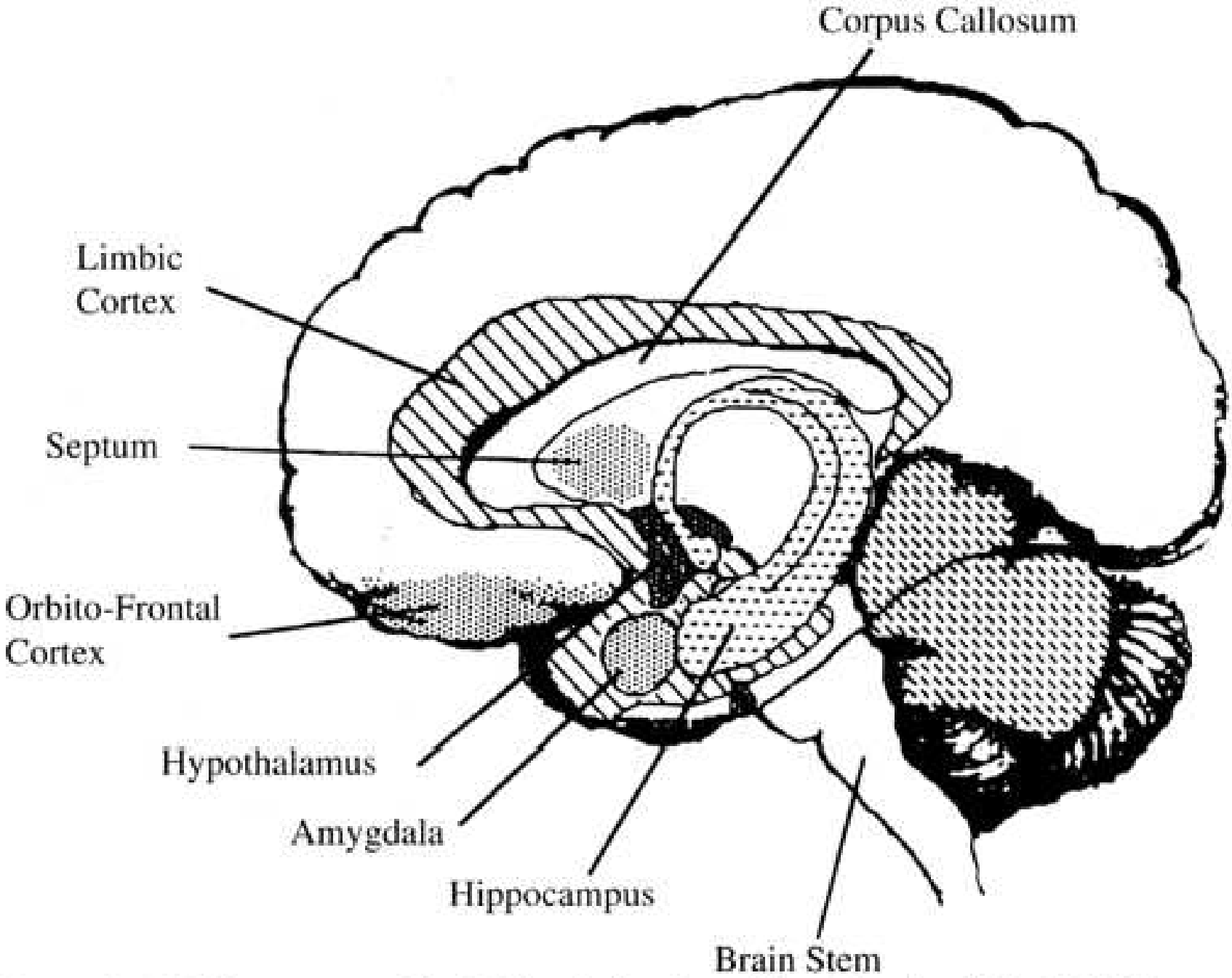
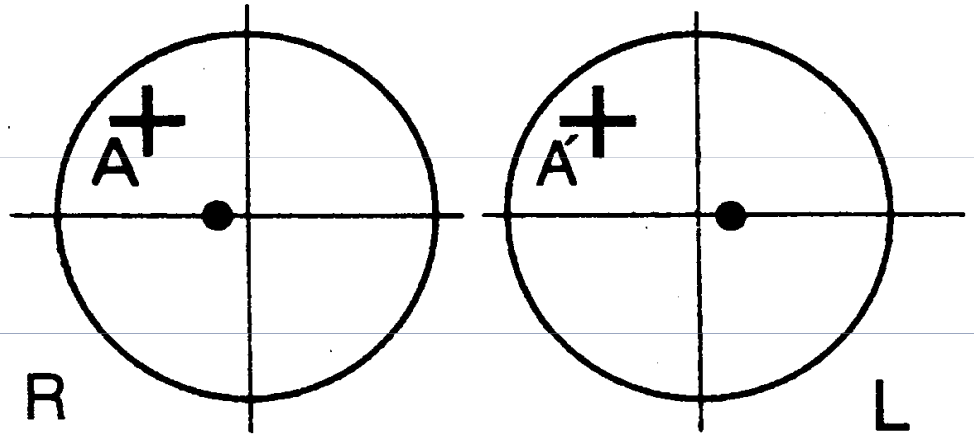


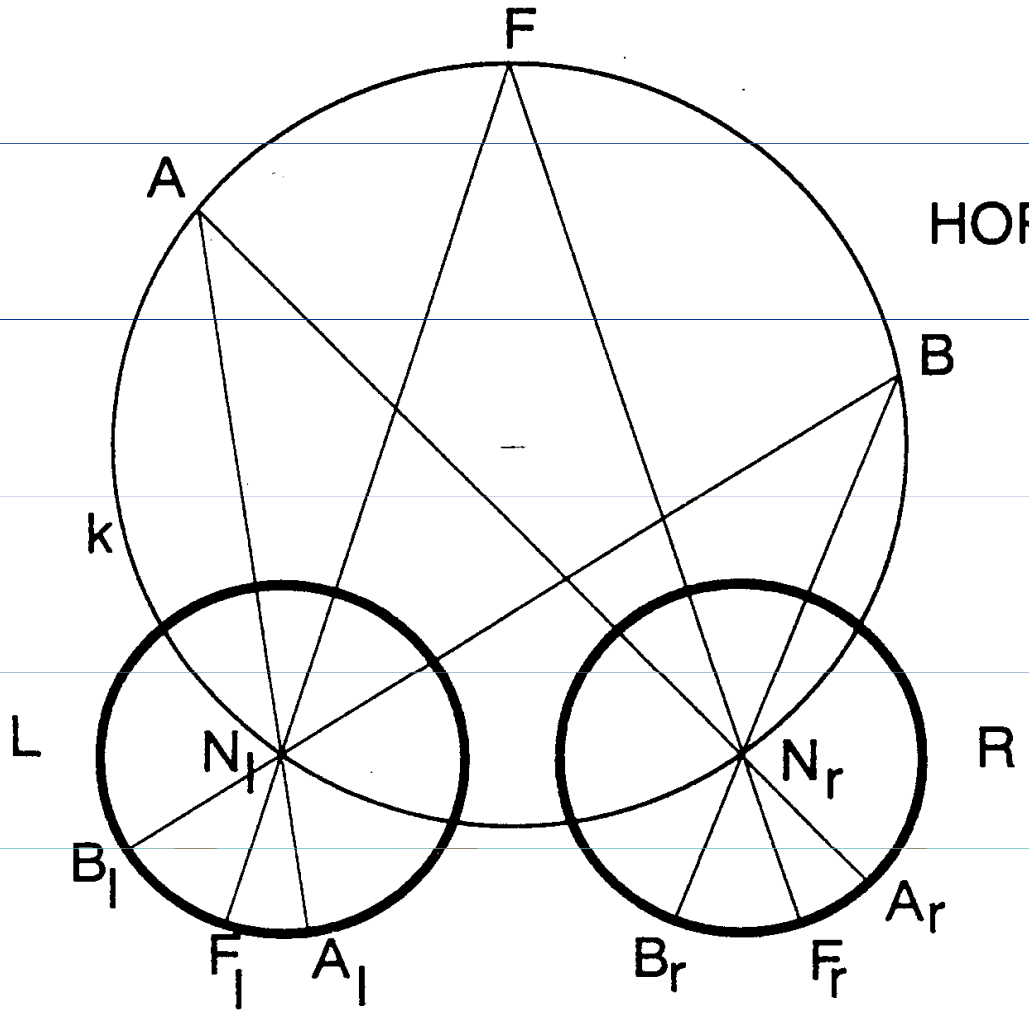
FIGURE 2. Limbic structures of the right hemisphere, lateral view. Cingulate is labeled limbic cortex (from Trevarthen, Aitken, Papoudi, & Roberts, 1998, and used with permission of Jessica Kingsley Publishers).

OBR. 57A

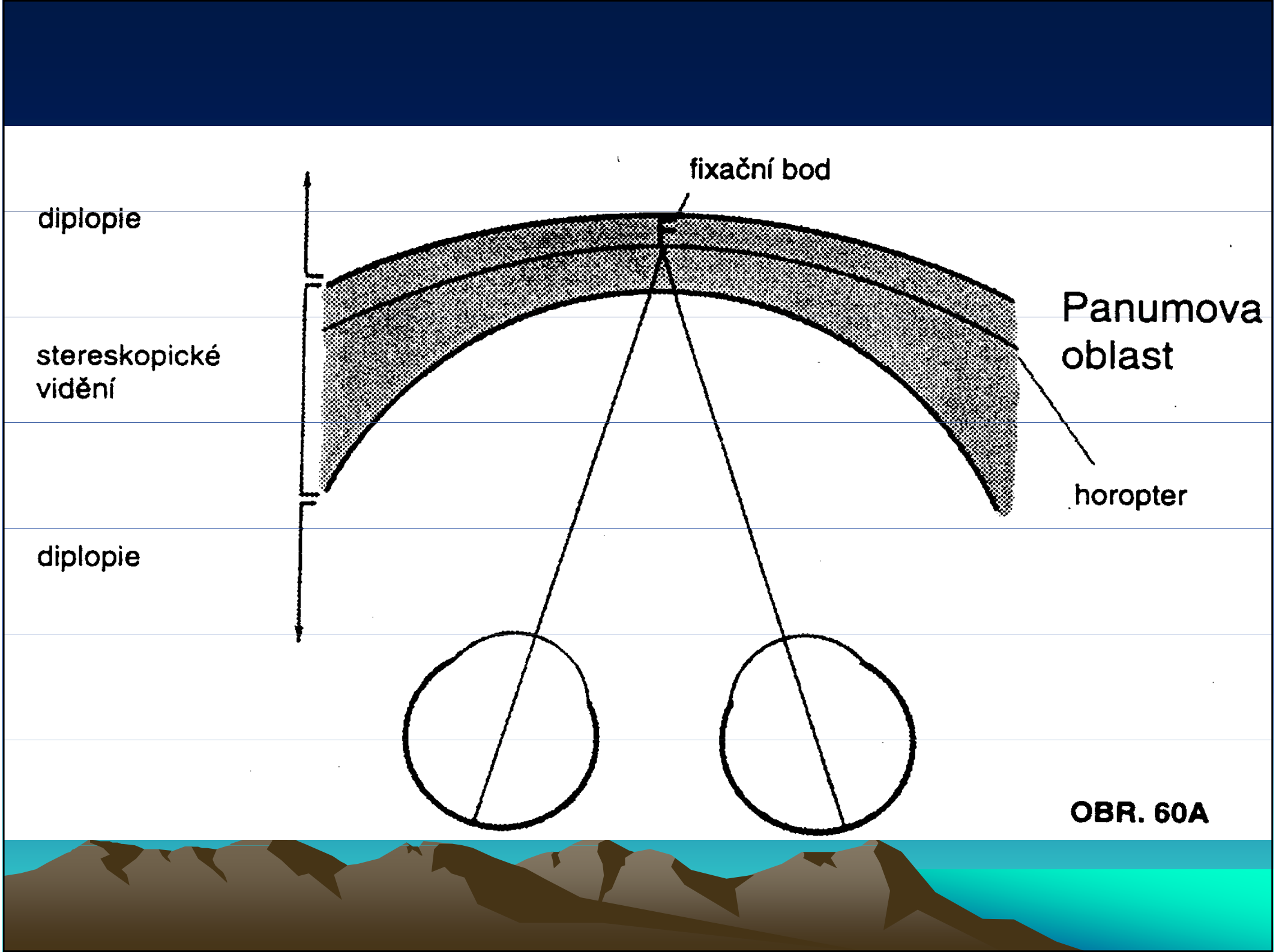
Sítnice pravého (R) a levého (L) oka. Body A a A' značí polohu identických míst. Černá skvrna znázorňuje centrální jamku.



OBR. 58A



HOROPTEROVÁ KRUŽNICE


fixační bod
diplopie
stereskopické vidění
diplopie
Panumova oblast
horopter
OBR. 60A

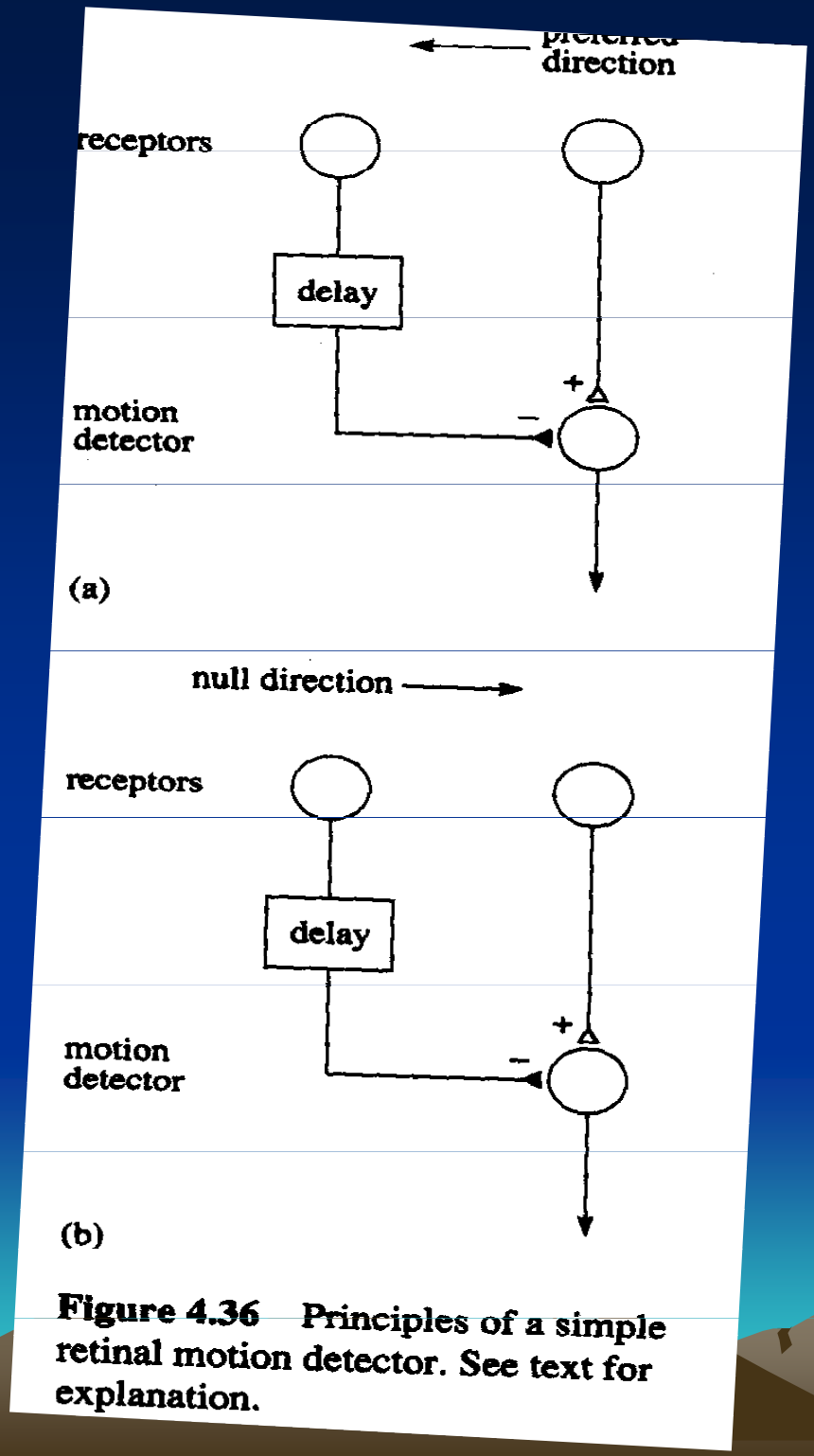
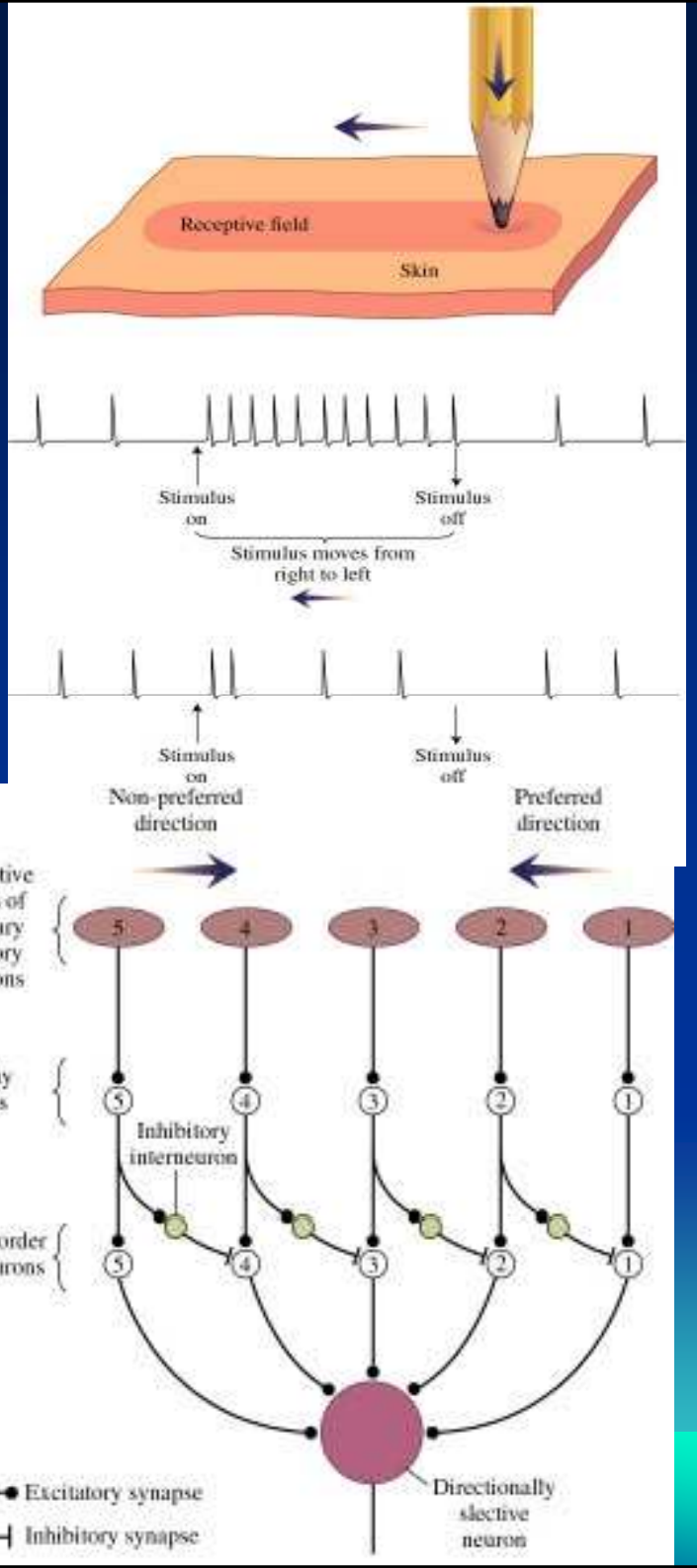
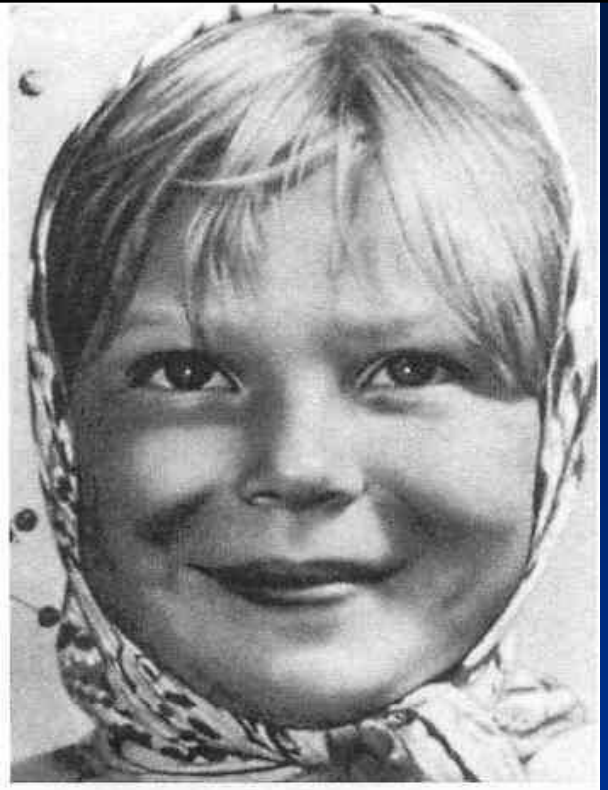
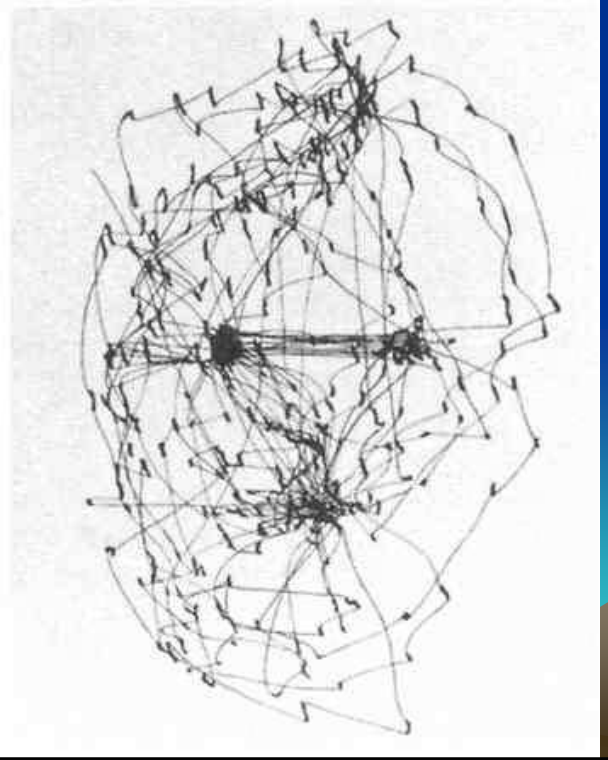


Figure 4.36 Principles of a simple retinal motion detector. See text for explanation.







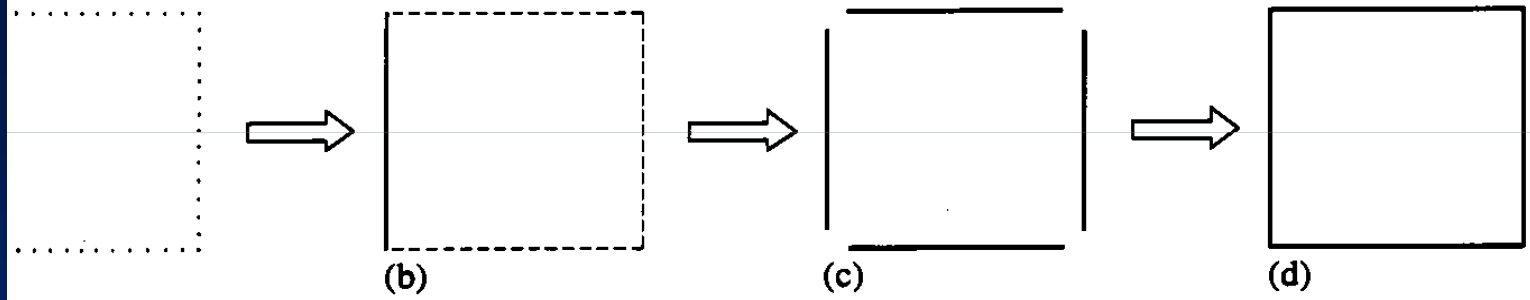


Figure 4.51 Descriptive advantages of visual grouping. See text for explanation.

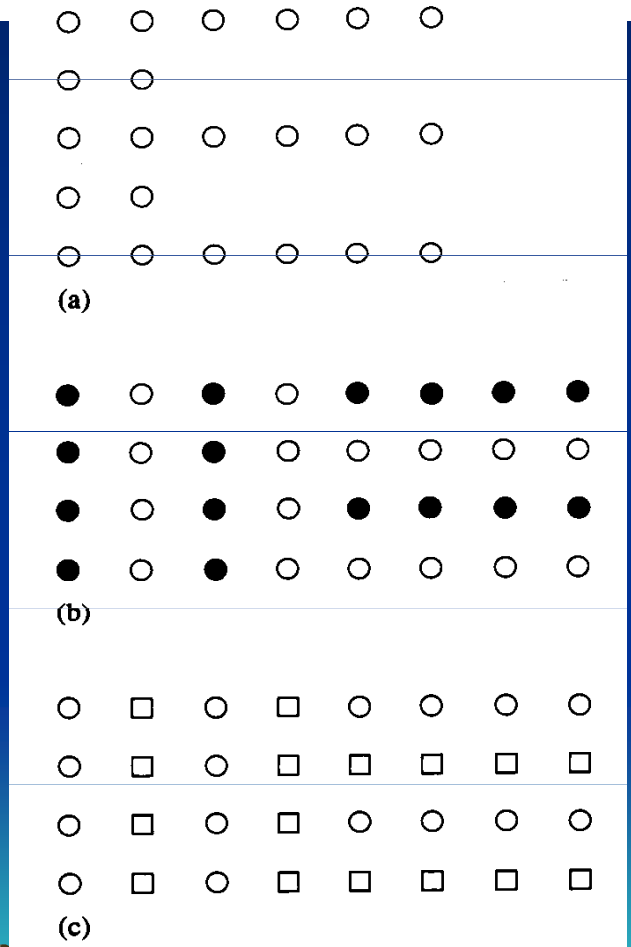
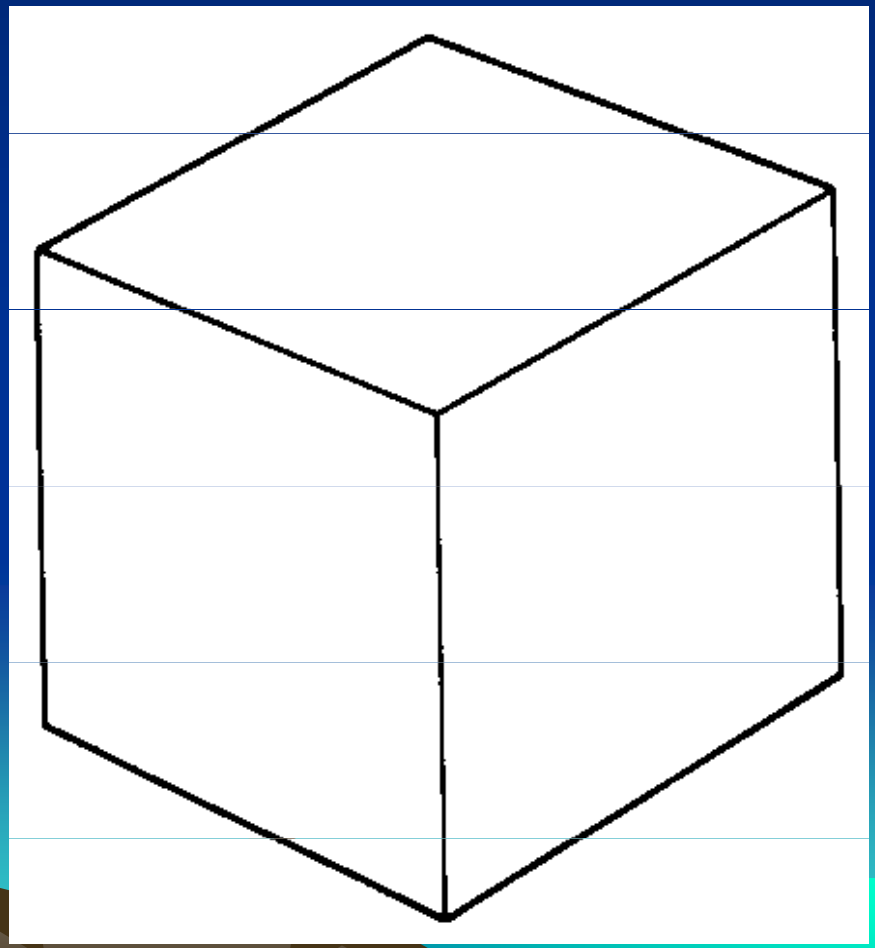


Figure 4.50 Examples of visual grouping: (a) Grouping by spacing. (b) Grouping by colour. (c) Grouping by shape.



Iluze, zdánlivé pohyby

Polarizované světlo

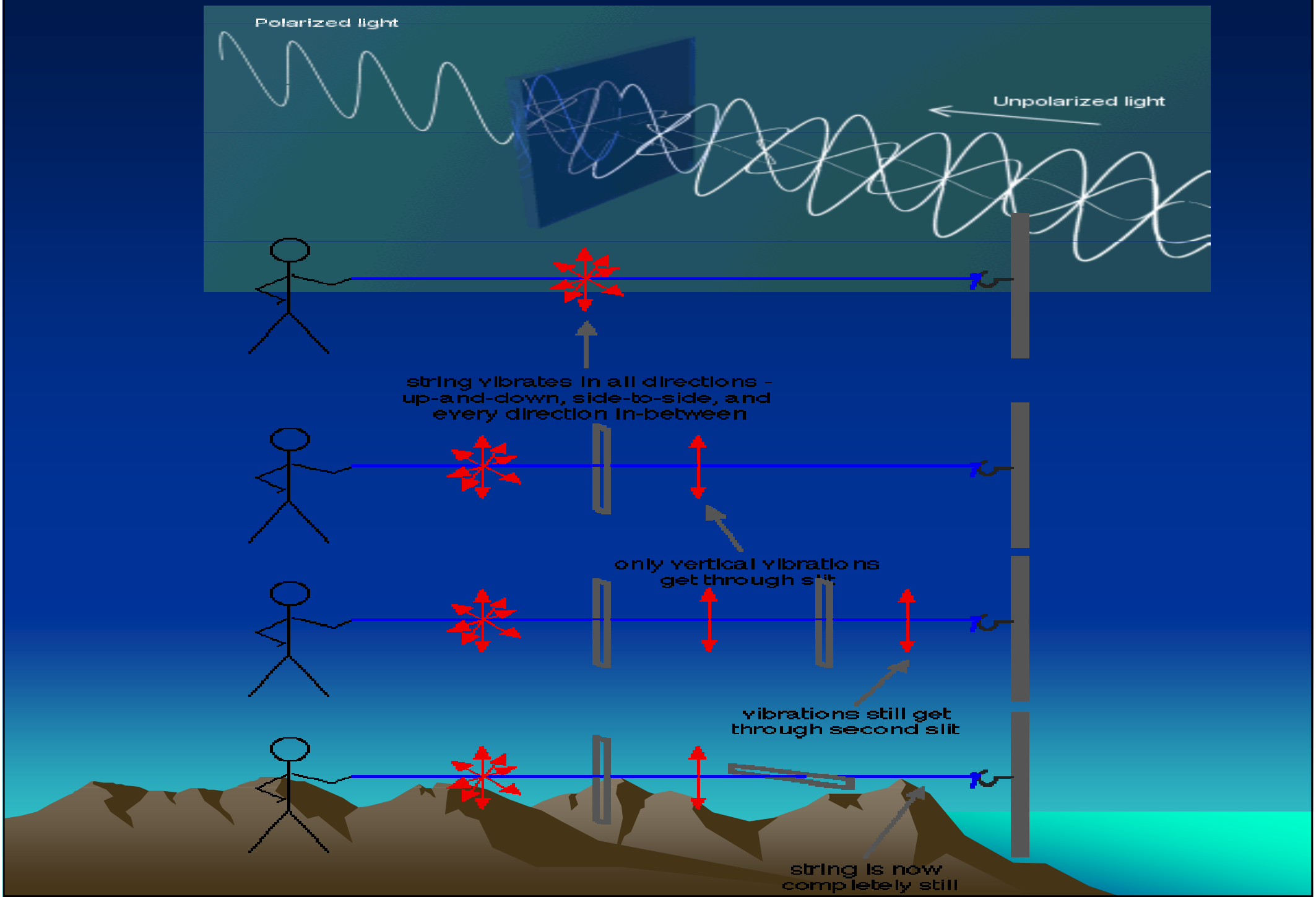
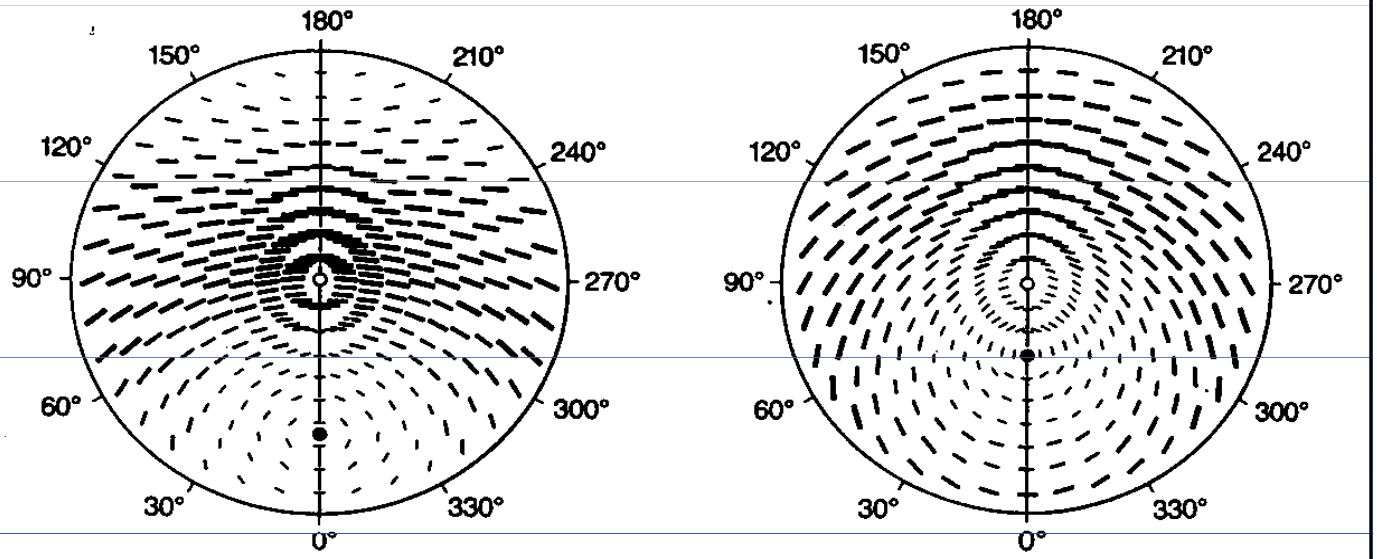


Fig. 3. Two-dimensional representations of the celestial E-vector pattern (the pattern of polarized light) depicted for two different elevations of the sun (filled circle): 25° in left figure, 60° in right figure. The orientation and size of each black bar mark the angle and degree (percentage) of polarization, respectively. The open circle indicates the zenith. The solar meridian (the line from the zenith down to the horizon) and the anti-solar meridian represent the symmetry plane of the celestial E-vector pattern. From Wehner (1994a).



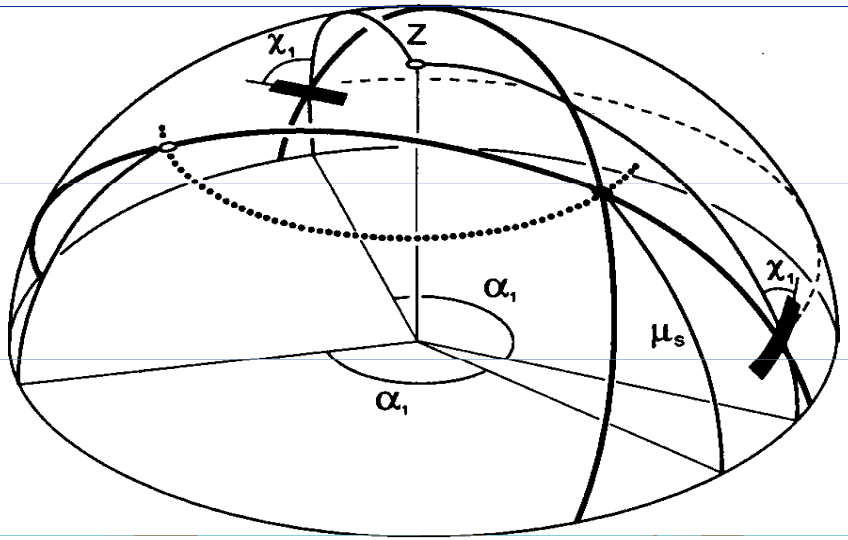
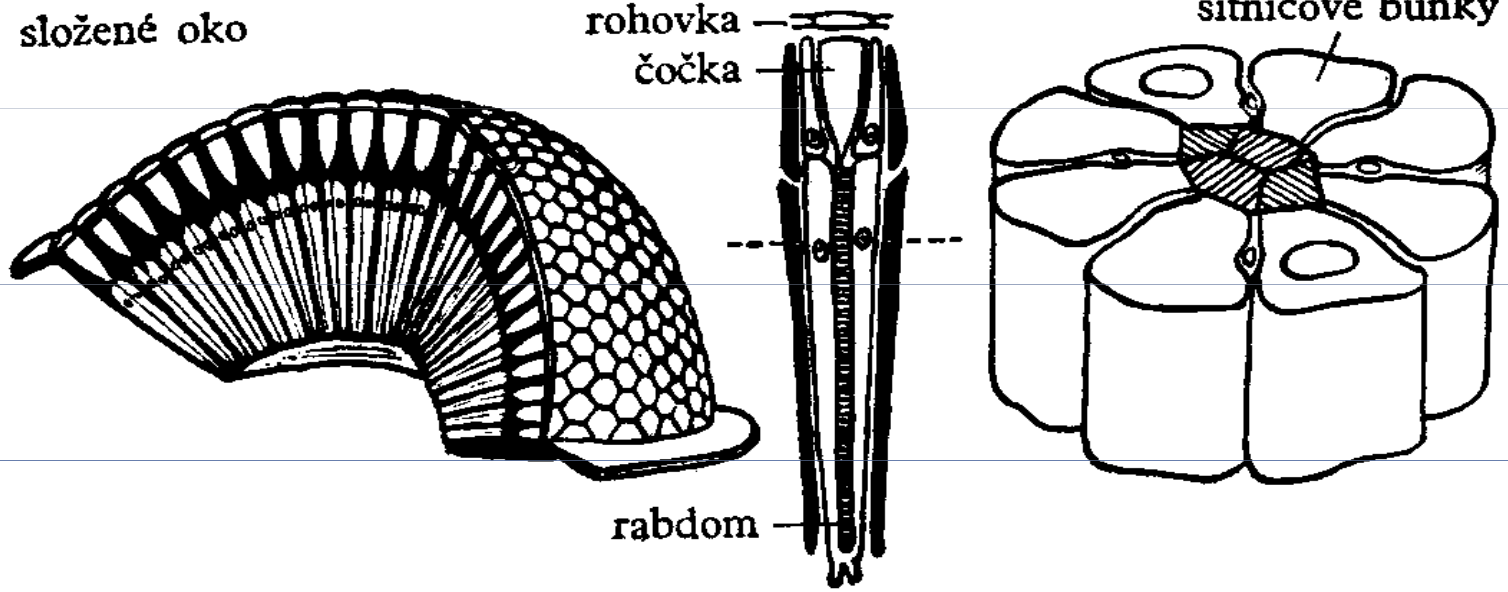
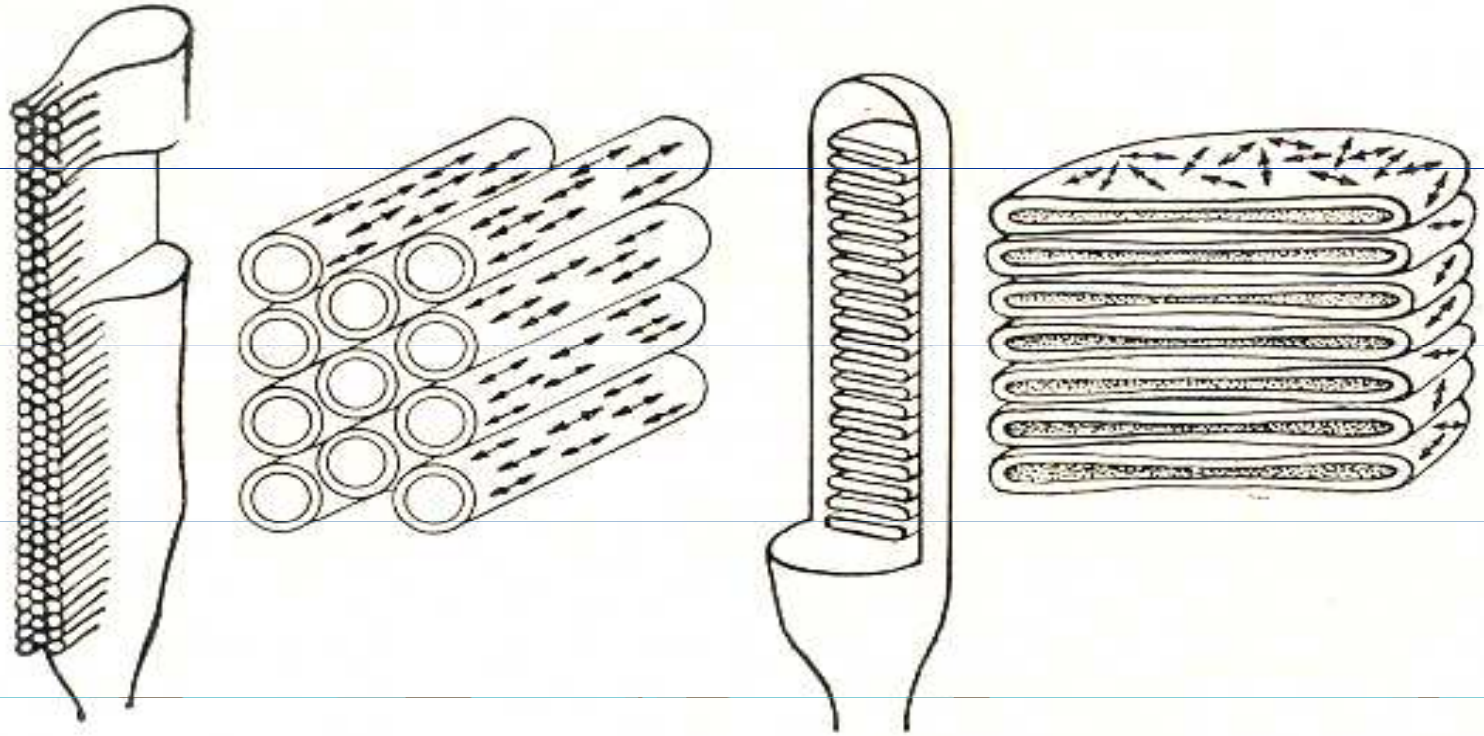


Fig. 4. Three-dimensional constructions required to infer the position of the sun – and hence the azimuthal position of the solar meridian – from at least two patches of polarized light in the sky. The black bars indicate the orientation of the E-vectors (χ) at two points in the sky. The following directives would yield an all-inclusive solution of the problem: First, determine the E-vector orientation at two points in the sky (a task not discussed here); then construct the great circles (heavy black arcs) running at right angles through the E-vectors; finally determine the position of the sun (filled circle) as the point of intersection of the two great circles. With one E-vector alone, the position of the sun cannot be determined unambiguously. If the elevation of the sun (μ_s) were known at a particular time of day, two intersection points of the great circle inclined orthogonally to χ_1 and the parallel of altitude defined by μ_s could be determined. These intersection points define the correct position of the sun (filled circle), as well as a fictive position (open circle), which is separated by the azimuthal difference α_1 from the correct one. The insect's E-vector compass does not operate this way, but is based on a set of simpler rules (see text and Fig. 5). Modified from Wehner (1981).



Složené oko hmyzu se skládá z mnoha omatidií, oddělených od sebe pigmentem. Každé omatidium má vlastní rohovku, čočku a sítnicovou tyčinku (rabdom) tvořenou osmi sítnicovými buňkami, jež přecházejí v nerv.

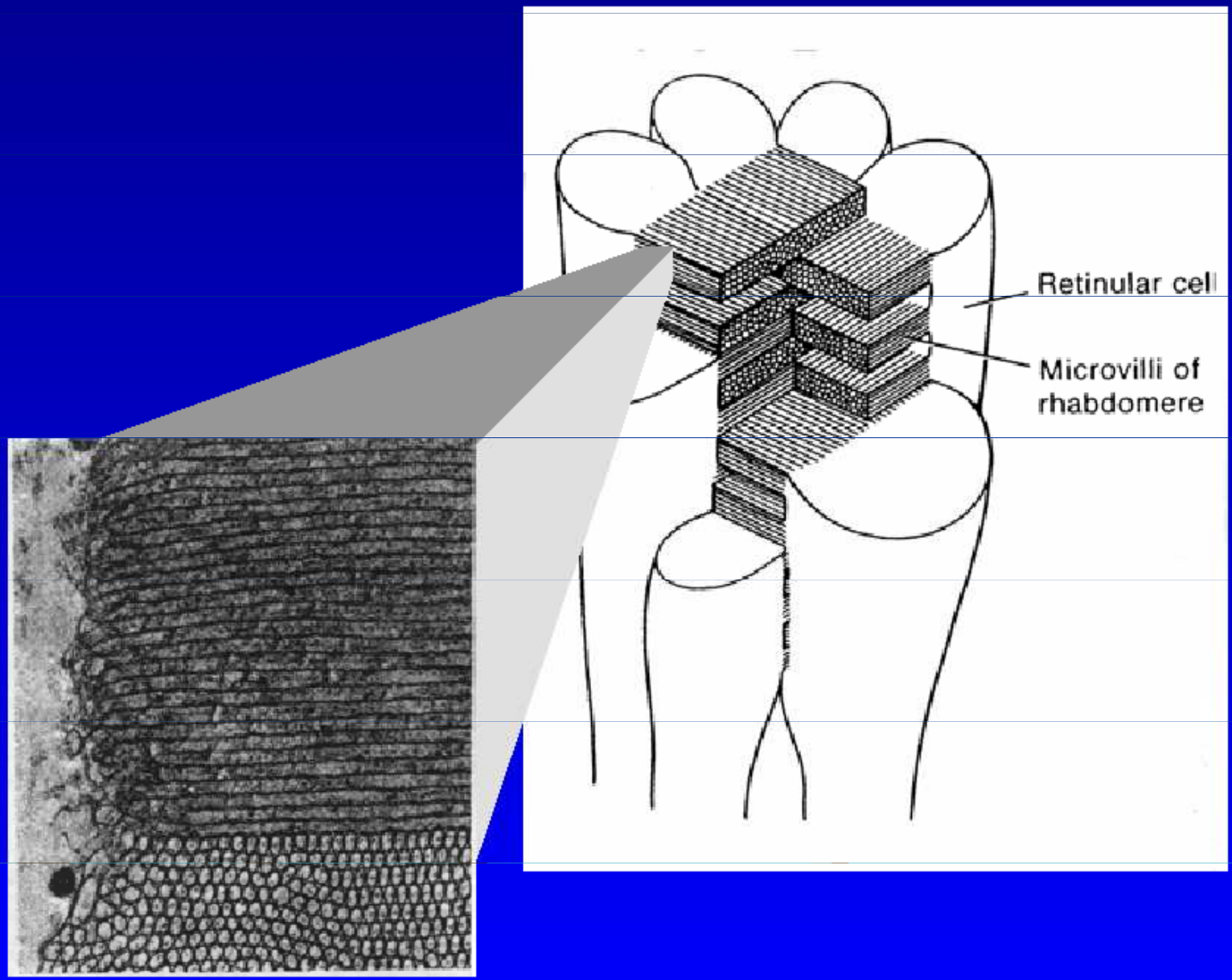


sítnicová buňka hmyzu

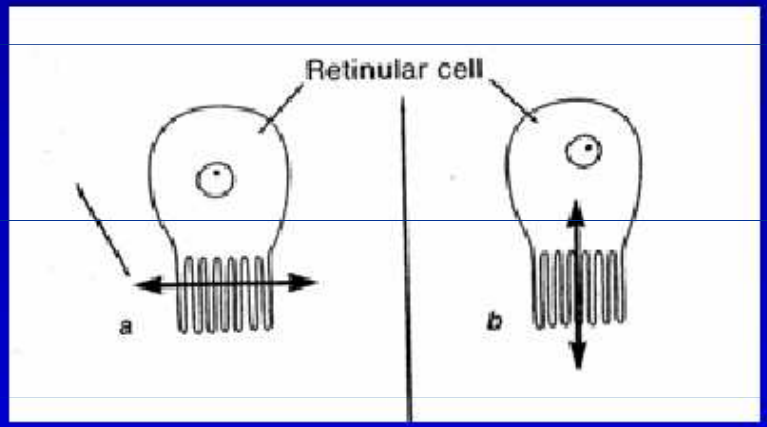
zraková tyčinka obratlovců

Molekuly světločivého pigmentu (radopsinu) jsou v tyčince hmyzího oka uspořádány jedním směrem, kdežto v tyčince oka obratlovce jsou neuspořádané. Vysvětluje to rozdíl ve schopnostech obou očí rozlišovat rovinu polarizovaného světla.

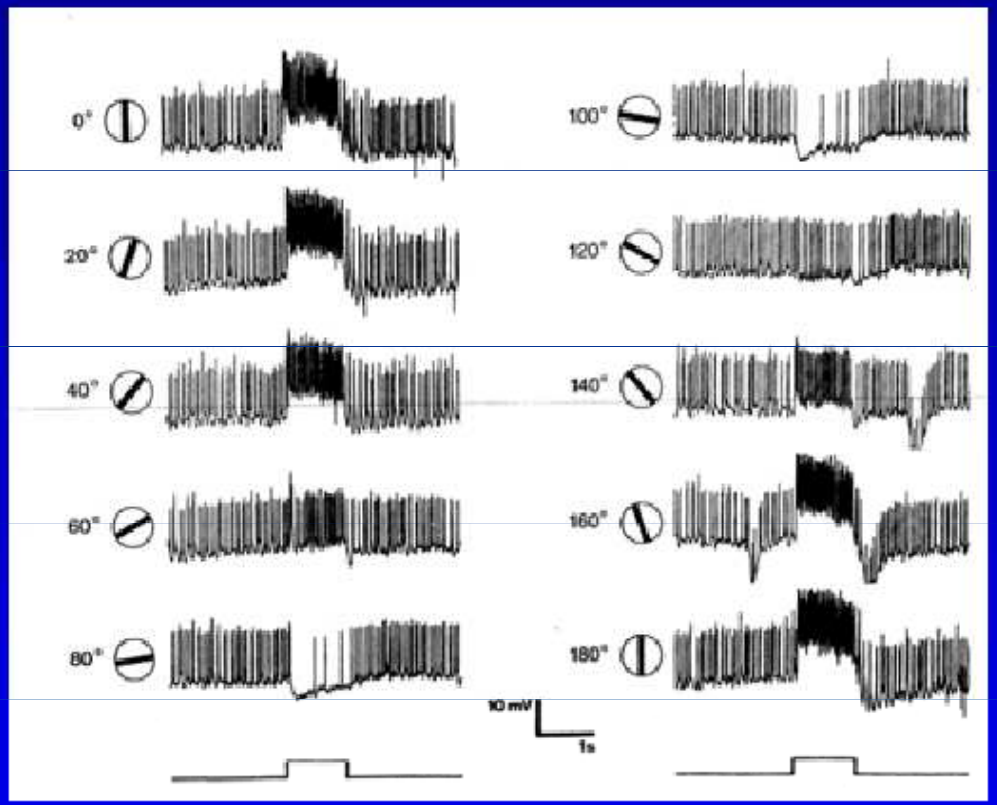
Organization of retinular cells allows for detection of polarized light



Arthropod visual neurons can be sensitive to specific planes of polarized light



Cricket



(Wehner 1989)