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Cellular Biophysics – Sensory Systems

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Contents of the lecture

- Sensory systems
  - ➢Example: visual system

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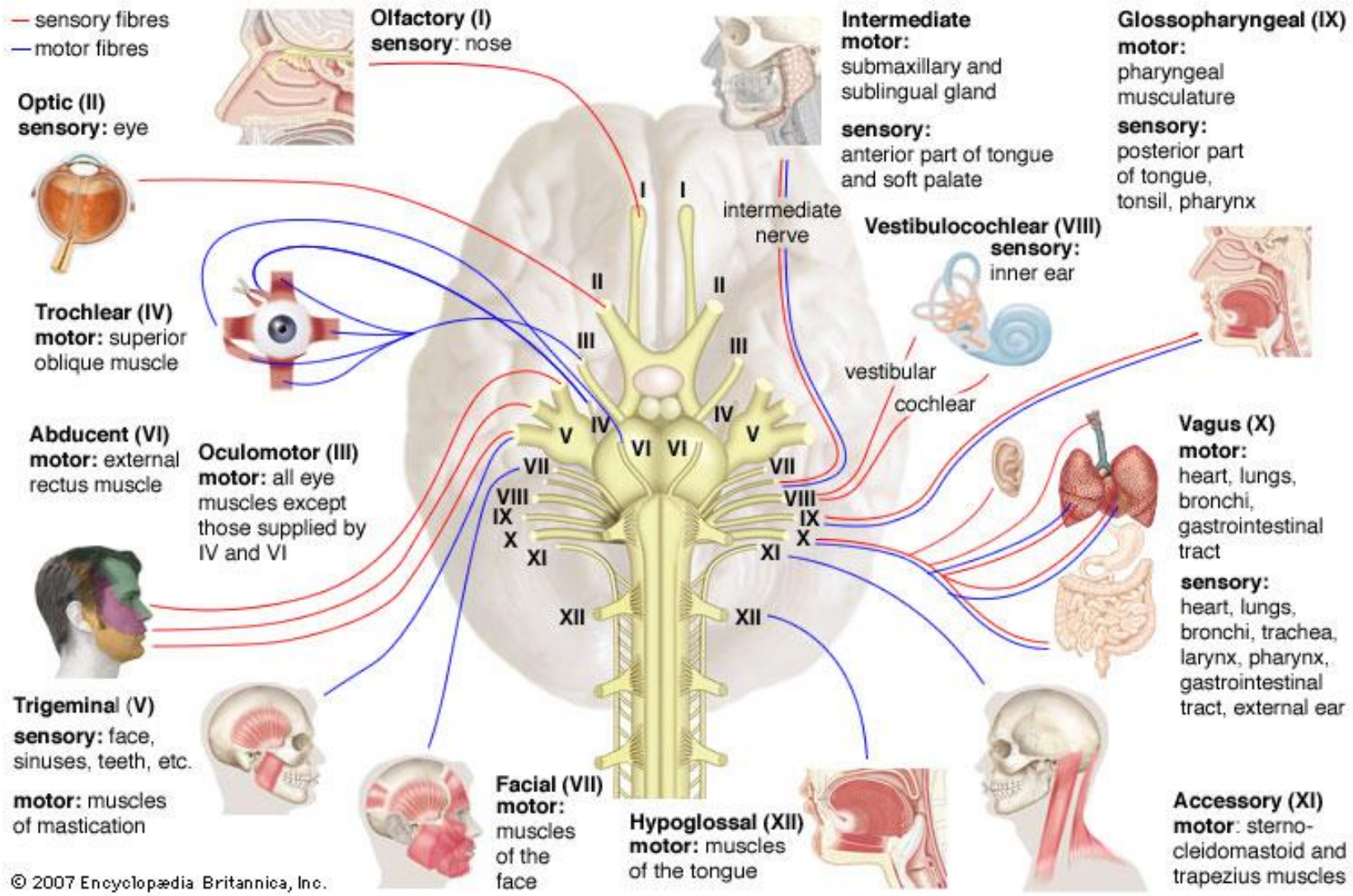
Sensory and motor systems



http://media-2.web.britannica.com/eb-media/44/54244-004-892C5169.jpg

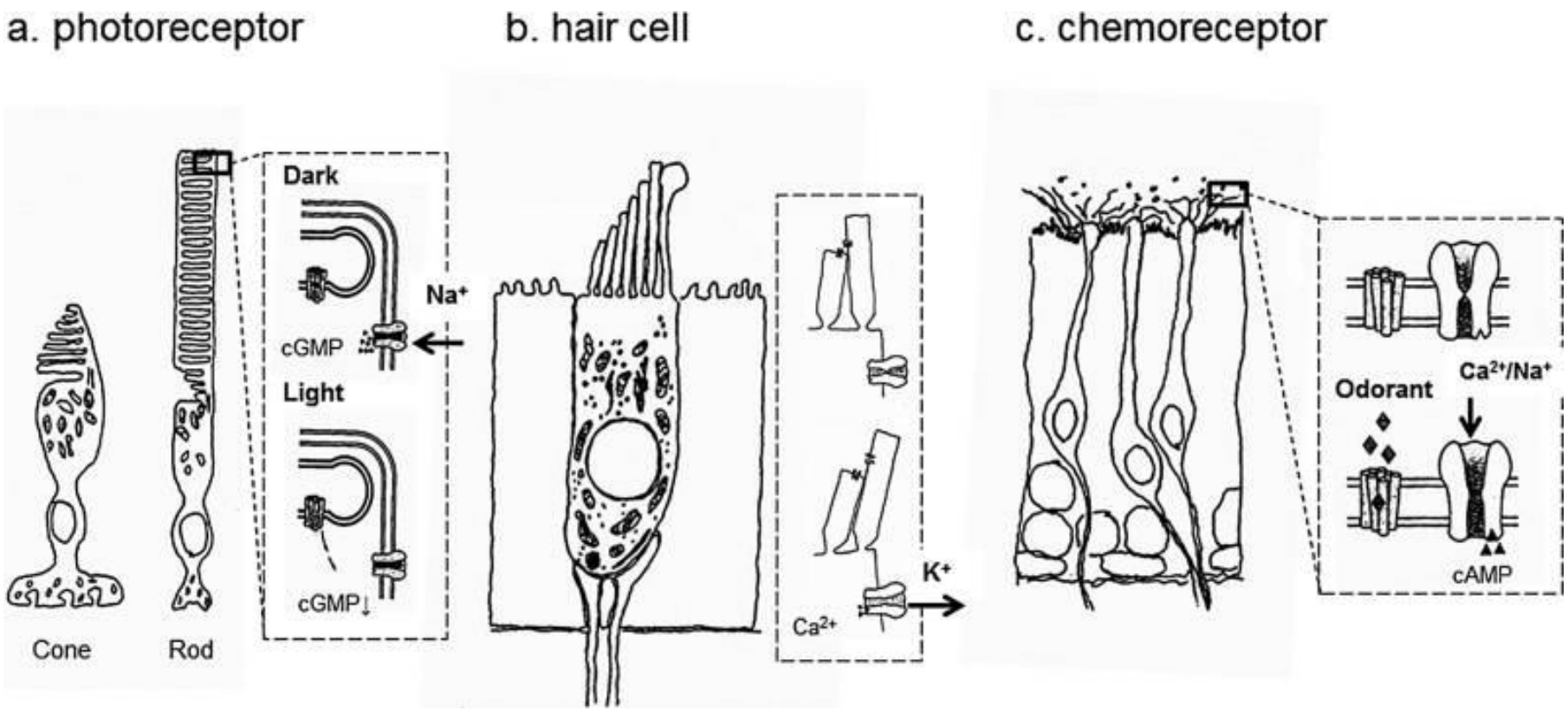
Sensory transduction

- Transformation of signal from the external world to the internal world

- Energy of the external world converted into electrochemical events
  - Examples: thermal energy (heat), electro-magnetic energy (light), mechanical energy (sound), energy from molecules (chemicals)

- Utilize receptors for energy conversion
  - Examples: photoreceptors (vision), sound receptors (audition), chemoreceptors (taste and smell), mechanoreceptors (tactile sense), thermoreceptors (temperature), noxious receptors (pain)

Ciliary cells for sensory transduction



Yoshioka & Sakakibara, *Biophysics*, 2013; **9**: 183–191

Second messengers

- Intracellular signaling molecules released by the cell to trigger physiological changes

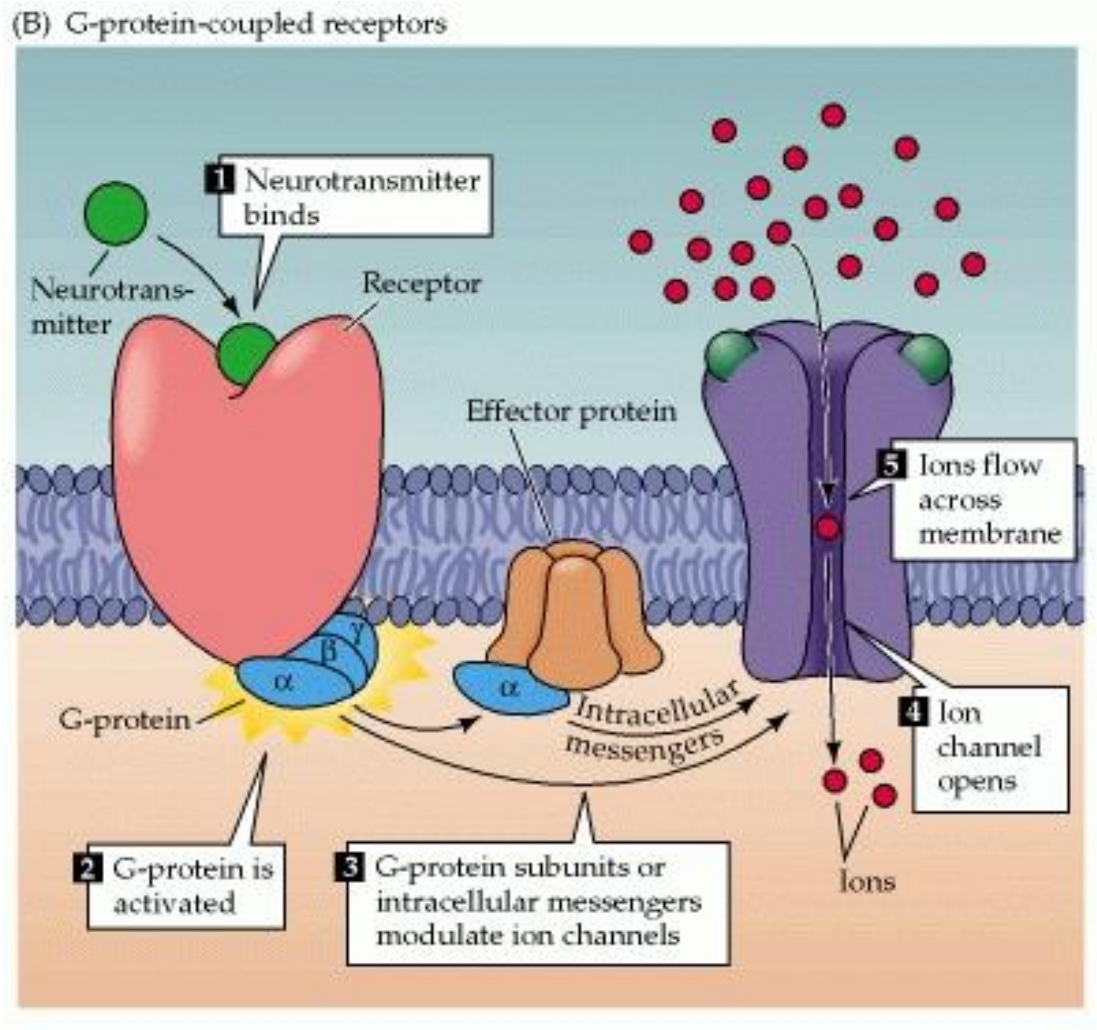
  => initiating components of intracellular signal transduction cascades

- Examples: cyclic AMP, cyclic GMP, Ca^{2+}
- Released in response to extracellular signaling molecules - the first messengers
- First messengers typically extracellular factors, e.g. hormones or neurotransmitters
- G-protein cascade a typical example

Metabotropic receptor and G-protein cascade

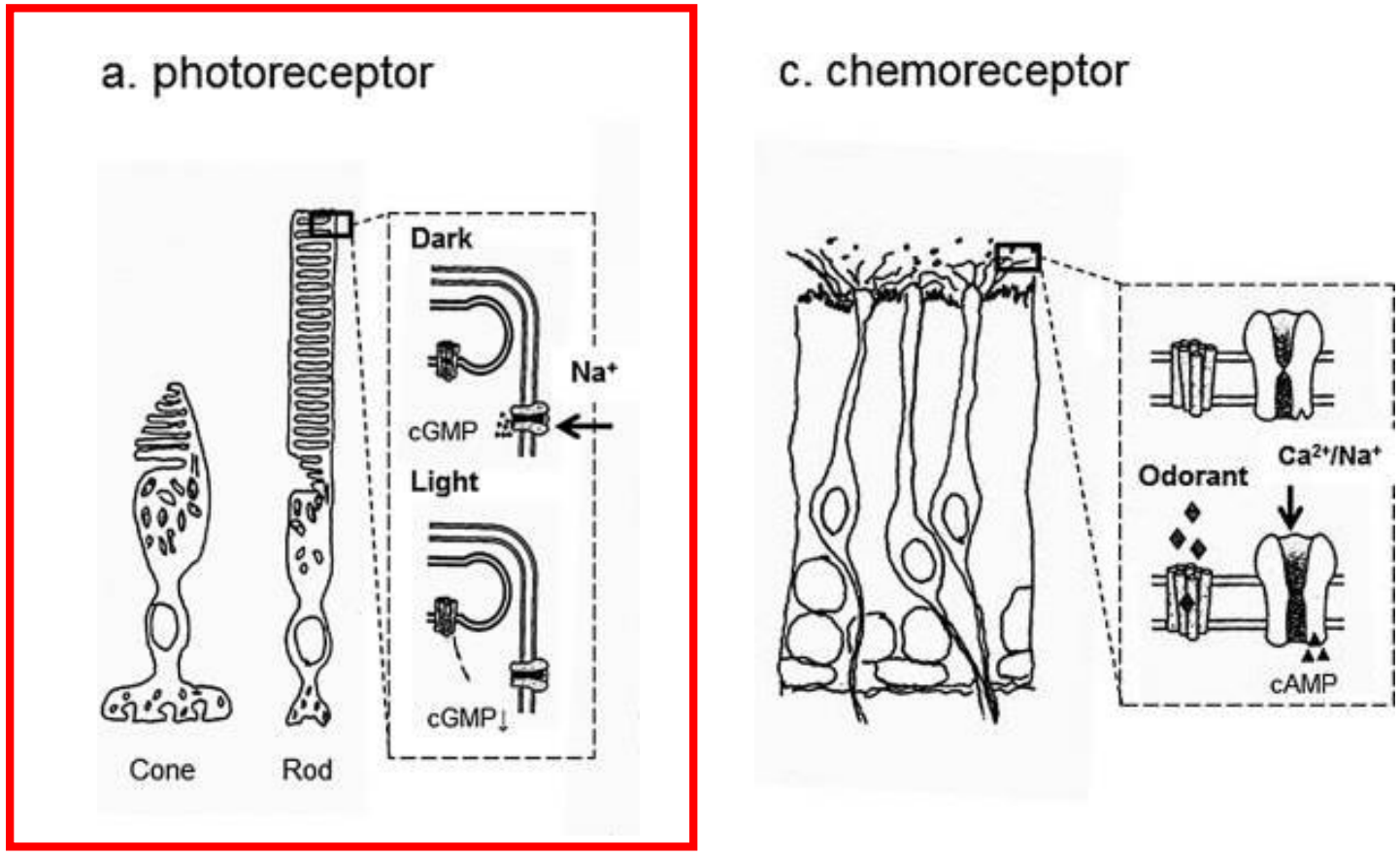
1) Binding of ligand to a metabotropic receptor initiates a cascade
2) The receptor typically activates a G-protein that activates the primary effector protein
3) The effector protein can activate second messengers or have other effects

Long lasting and more widespread effects compared to ionotropic receptors but enable amplification of the signal



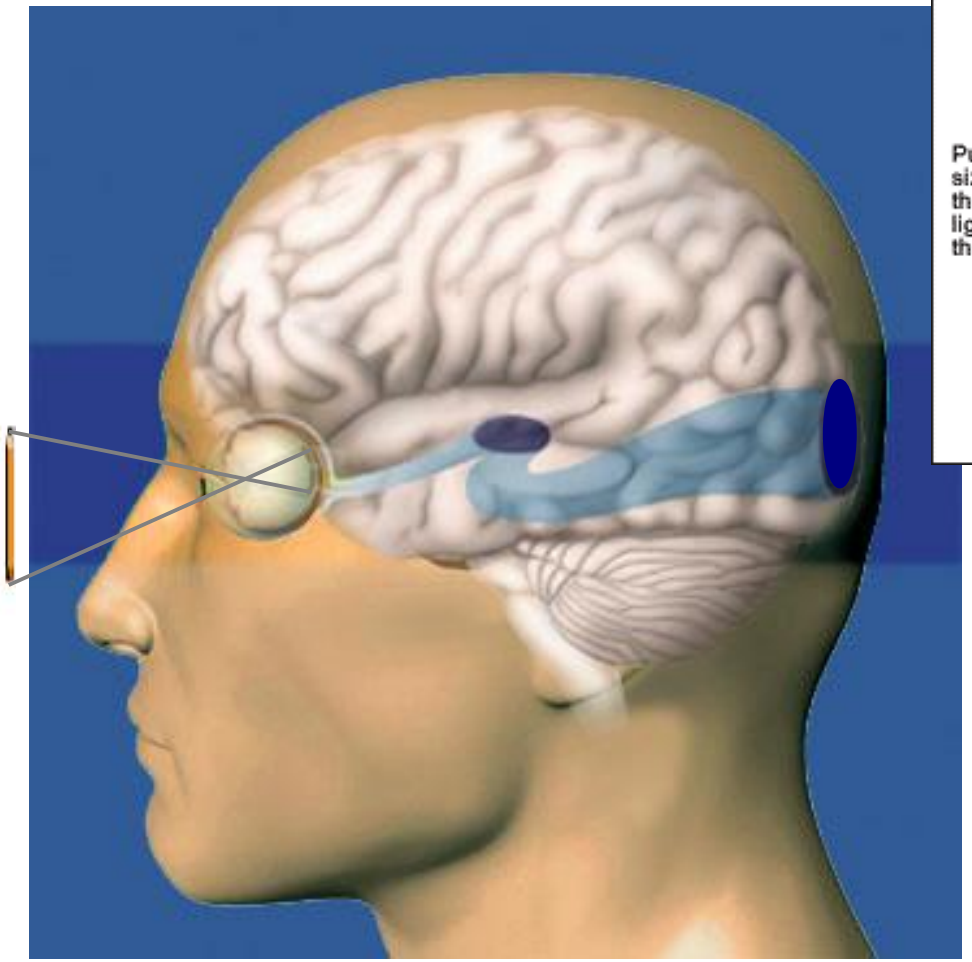
Purves (Ed.), Neuroscience

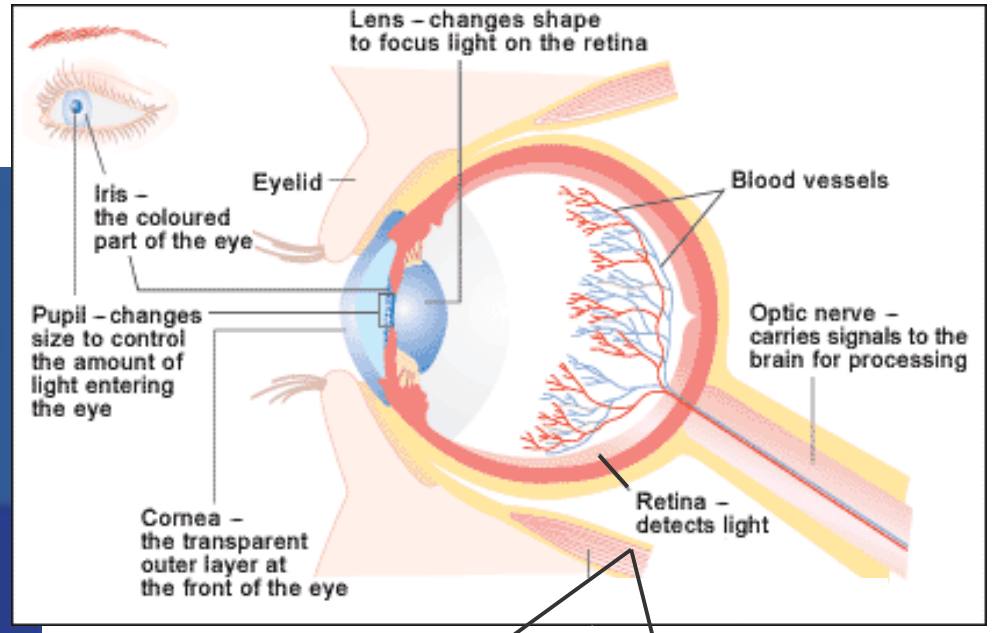
Utilize G-protein cascade and cAMP/cGMP

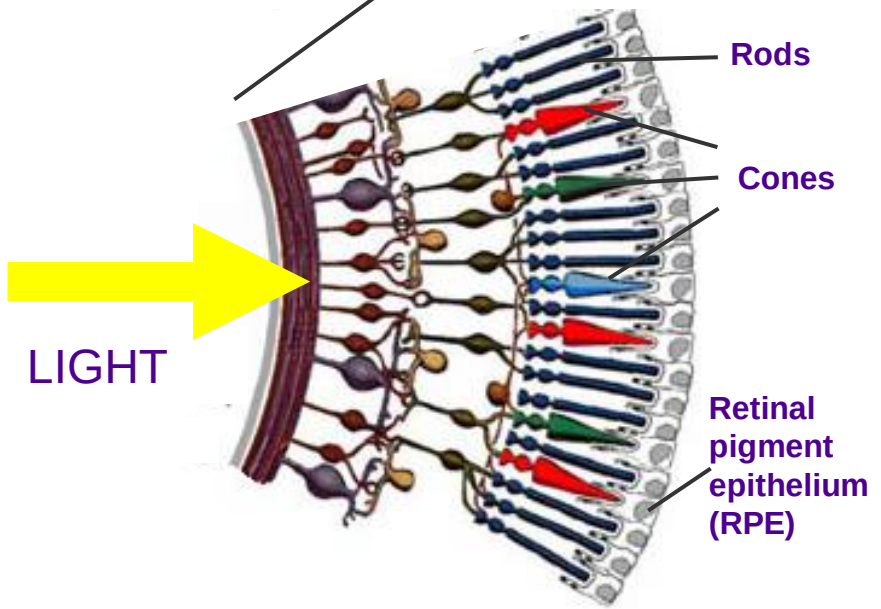


Yoshioka & Sakakibara, *Biophysics*, 2013; **9**: 183–191

Sensory functions - Vision







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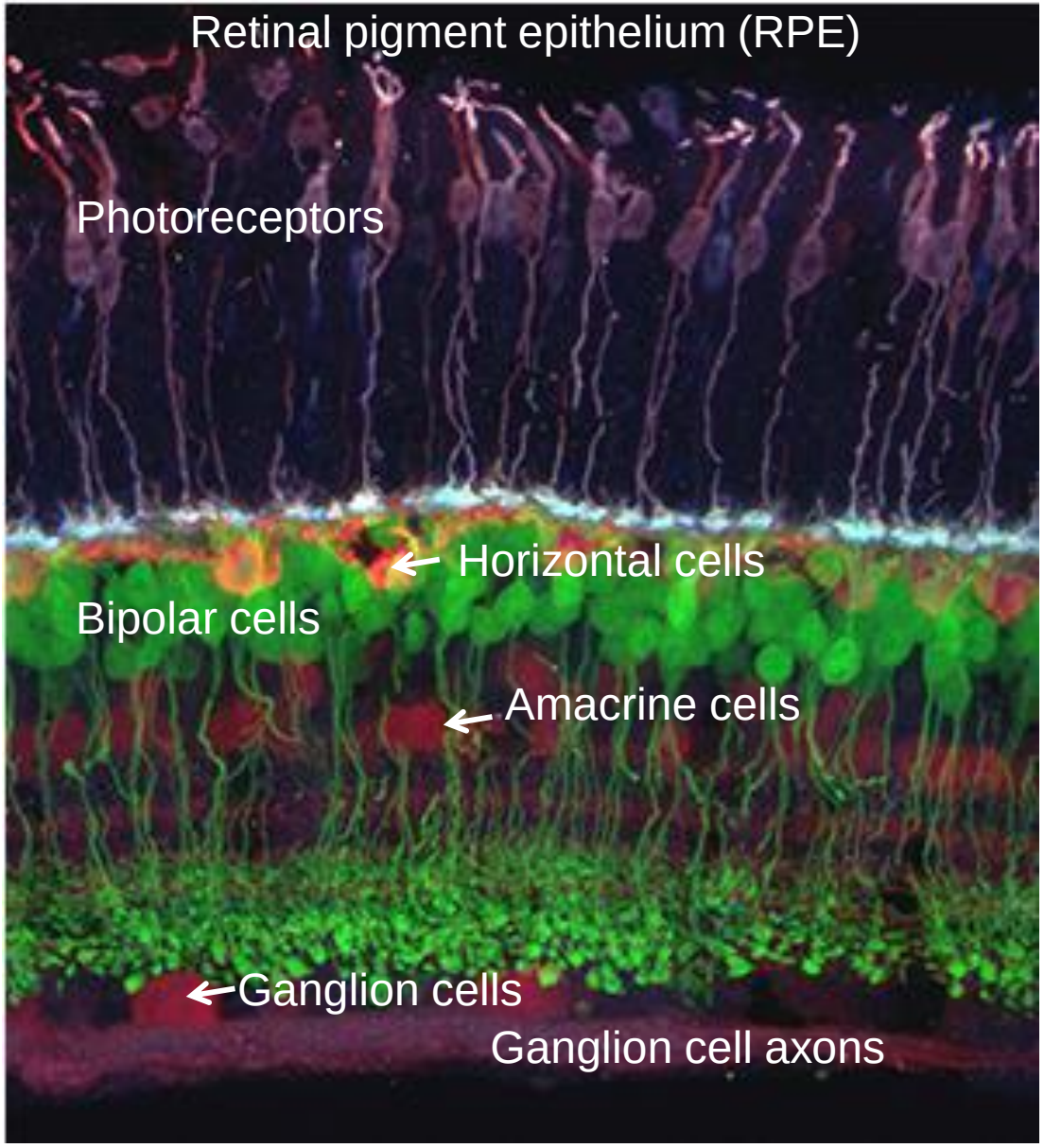
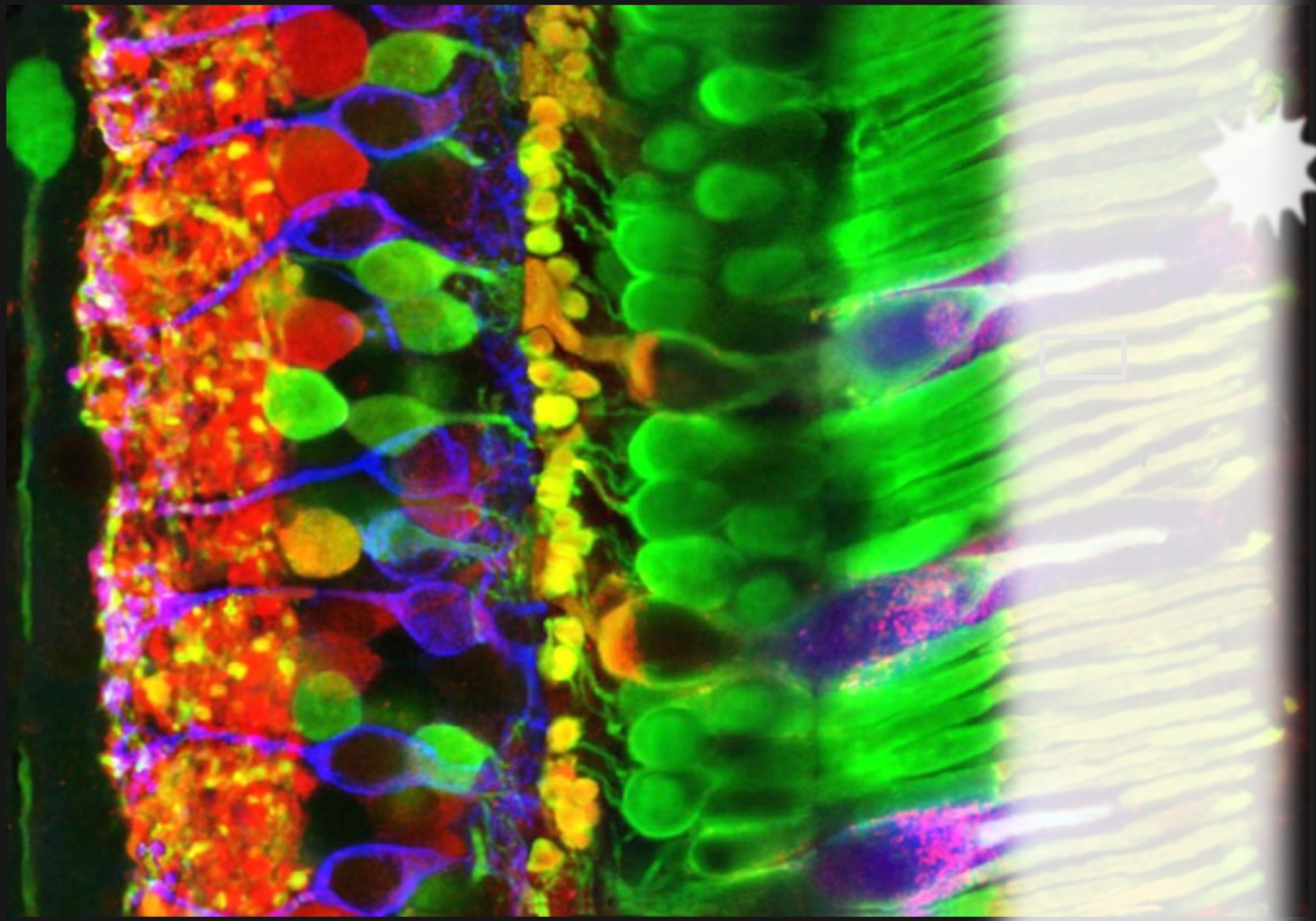
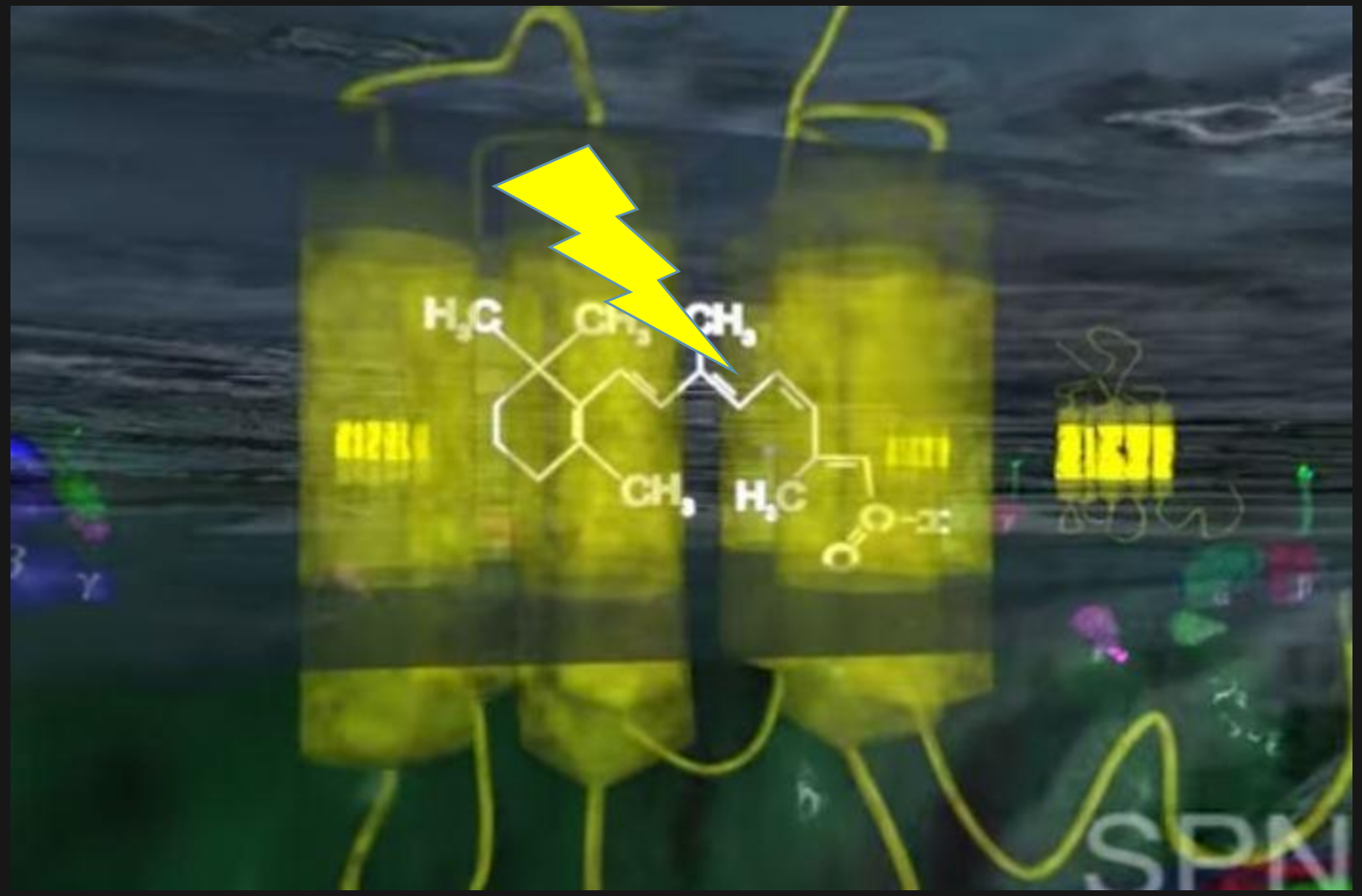
Sensory functions - Vision

- Vision is based on light sensitive neural tissue – the retina
- Many types of neurons organized to form a complex neural tissue – comparable to brain tissue
- Layered structure with lots of information processing



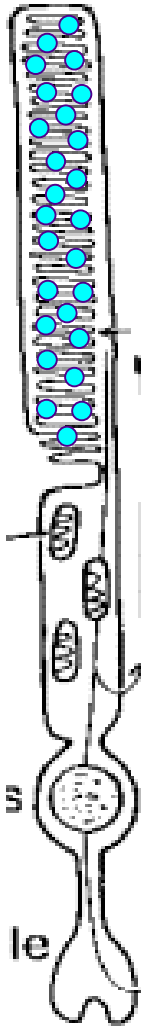


Nicolas Cuenca – Retinal Microscopy – 2008

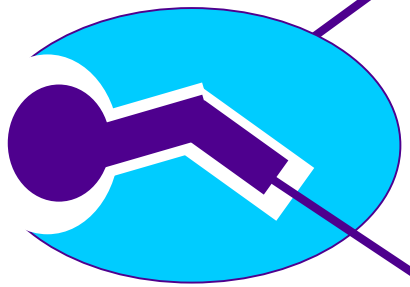

H3C
CH3
CH3
CH3
H3C
O
O-
SPN

Visual pigment structure

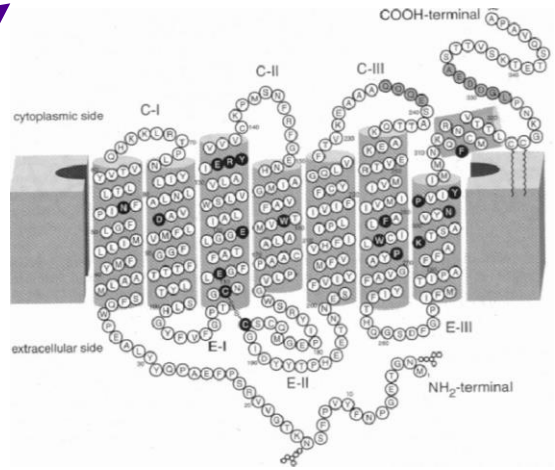
ROD



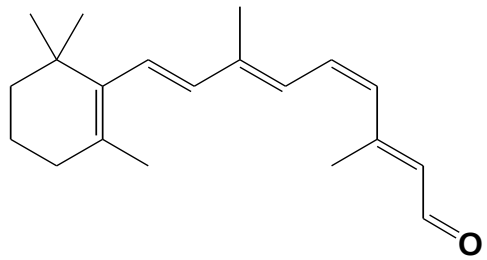
RHODOPSIN



Opsin Protein



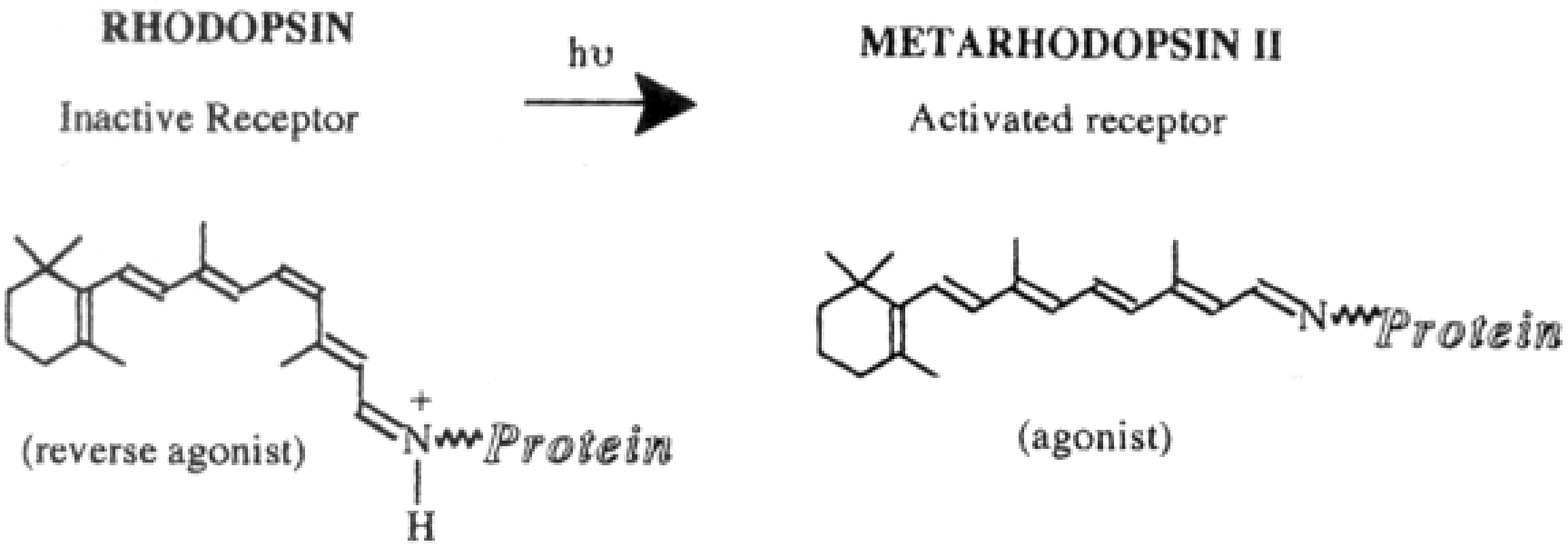
11-*cis* retinal



In the dark, 11-*cis* retinal is bound to opsin by a covalent bond which maintains the pigment in an inactive configuration

Light does one and only one thing….

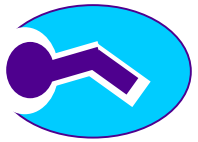
Photoisomerization



11-*cis* retinal

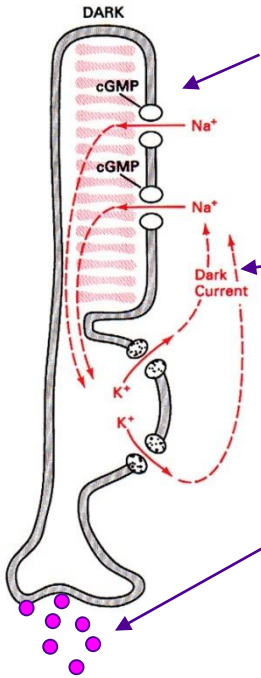
All-*trans* retinal

DARK:



11-*cis*

Inactive Rhodopsin

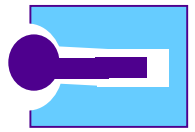


cGMP-gated channels OPEN

Dark current

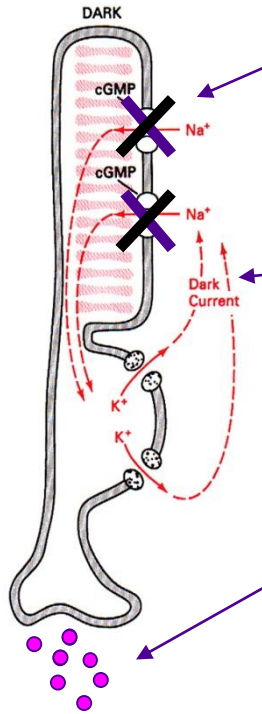
Continuous glutamate neurotransmitter secretion

LIGHT:



all-*trans*

Activated Rhodopsin



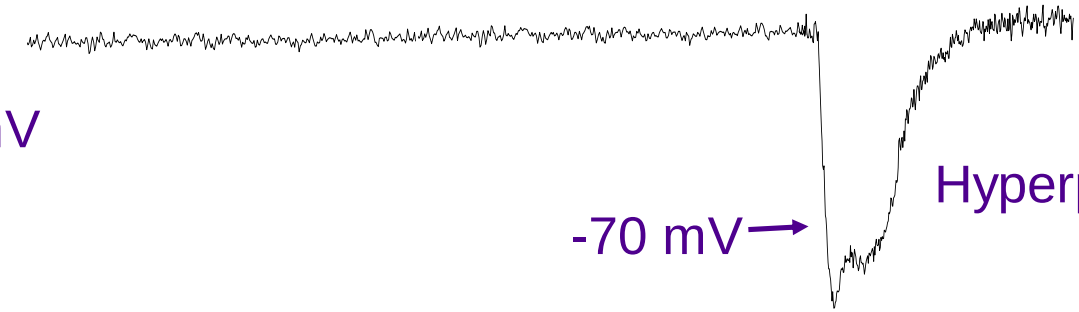
cGMP-gated channels CLOSE

Dark current declines

Reduction of glutamate secretion

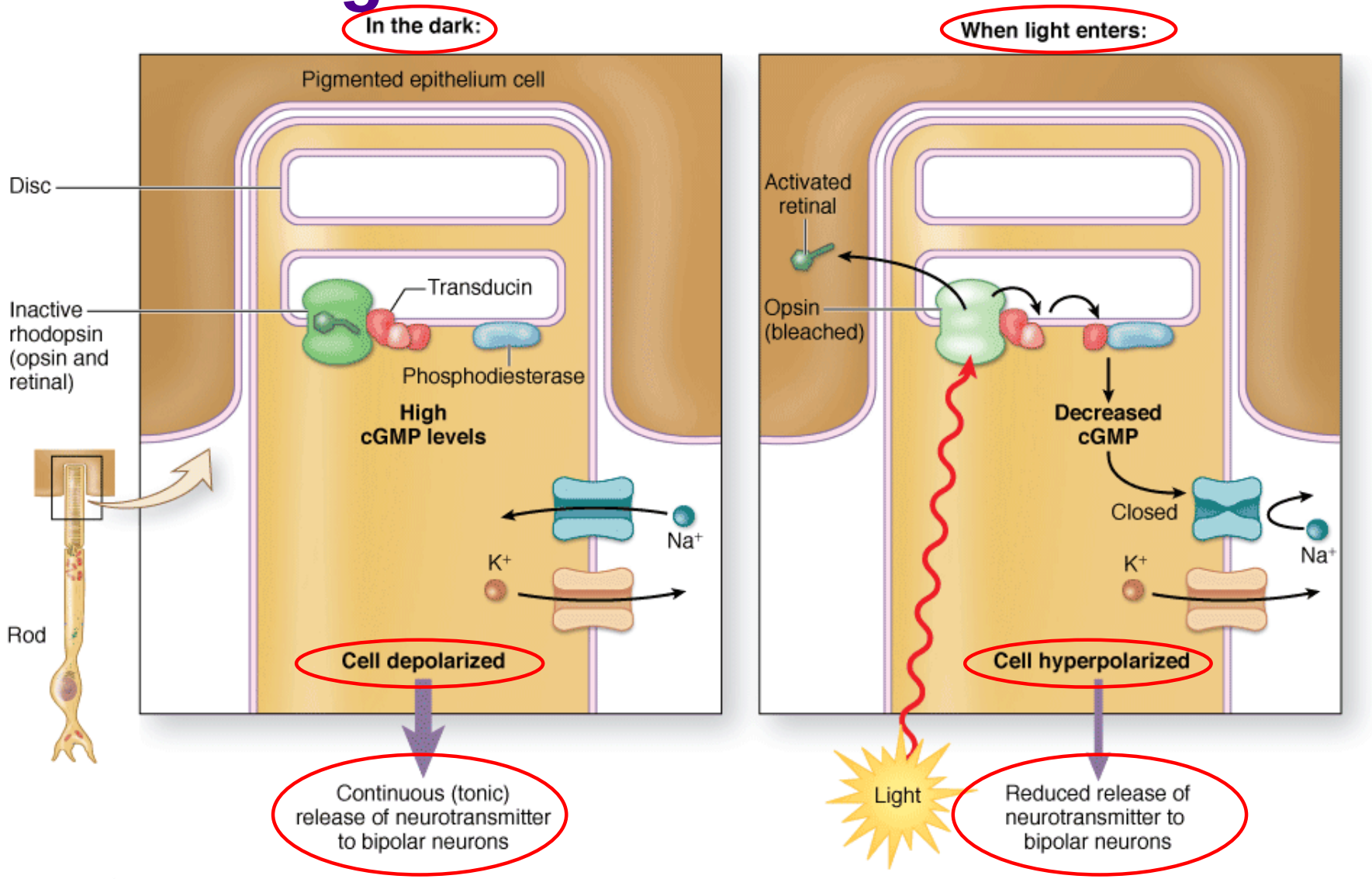
Cell continuously depolarized

V_m = -35 mV



Hyperpolarized

Phototransduction – conversion of light signal into electrical signal



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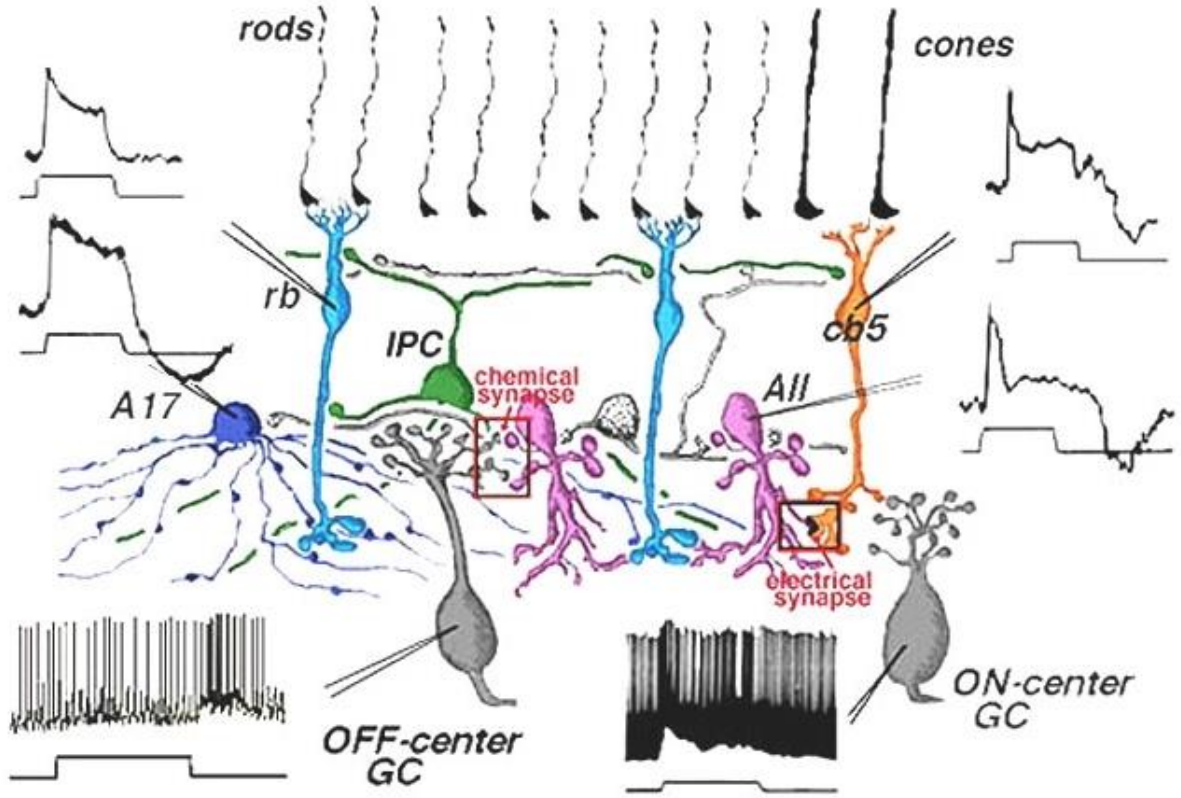
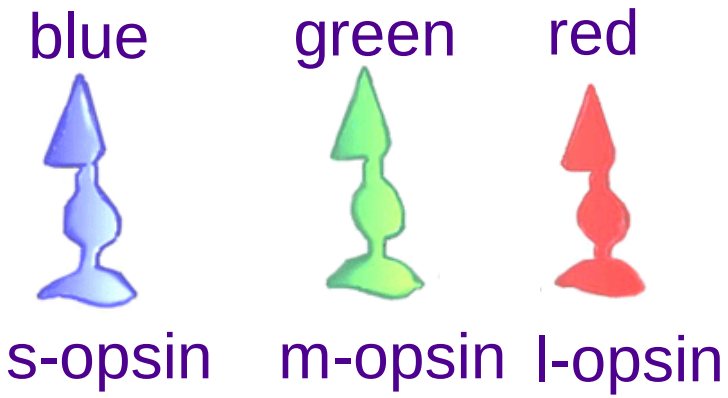
Vision and retinal signaling

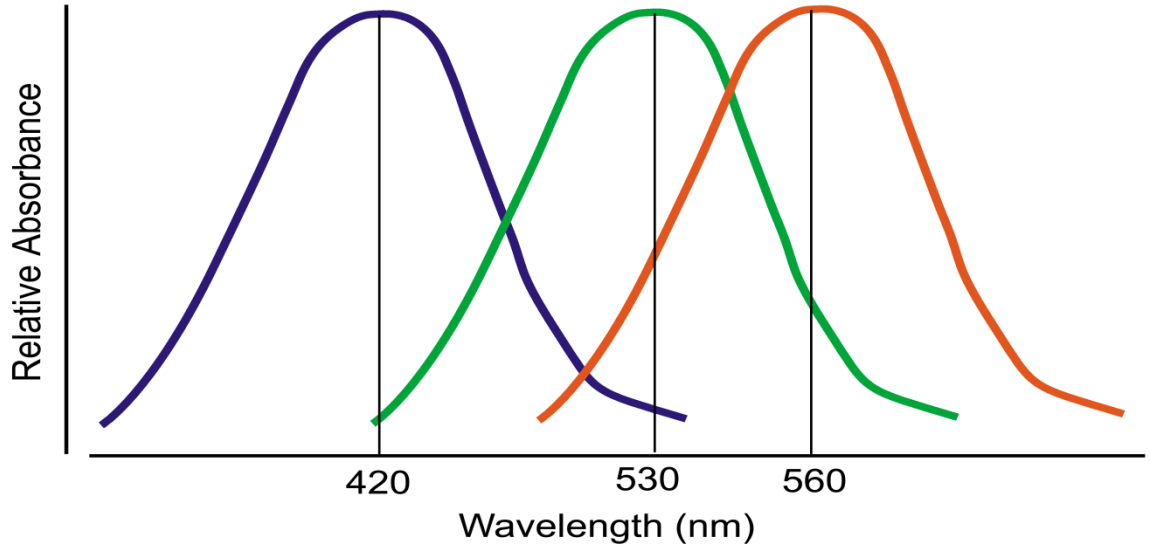
- Photoreceptors transform the light signal into an electrical signal
- This electrical signal is then passed via a complex retinal circuitry to ganglion cells
- Ganglion cells generate action potentials and send this information to brain for further processing



How do we see color?

- We have 3 cone types
- Each cone has a different opsin type.
- Each opsin has a different spectral sensitivity curve



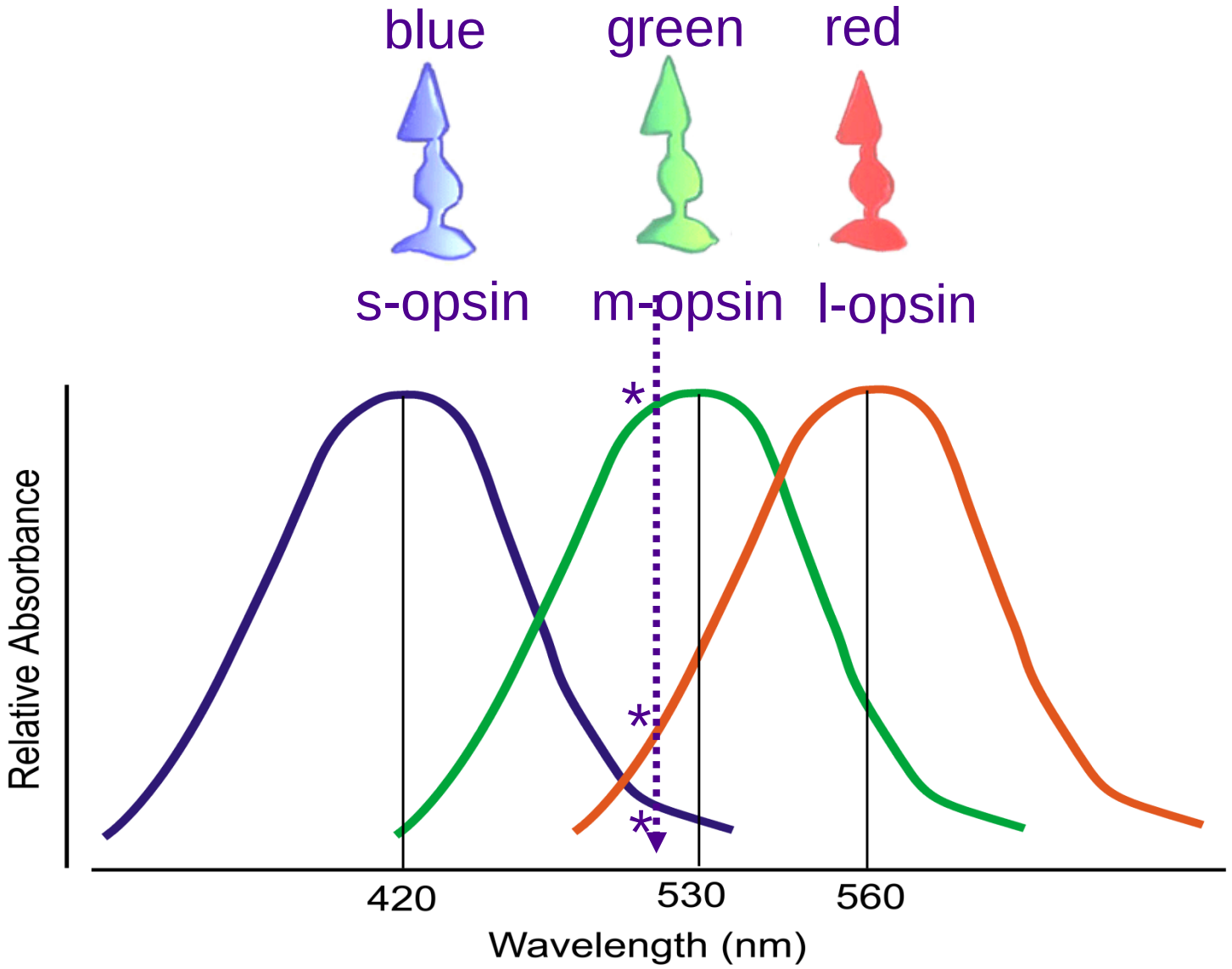


Why do we need more than one cone type for color vision?

RUSHTON'S PRINCIPLE:

- The receptor potential of a photoreceptor depends upon its quantum catch, but not upon *what* quanta are caught.

Translation: The response of each photoreceptor depends upon the number of photons absorbed (and subsequent visual pigment molecules photoisomerized) but not upon the wavelength.



The human visual system extracts color information by *comparing* the output of the three different cone types

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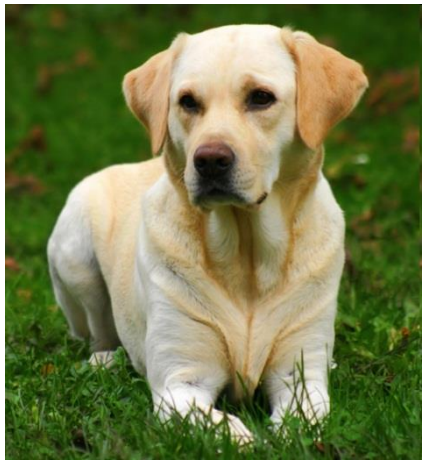
The more opsin types, the better the color discrimination

1 Monochromatic

2 Dichromatic



3 Trichromatic

4 Tetrachromatic

6 Hexachromatic

12 Dodecachromatic

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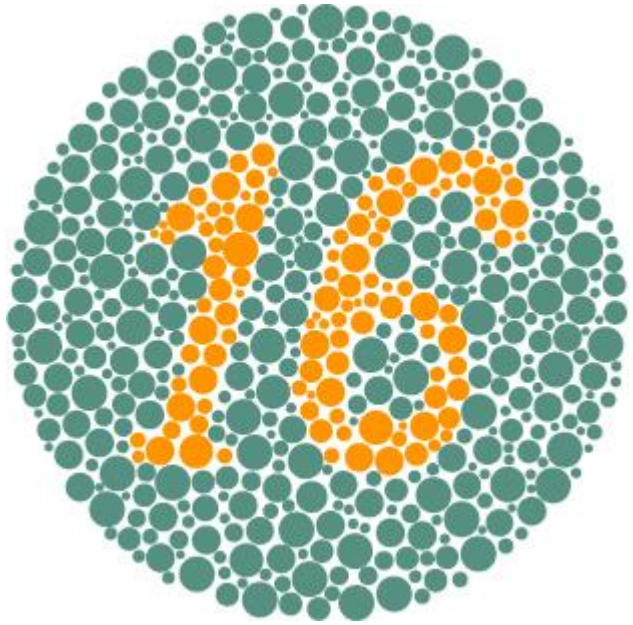
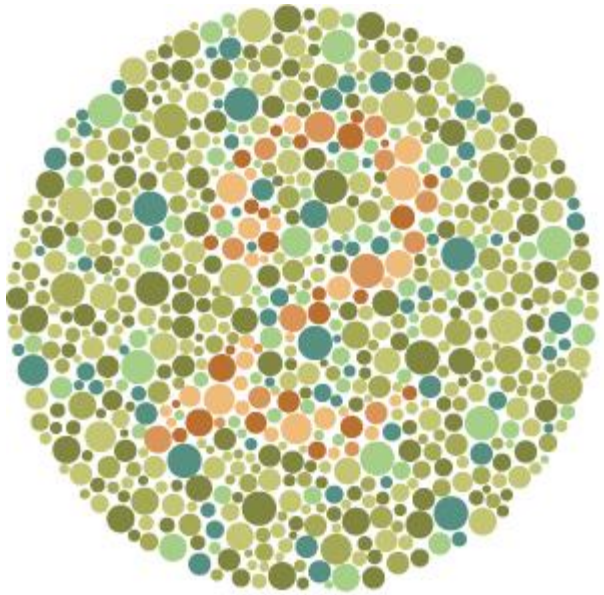
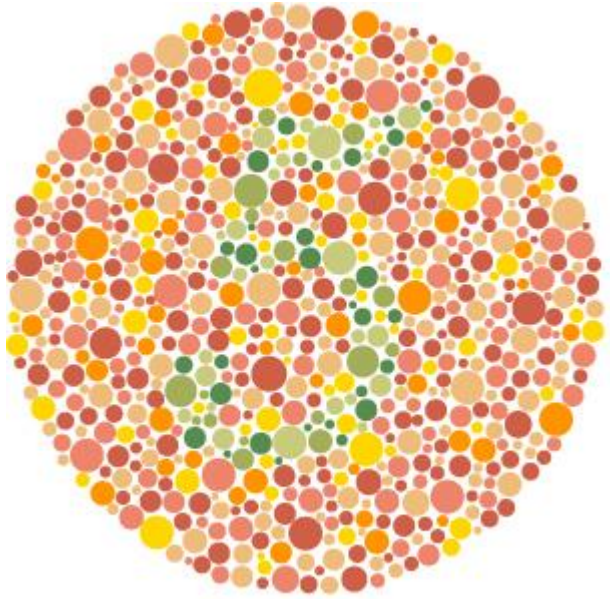
Color vision test







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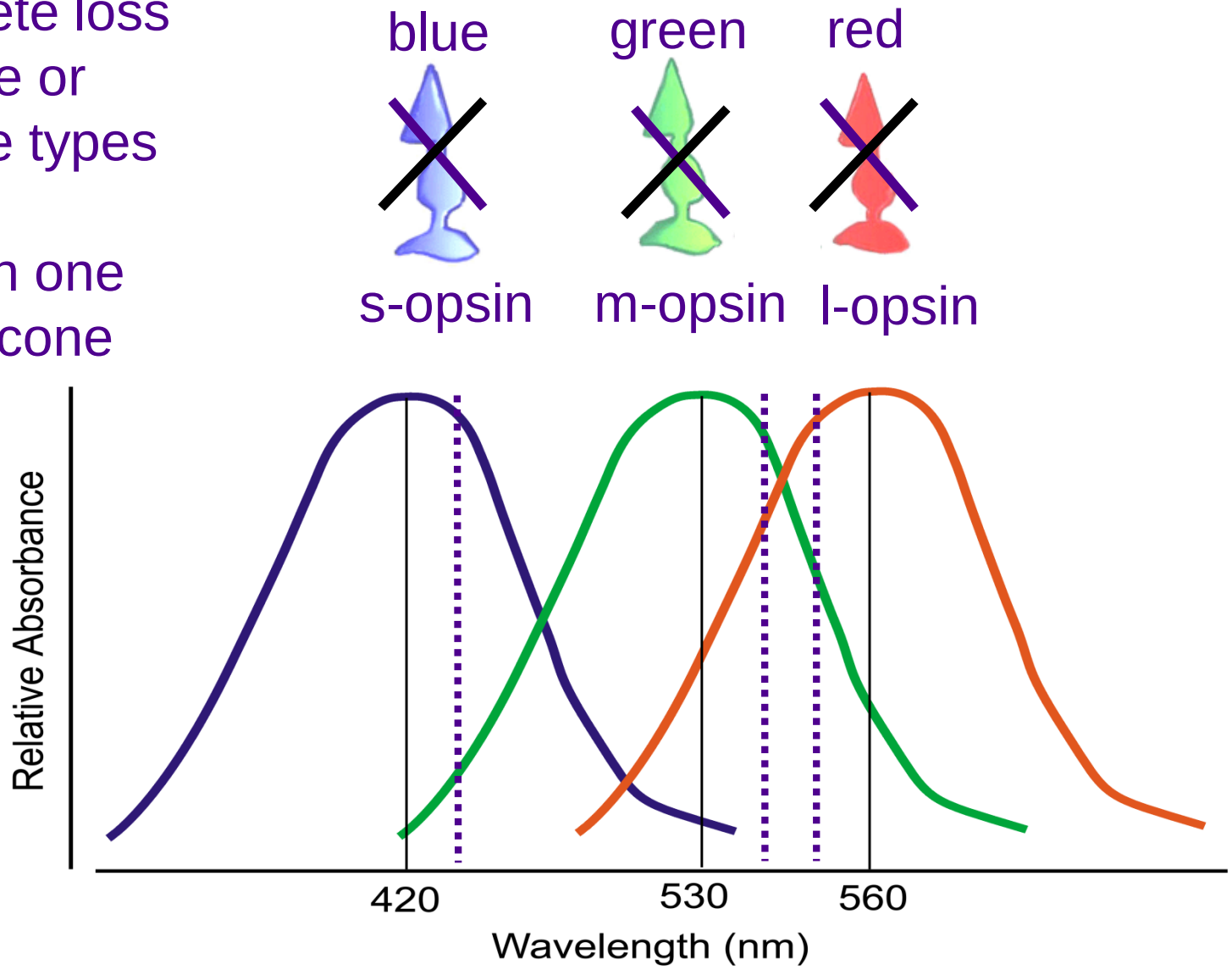
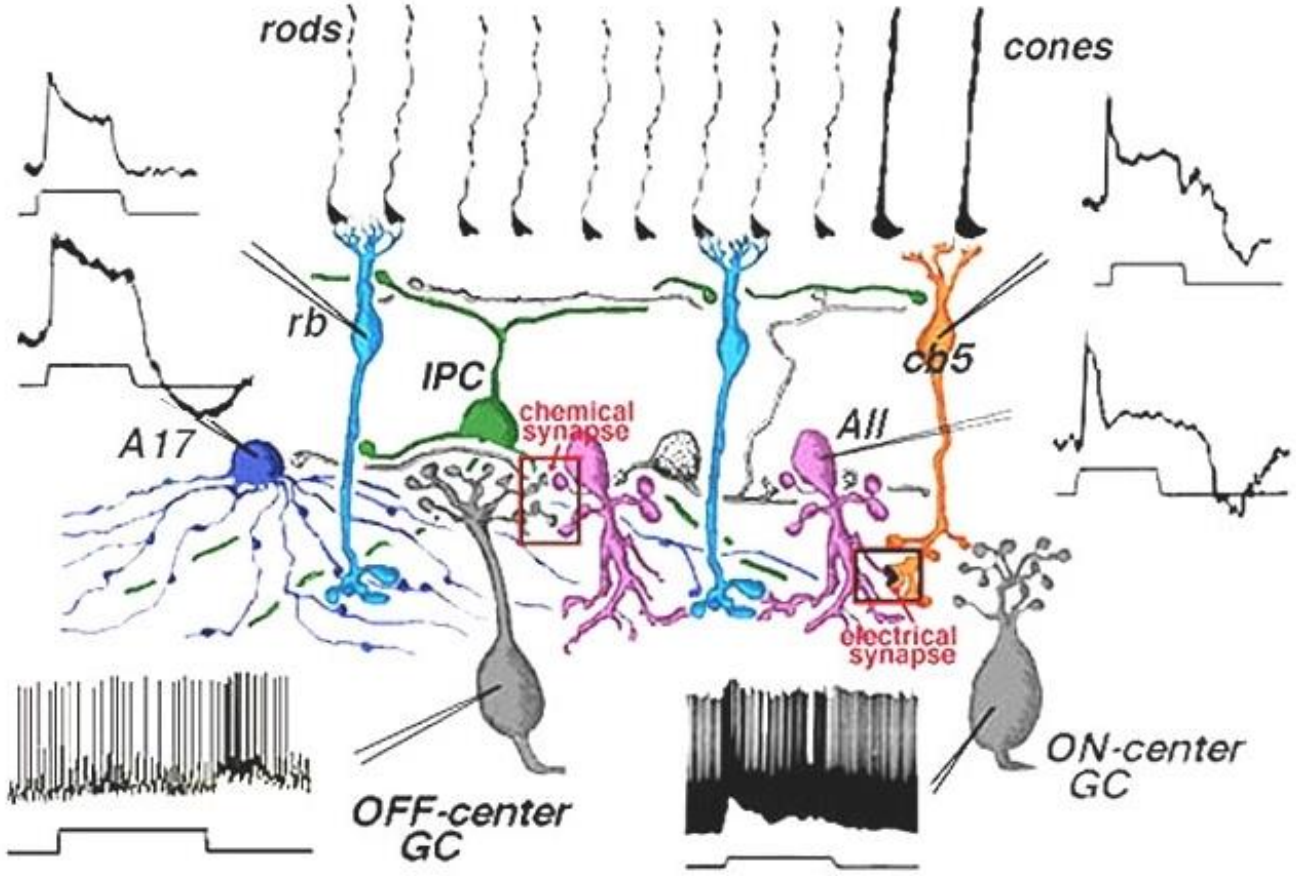
Color blindness

Partial or complete loss of function of one or more of the cone types
OR
Visual pigment in one (or more) of the cone types abnormal



Retinal electrical signals

- Graded potentials: receptor neurons (photoreceptors, absorb light), bipolar cells, amacrine cells, horizontal cells
- Action potentials: ganglion cells (send long axons to brain)



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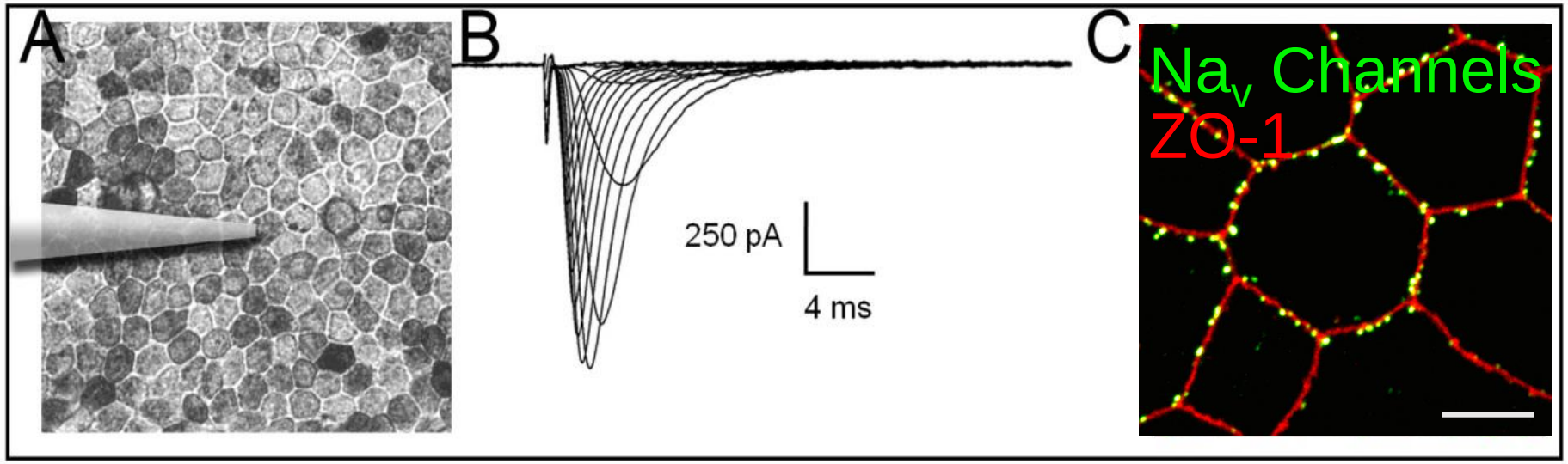
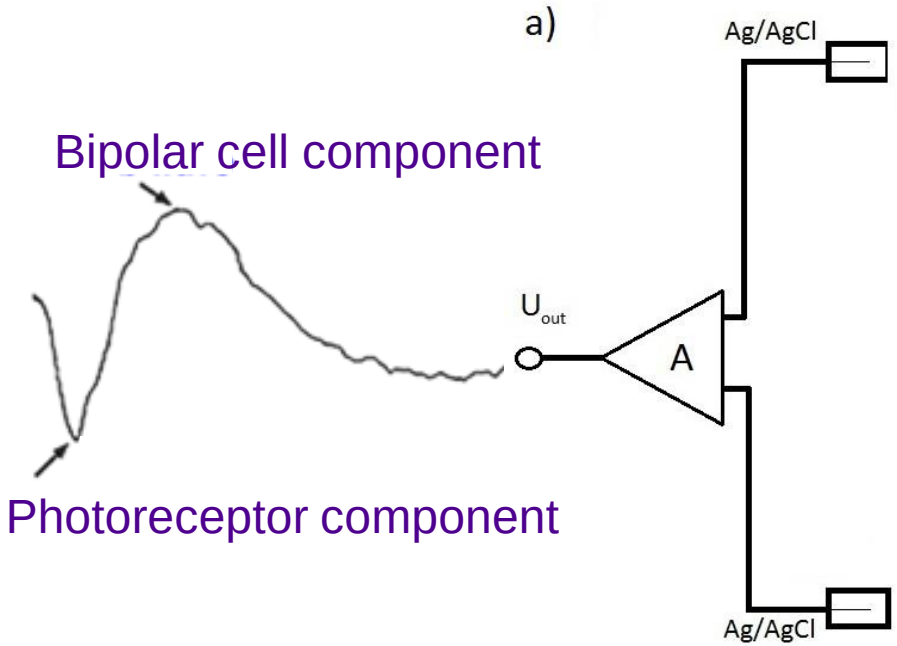
Electrical signals from retinal pigment epithelium (RPE)

Patch clamp –recordings from voltage-gated Na^+ channels



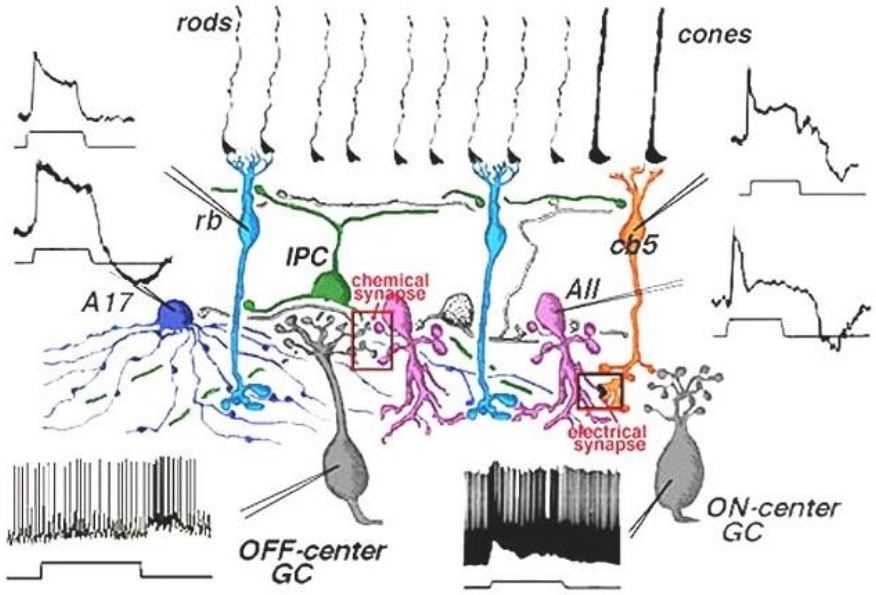
Retinal recordings *in vitro*

- Outside the tissue:



Electroretinogram (ERG)

- Inside the tissue:



Patch clamp

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ERG *in vivo*

some corneal ERG electrodes

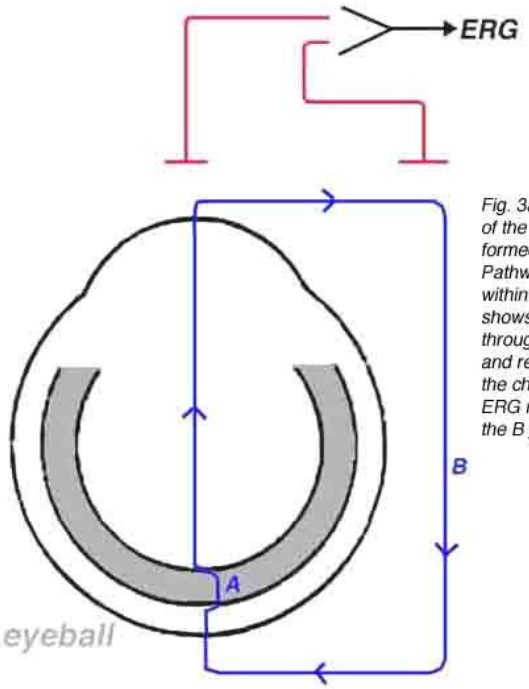
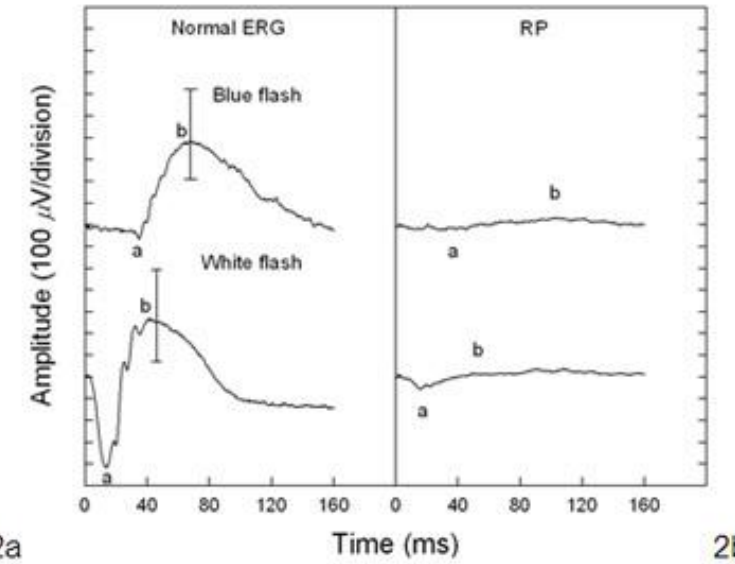
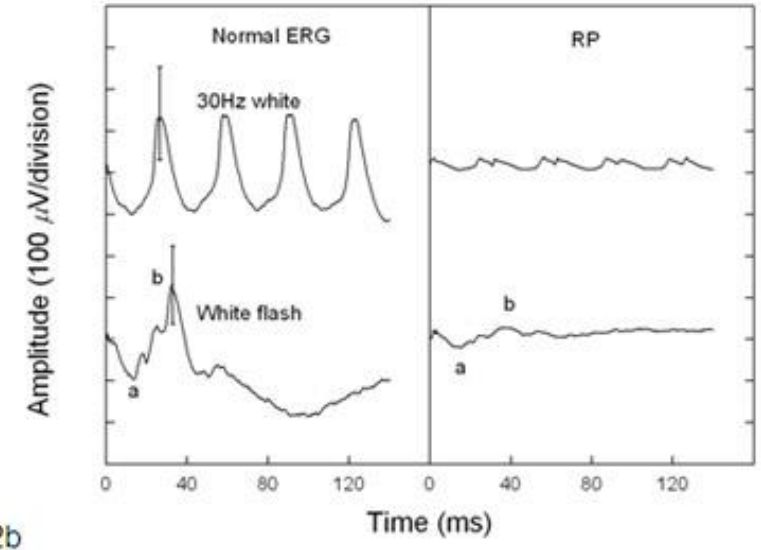


Fig. 3a. A schematic representation of the extracellular currents that are formed following light stimulation. Pathway A represents local currents within the retina, while pathway B shows the currents leaving the retina through the vitreous and the cornea and returning to the retina through the choroid and the pigment epithelium. ERG recording in human is done along the B path.



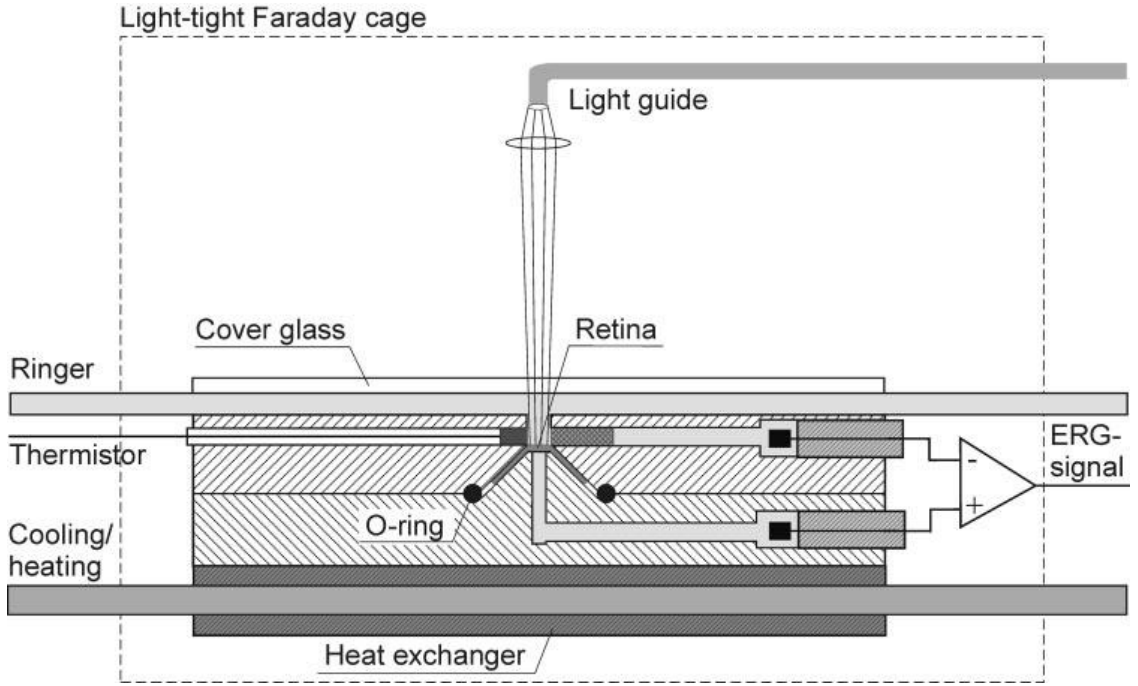
2a



2b

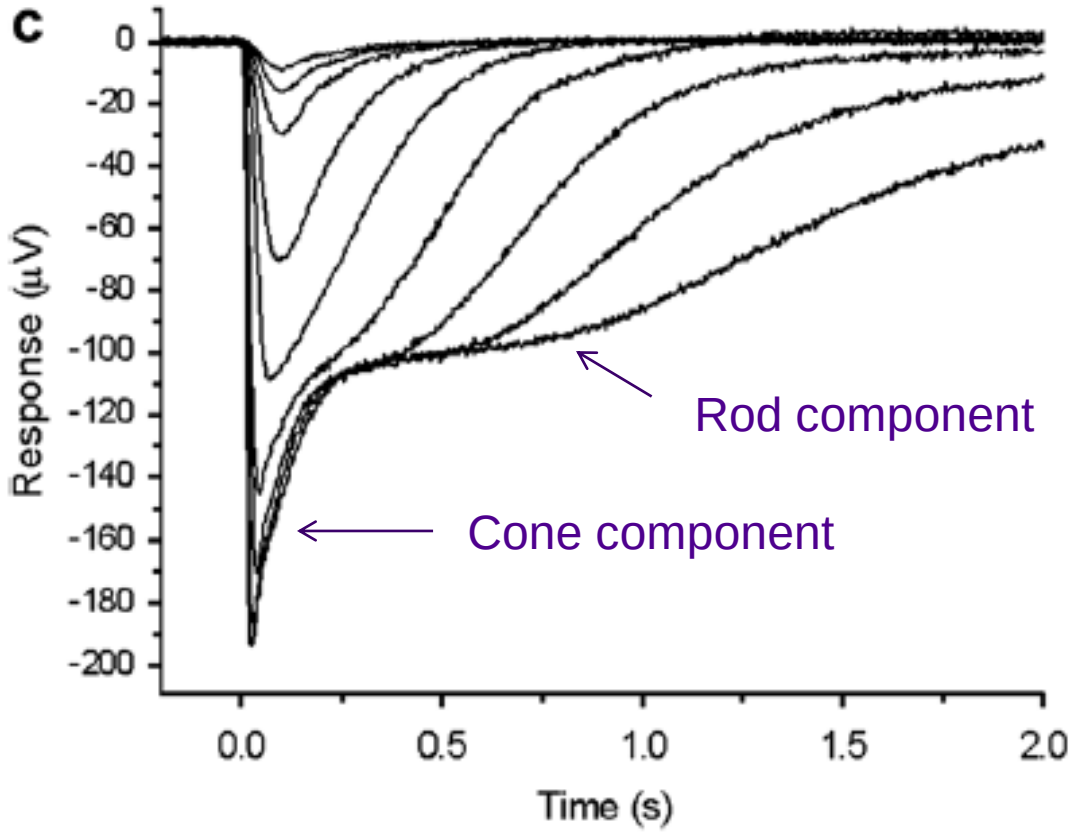
Field potential recordings

- Electroretinogram (ERG) is a field potential
- Field potentials can be recorded by placing electrodes outside the recordable tissue
- Wire electrodes and pellet electrodes common

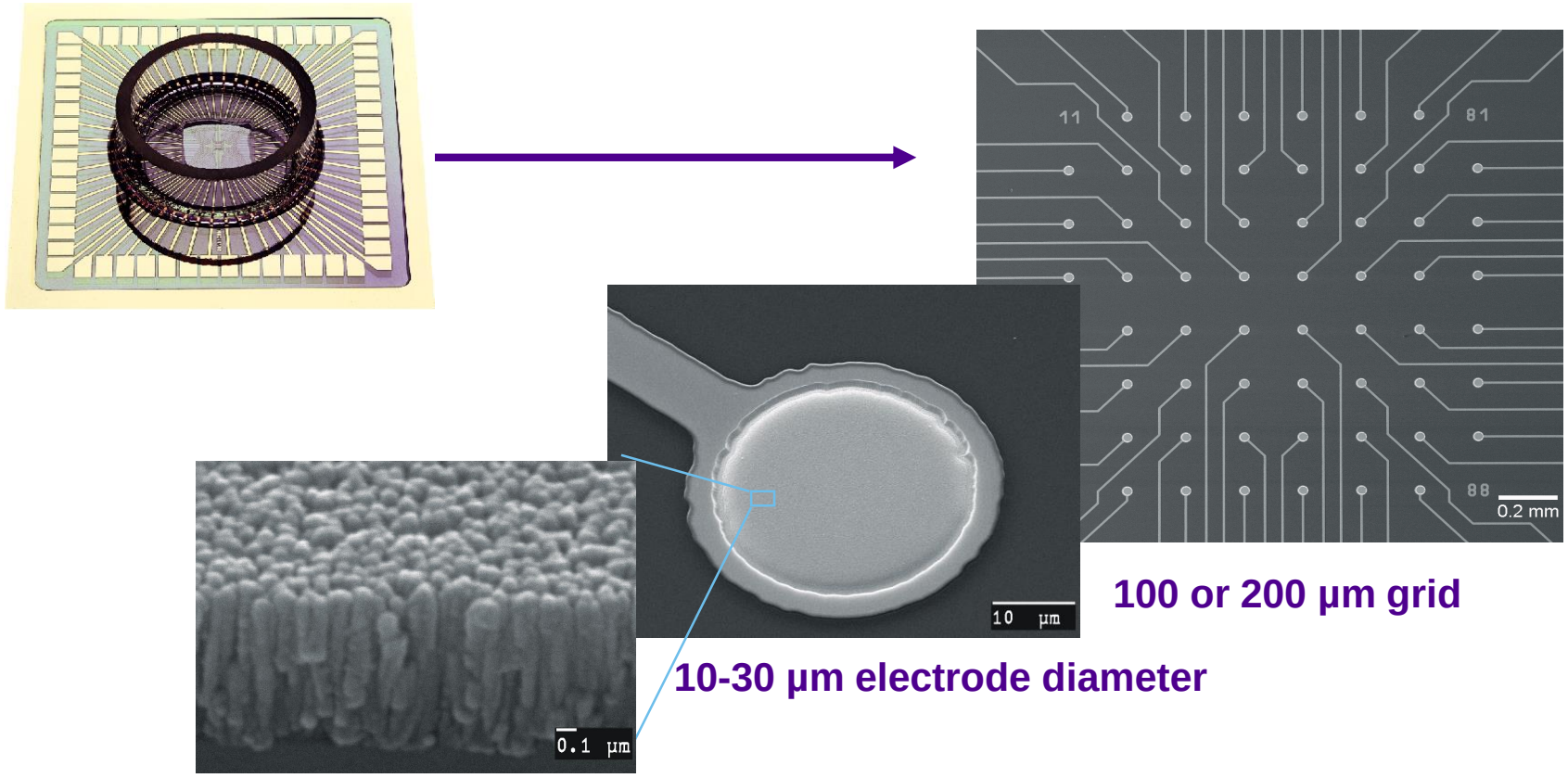


ERG recordings from mouse retina

- Photoreceptor responses, other signal components blocked by pharmacological compounds



Microelectrode array (MEA) technique



100 or 200 µm grid

10-30 µm electrode diameter

impedance: 30-300 kΩ

Egert et al. 1998

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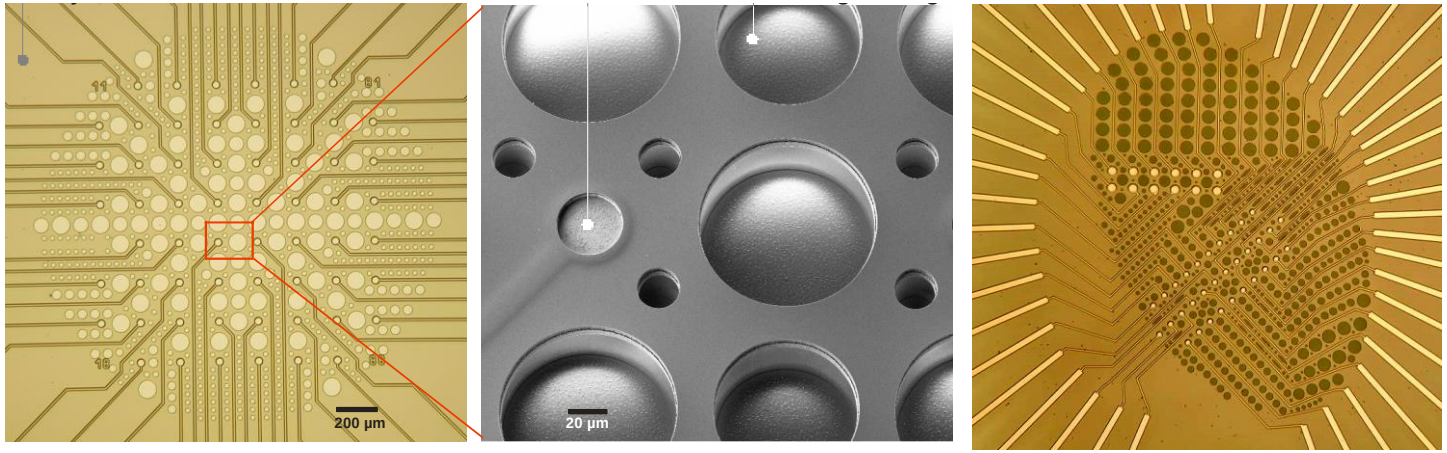
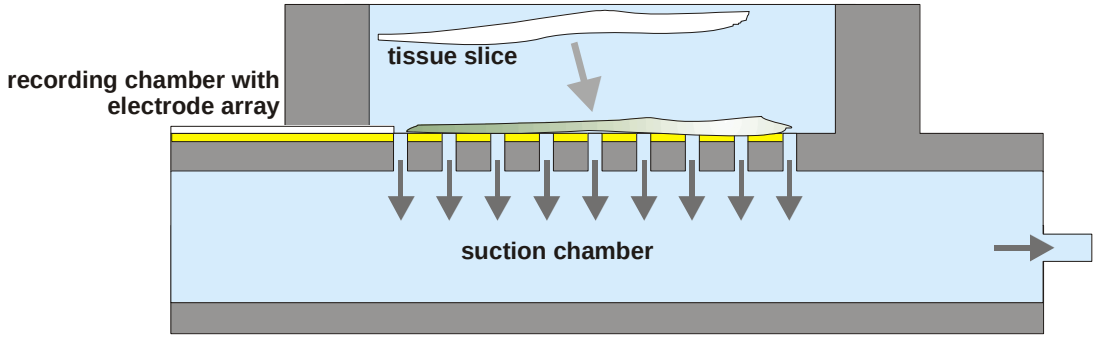
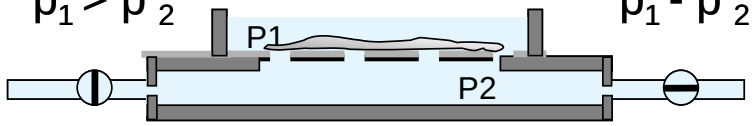
Perforated MEAs



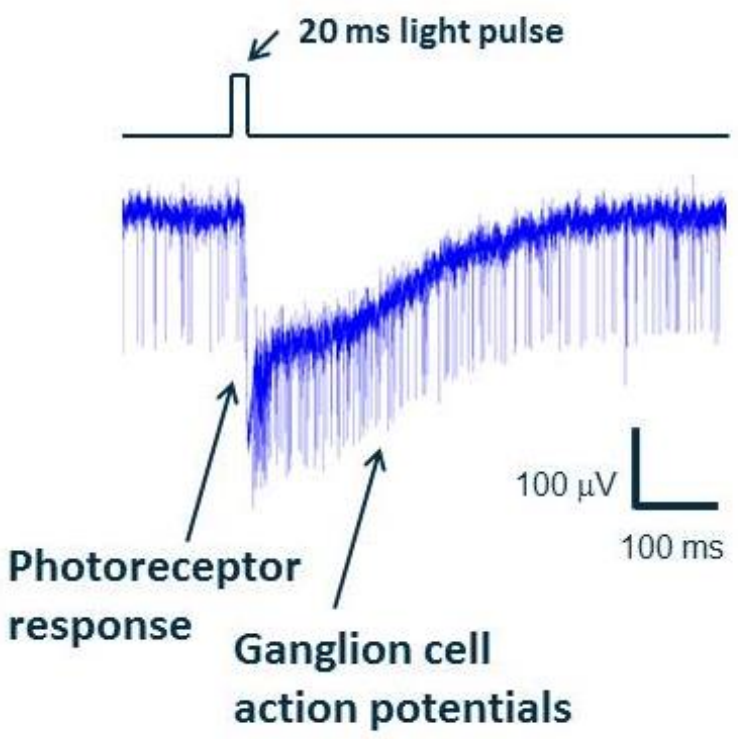


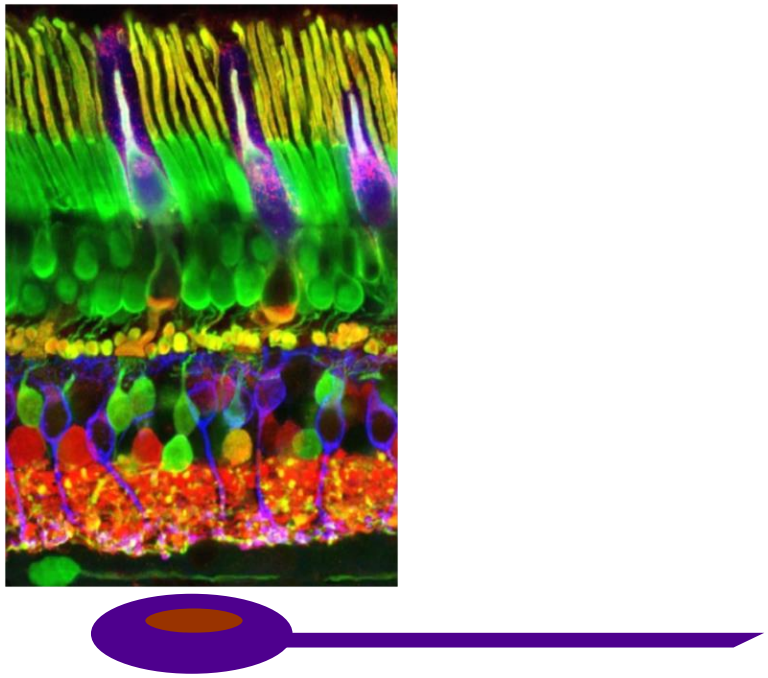
$p_1 > p_2$



$p_1 - p_2 = \Delta p$

Retinal recordings with MEA





Microelectrode array (MEA)

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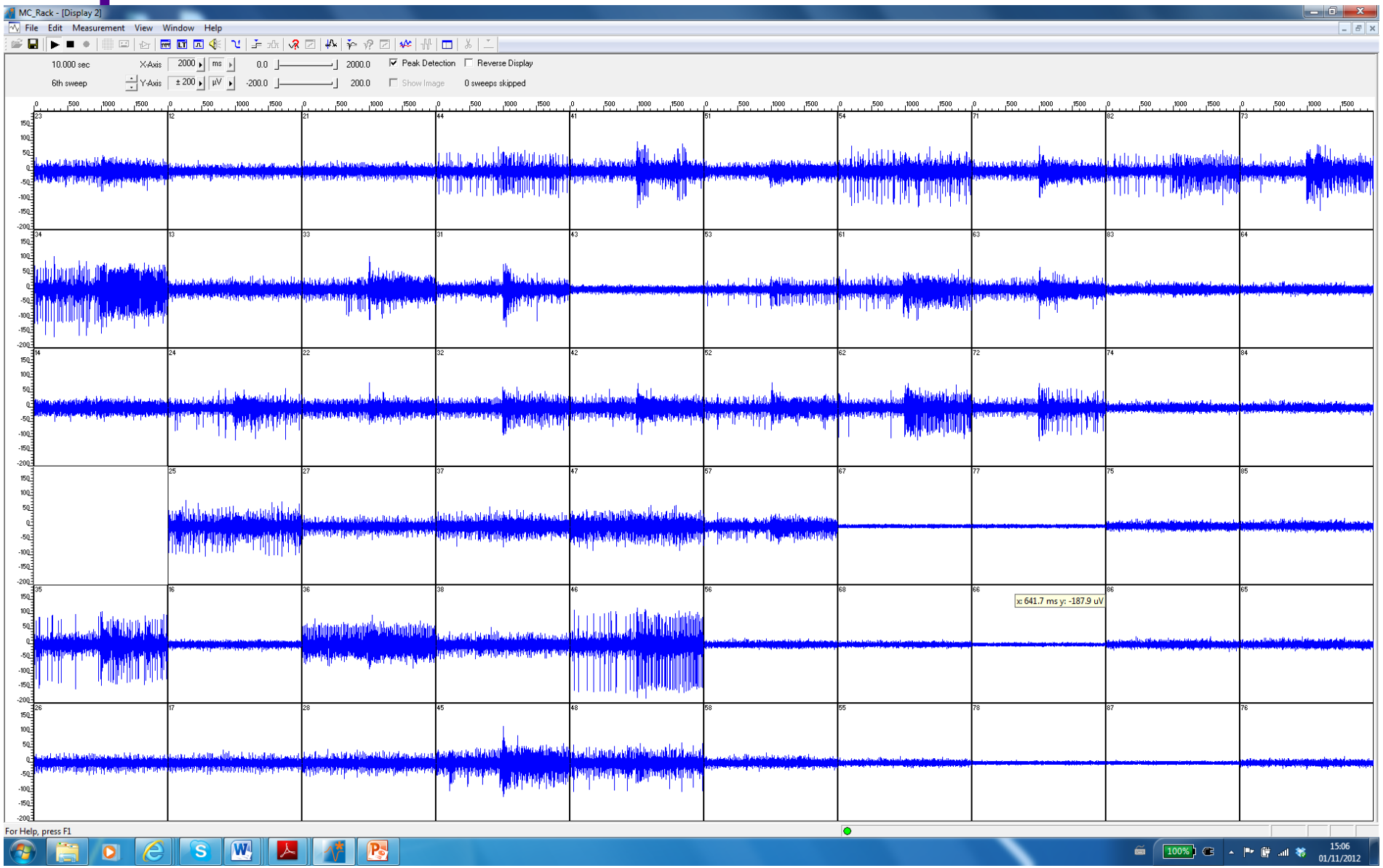
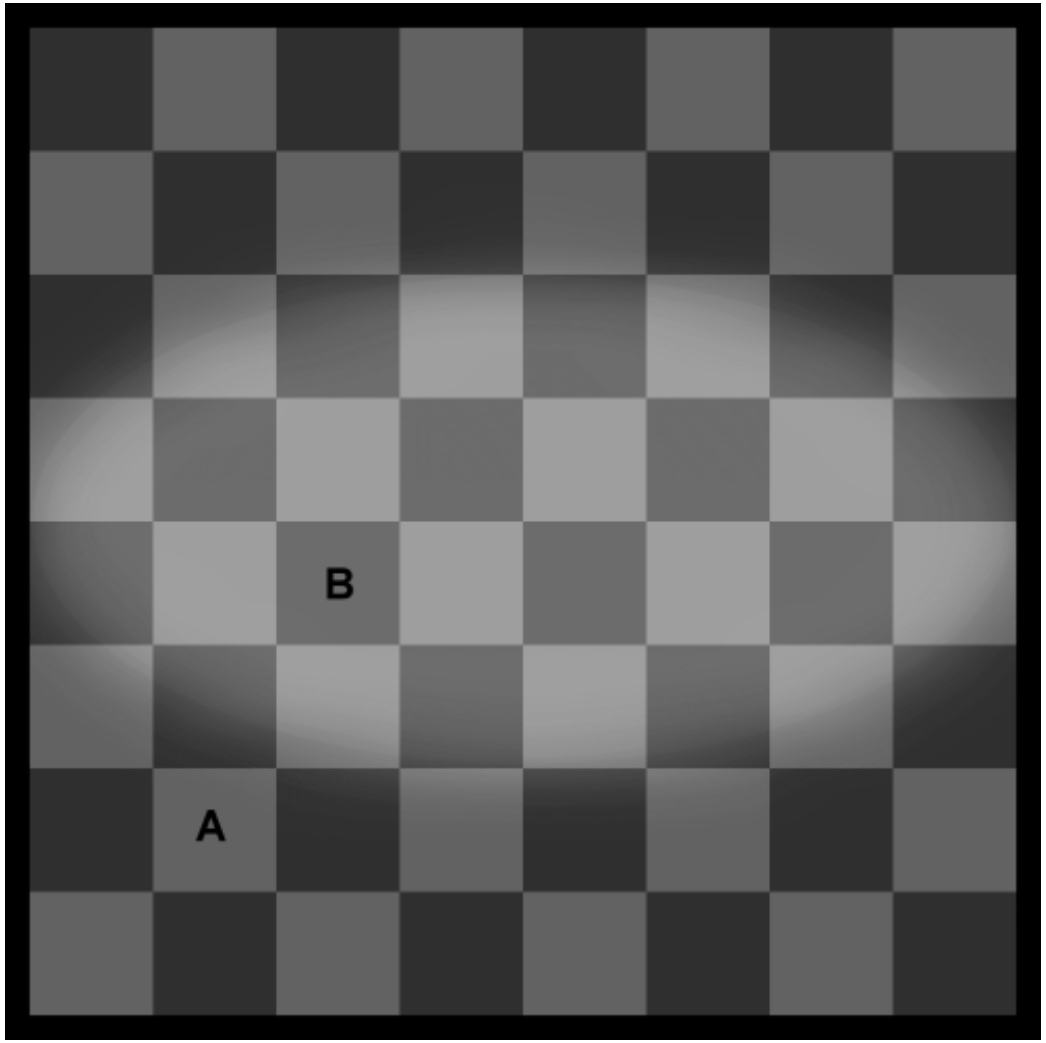
MEA recordings – retinal action potentials

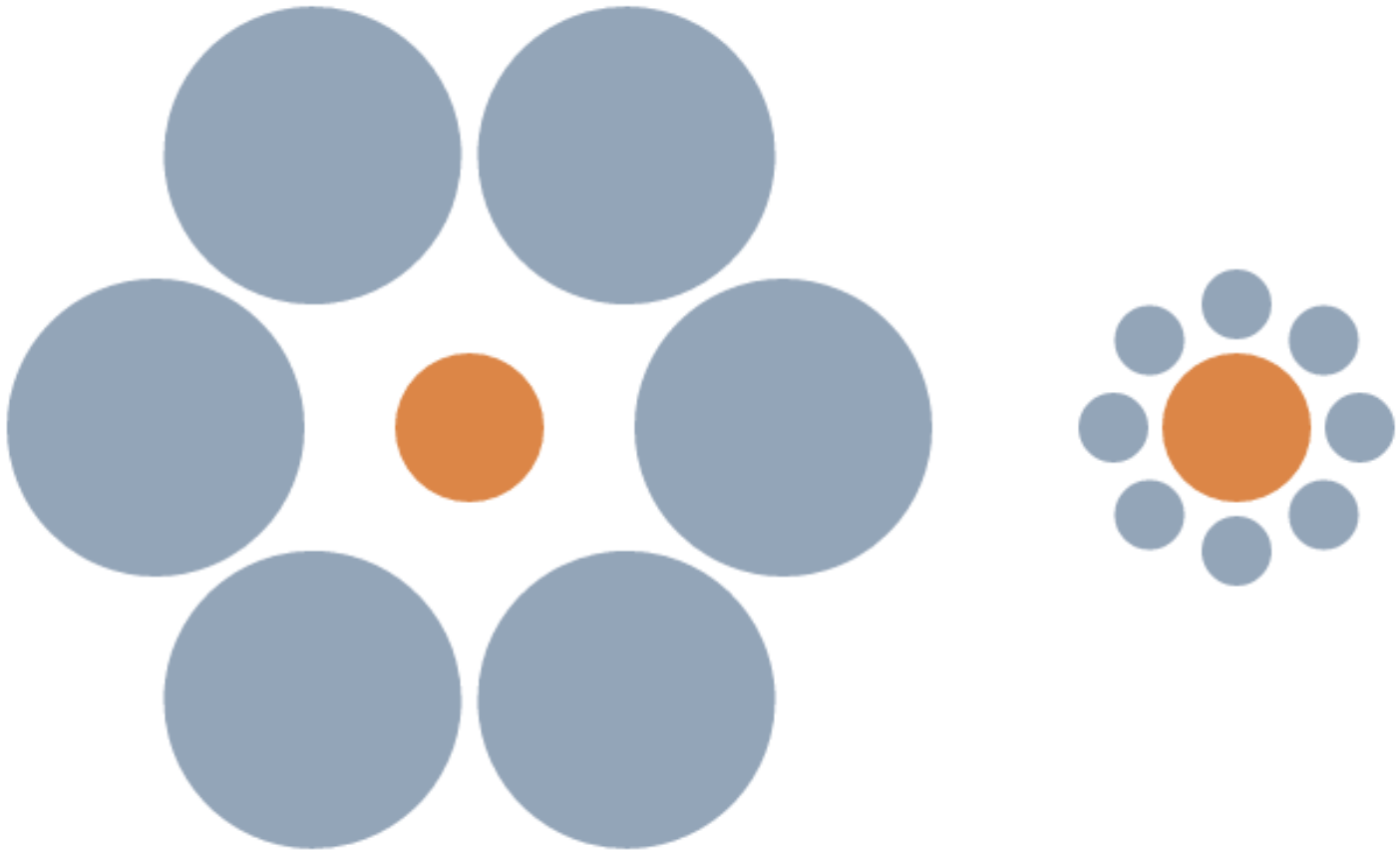
Signal filtered > 200Hz



Amazing visual system

- https://www.youtube.com/watch?amp&v=VT9i99D_9gI


B
A



Which disk is turning faster, A or B?