ERGs

PART 2

Summary

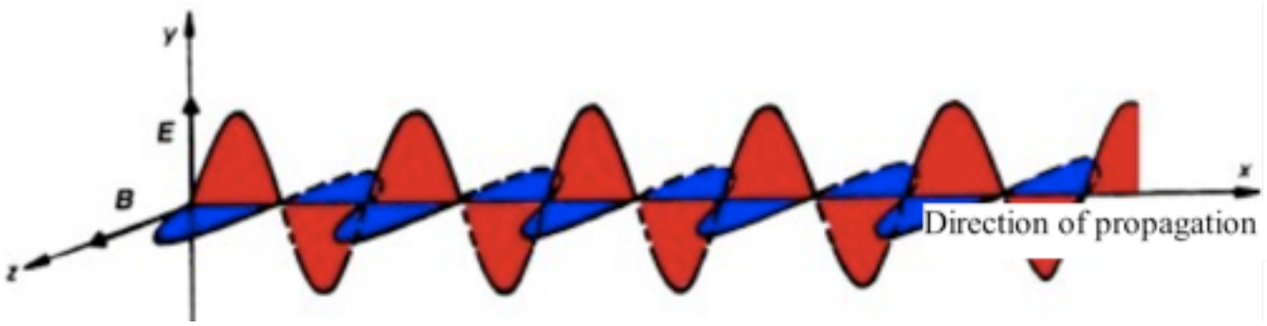
- The electromagnetic wave
  - The light
  - The polarization
  - The photons
- How to generate an electromagnetic wavefront
- Shining light into the eye
- The photo transduction
- The “dark current”
- The electrical basis of ERG recordings

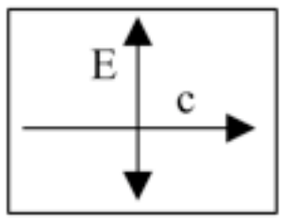
The electromagnetic wave

The light

- The light:
  - Consist of a propagation in space, at the light speed, of an electrical field E and a magnetic field B vibrating in phase.
  - is a high frequency electromagnetic wave (ν from 4.3 to 7.5 ·10^{14} Hz) and
  - has consequently/intrinsically a short wavelength (λ from 700 to 400 nm)
  - has a polarization state (vertical/horizontal/linear/circular/none/...)
  - is composed of photons

- Example of a linear plan polarized wave.
  - The electrical field (E) is always represented vertically and
  - The magnetic field (B) always horizontally.
  - The **polarisation** plan is vertical.
  - The waves travel at the c speed (3 x 10^8 m/s from left to right).





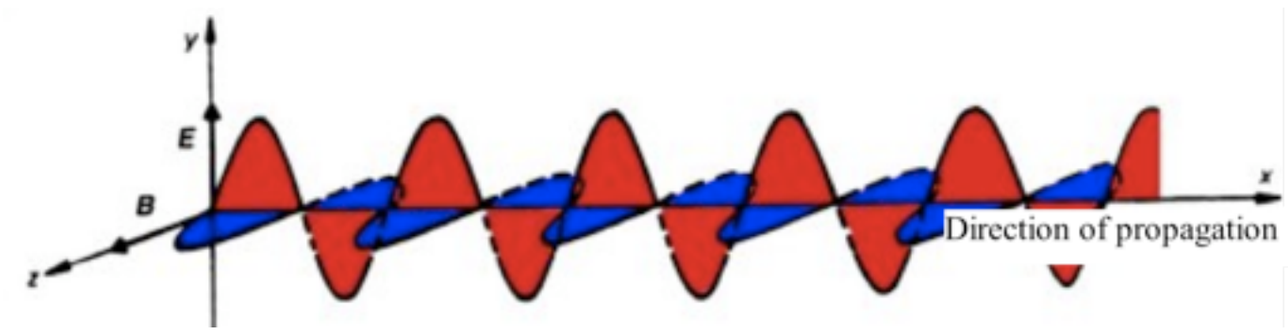
The electromagnetic wave

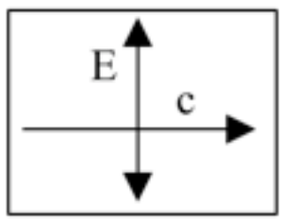
The polarization

- The plan formed by the vector E and the direction of propagation (vector c) is called plan of polarization.

- The direction of the vector E is taken by agreement as direction of polarization of the wave.

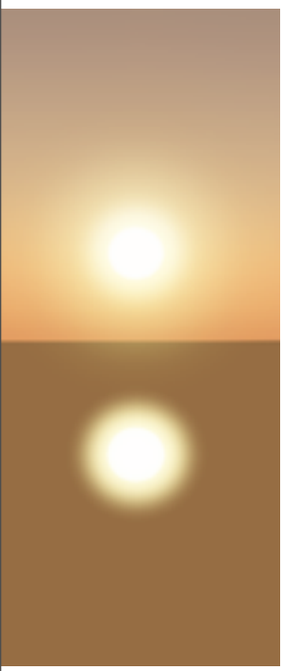
- It is generally said that the emitted light by light bulb or by led, is not polarized. However, for a duration of ultrashort observation, any light is intrinsically polarized.





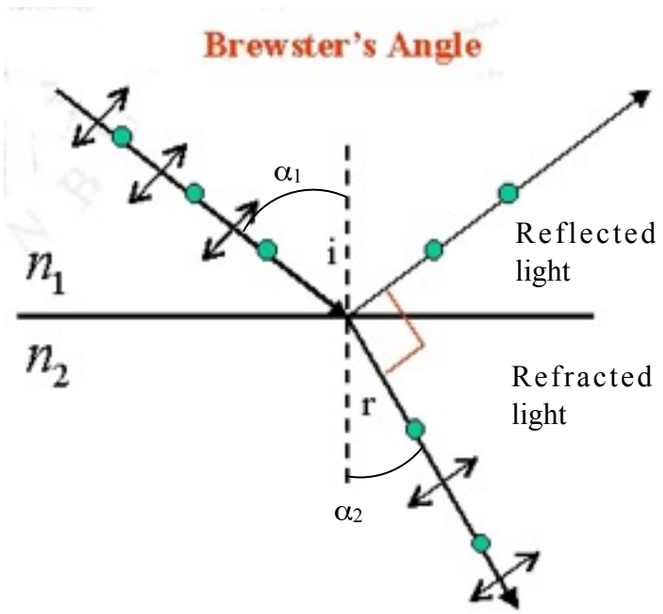
The electromagnetic wave

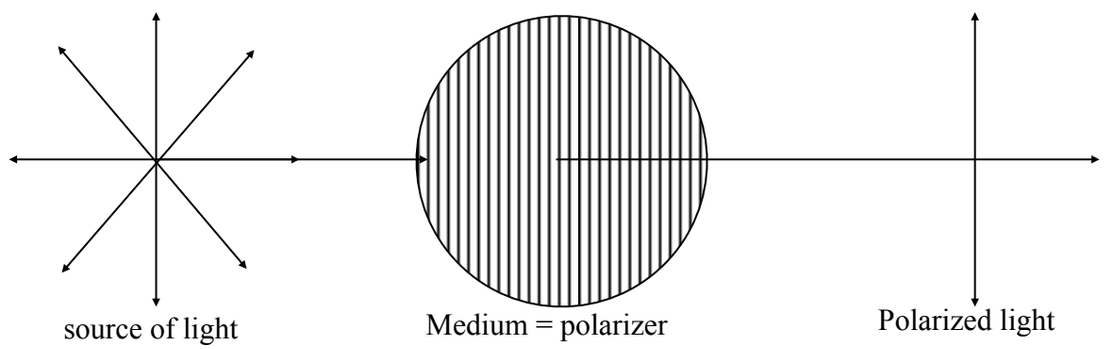
The polarization



http://photos1.blogger.com/x/blogger2/3378/182793521743 30/1600/963301/badsun.png

- Illustration of the polarization effect with a natural light (sun light) coming through a window and reflecting on a table:
  - If we look at the table we can see a brilliant white spot.
  - If we look through a polarizer (quarter wave plate), we can see in the **P** polarization (DE: **P**arallele / EN: Parallel) the same brilliant white spot.
  - On the contrary, in the **S** polarization (DE: **S**enkrechte / EN: Perpendicular) the white spot disappears.

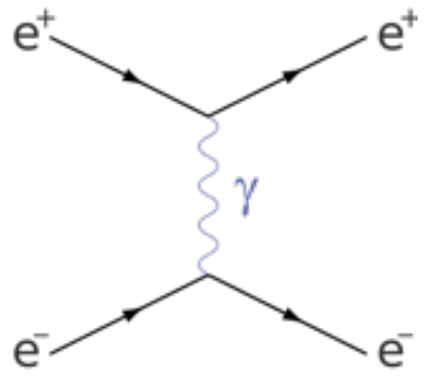




The electromagnetic wave

The photon

- In physics, the photon is an elementary particle, the quantum of the electromagnetic field and the basic unit of light and all other forms of electromagnetic radiation.

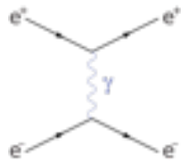


http://en.wikipedia.org/wiki/File:Electron-positron-scattering.svg

exchange of a virtual photon (symbolized by an oscillating line labelled γ (gamma) between a positron and an electron.

The electromagnetic wave

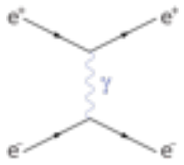
The photon

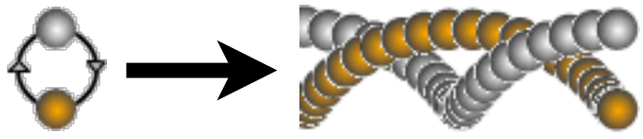


The electromagnetic wave

The photon

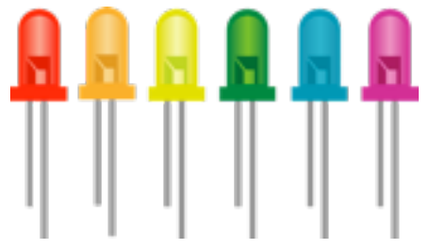
- The photon is:
  - massless
  - has no electric charge
  - does not decay spontaneously in empty space (without absorption).
- A photon has two possible polarization states:
  - horizontal
  - vertical
- A photon is described by exactly three continuous parameters:
  - the components of its wave vector,
  - which determine its wavelength λ
  - and its direction of propagation.





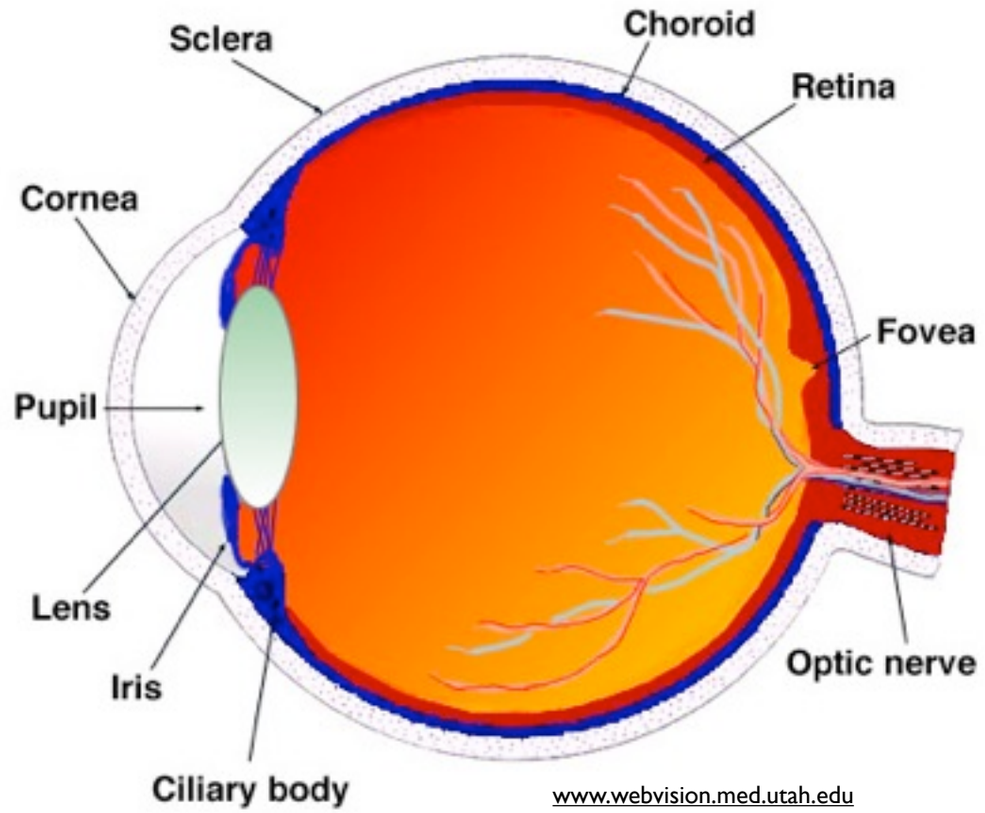
http://lighttheory.com/light/experiments.htm

How to generate an electromagnetic wavefront

- We generally use as a light source, either:
  - bubble lamp (white)  (+ filters)
  - LEDs (Light Emitting Diode) 
- and the driver is respectively, either:
  - an electrical/electronic dimmer
  - a PWM (Pulse Width Mode) generator

Shining light into the eye

- The area illuminated at the retina depends on the shape of the incoming light (angle) and of the pupil size (aperture/ diaphragme)



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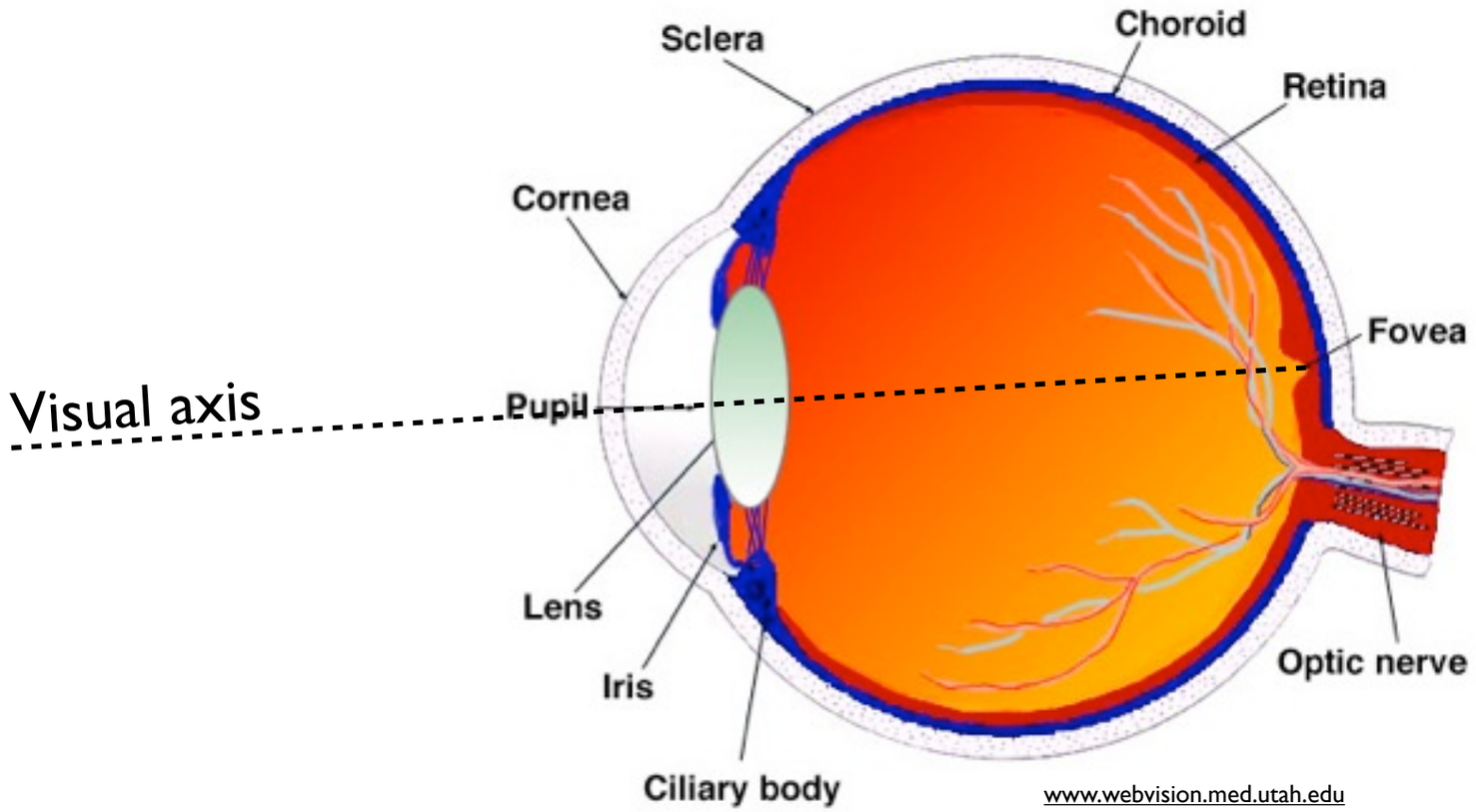

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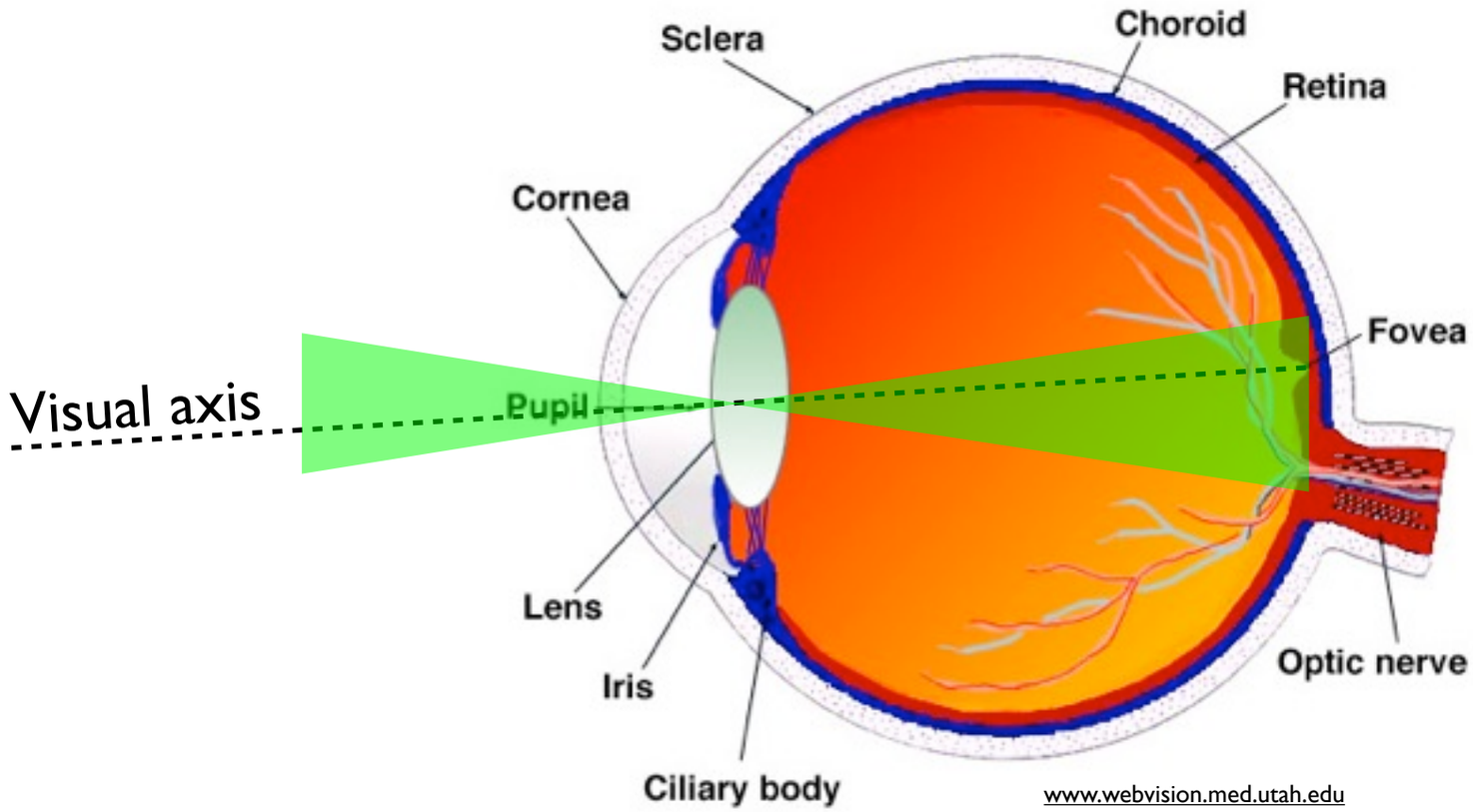

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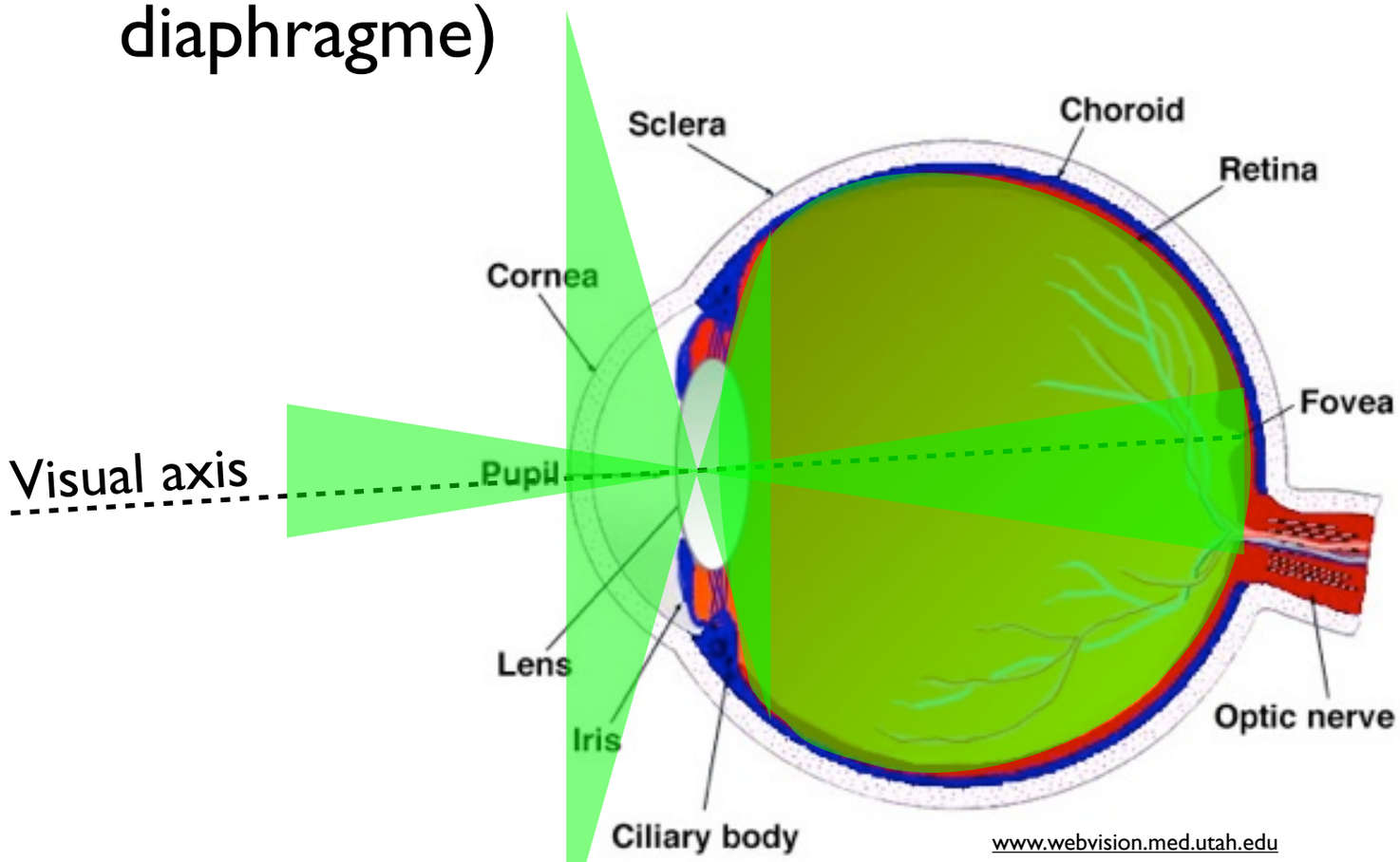


- To do a full field illumination of the eye fundus, the emitting source **must** enter with an open angle (large stimulation area and dilated pupil).

Shining light into the eye

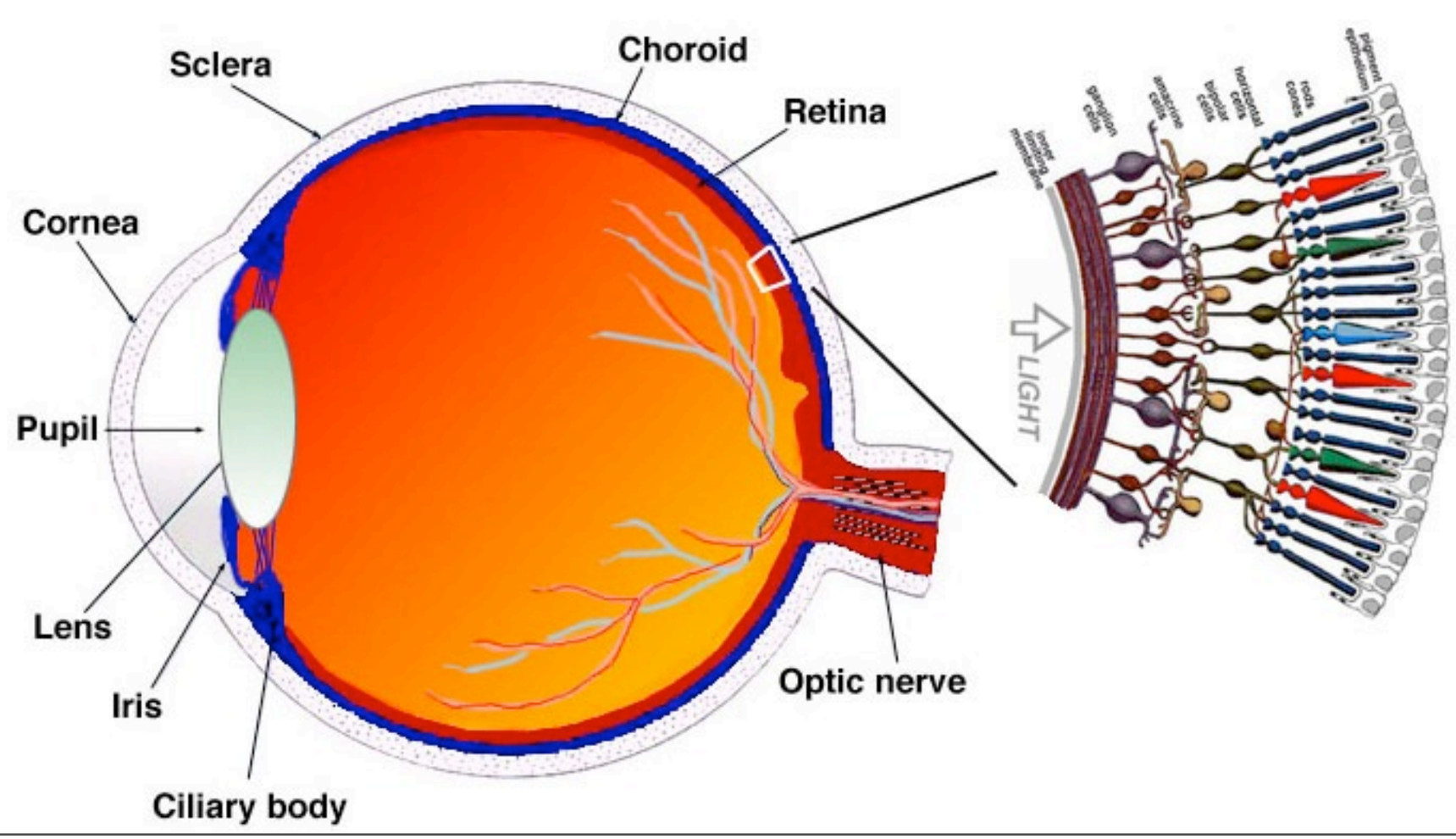
- To achieve this, we can use for example:
  - googles (LEDs)

  - a ganzfeld

The photo transduction

The light (photons) is entering the eye and reaches the photoreceptors located in the outer part of retina.

a photon



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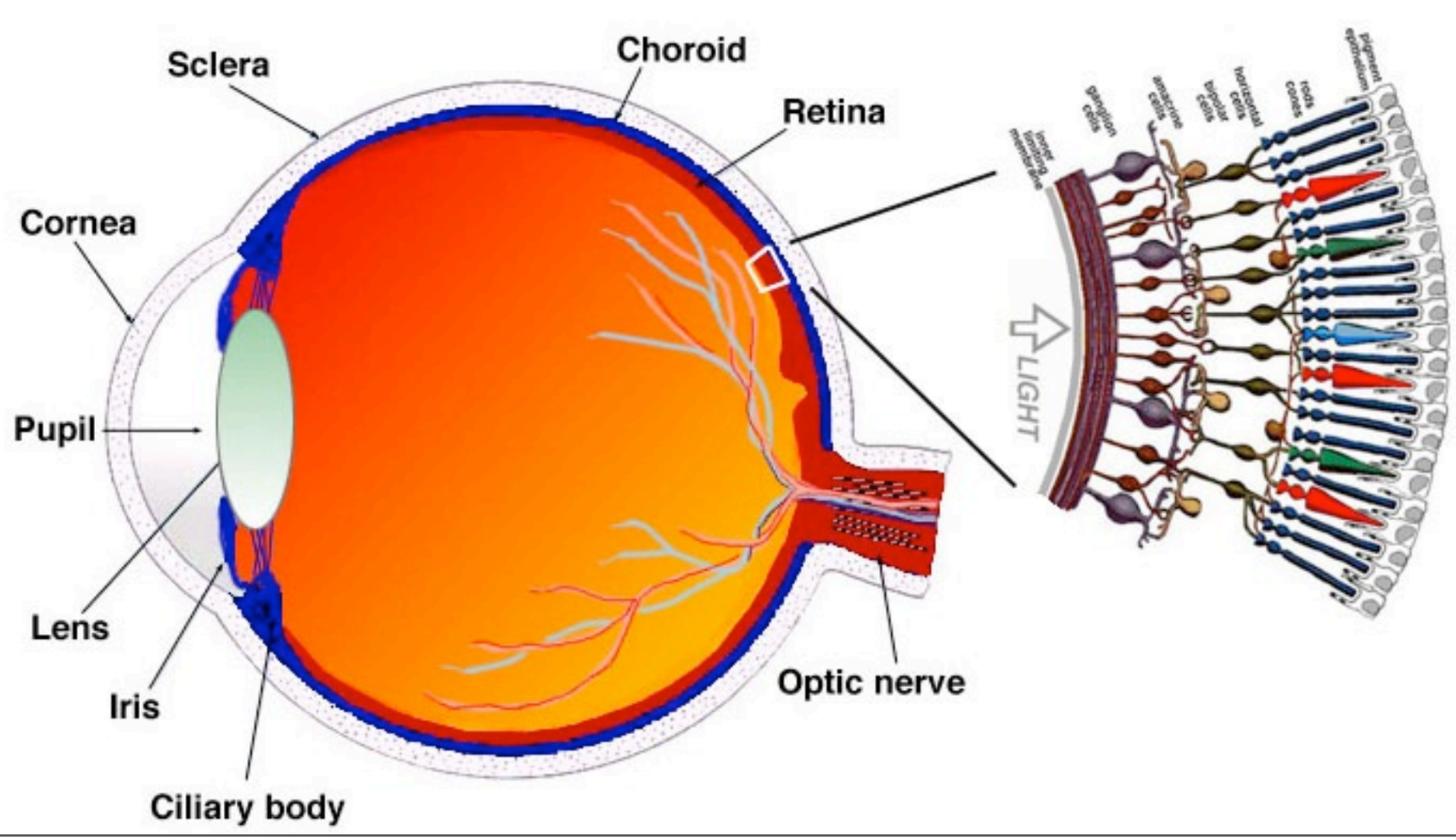

The photo transduction

① Light stimulation of rhodopsin in the receptor disks leads to the activation of a G-protein (transducin).

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The photo transduction

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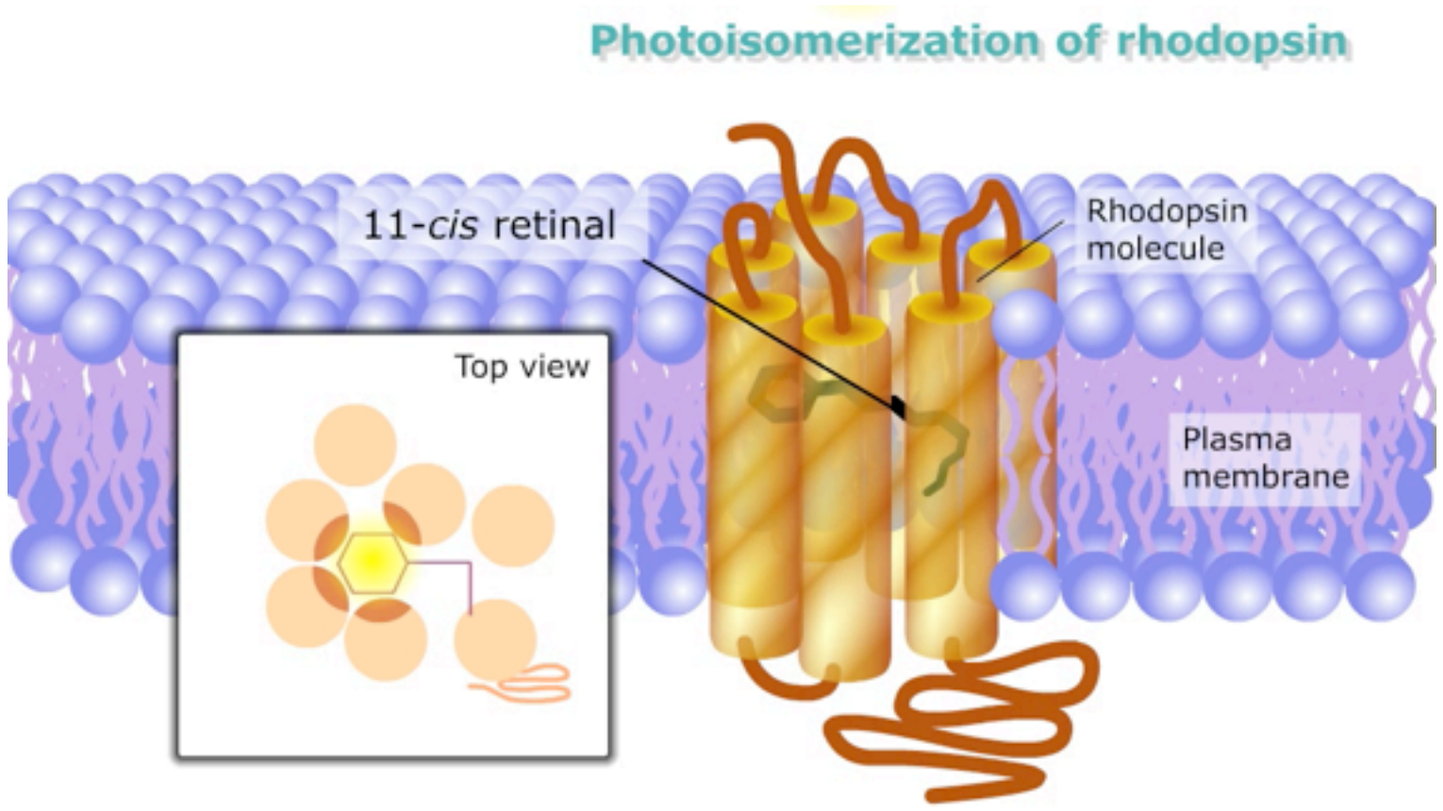

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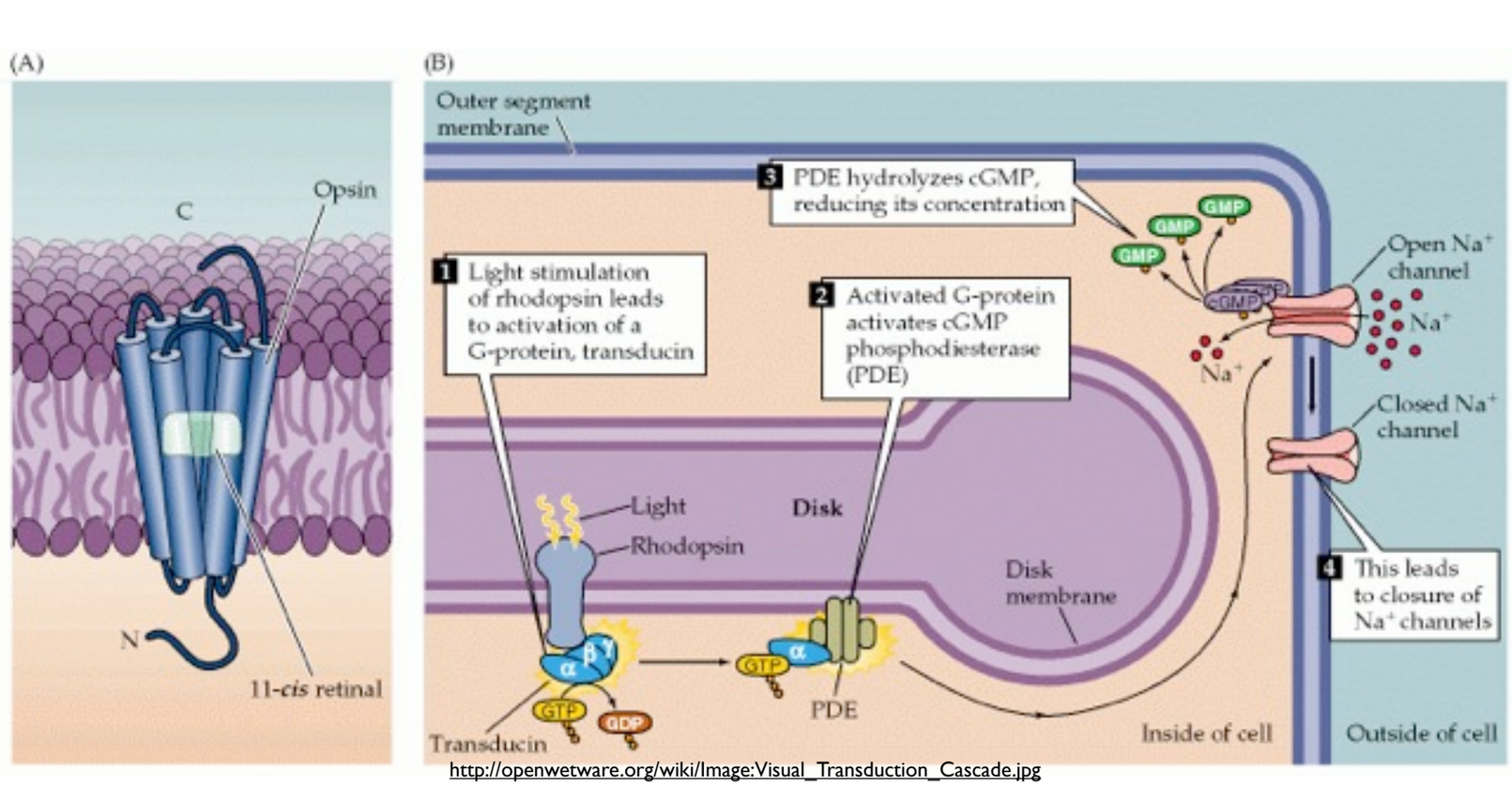
BACK

The photo transduction

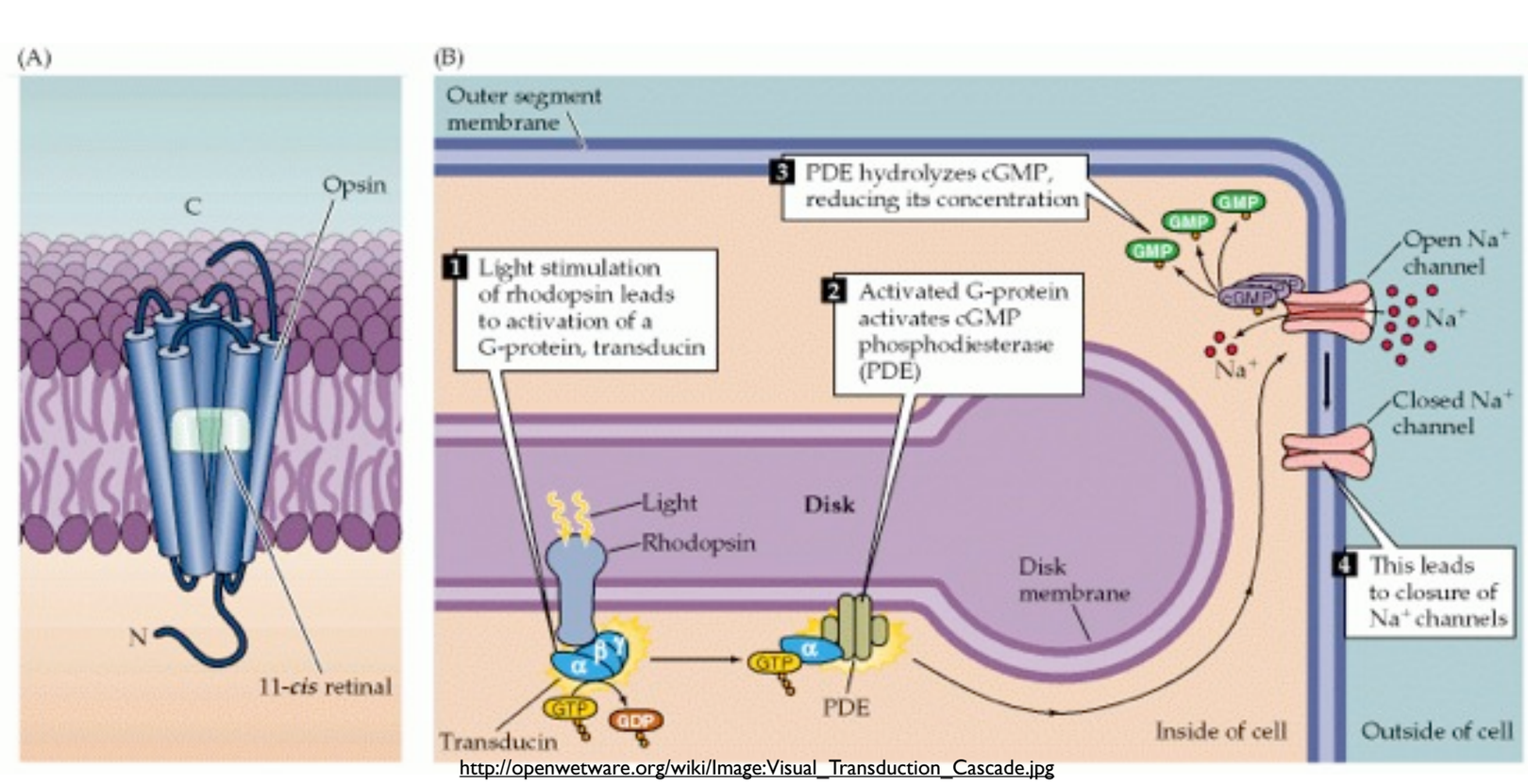
① Light stimulation of rhodopsin in the receptor disks leads to the activation of a G-protein (transducin).



http://openwetware.org/wiki/Image:Visual_Transduction_Cascade.jpg

The photo transduction

② The GTP-bound alpha subunit of transducin activates a phosphodiesterase (PDE).



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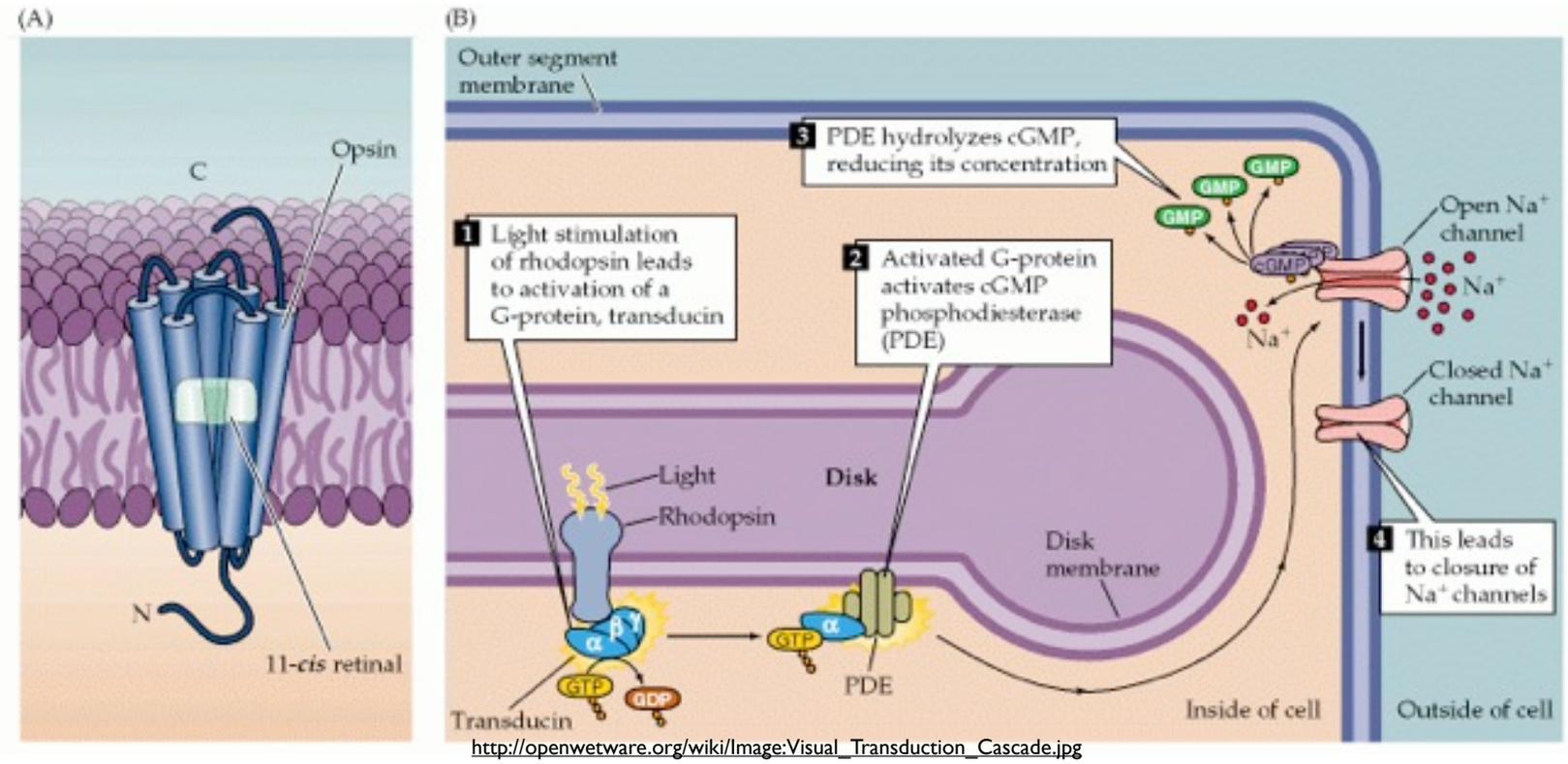
The photo transduction



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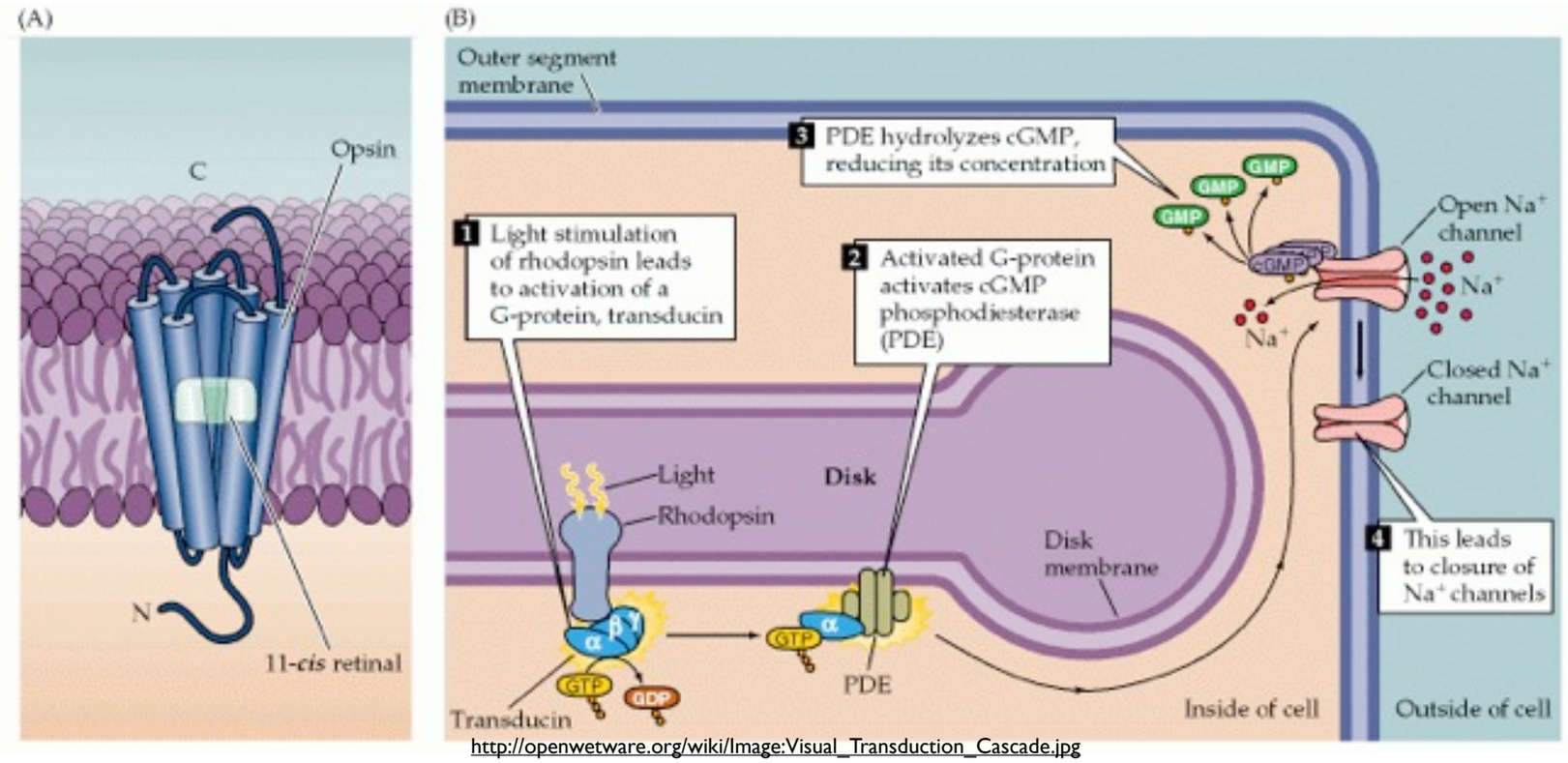
The photo transduction

③ The activated phosphodiesterase hydrolyzes cGMP into GMP, reducing its concentration in the outer segment and leading ④ to the closure of cGMP-gated ion channels in plasma membrane.



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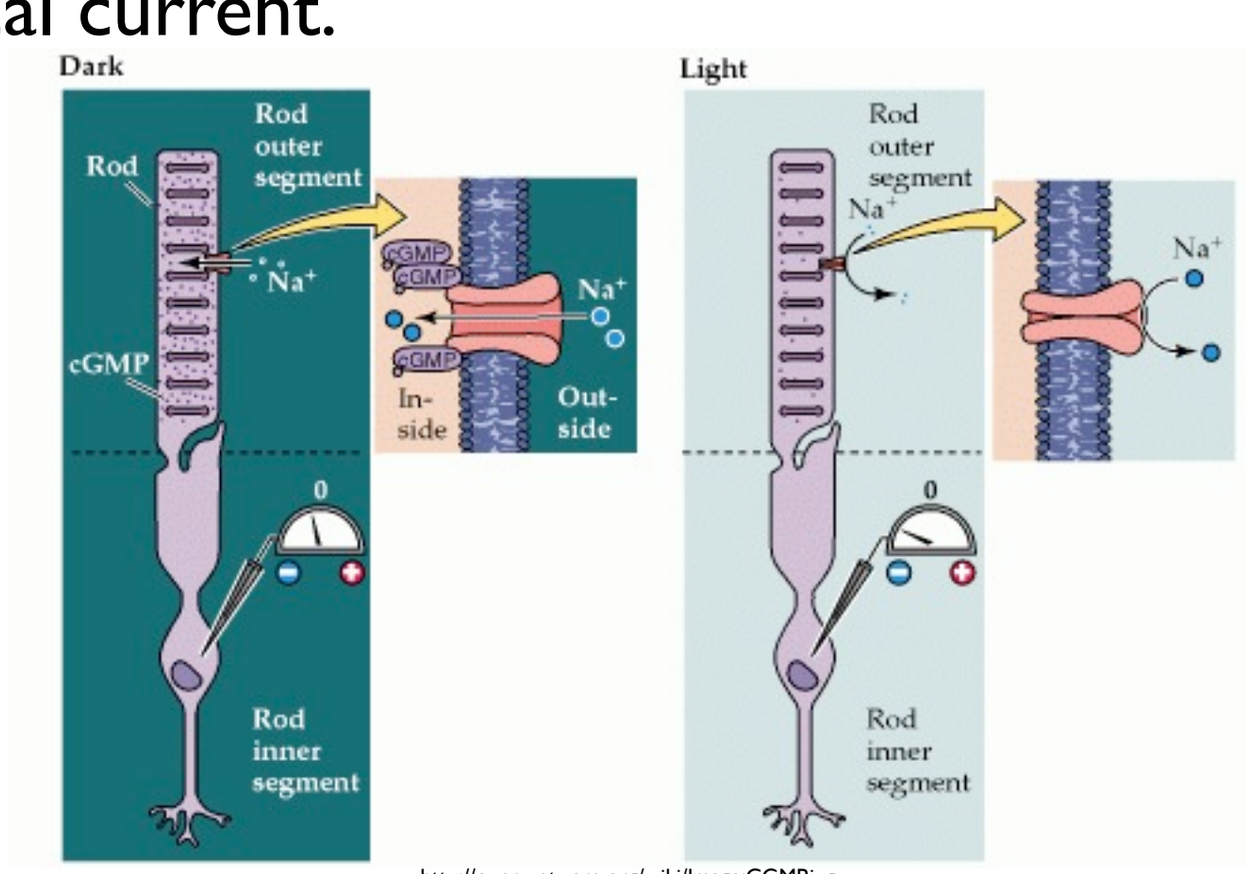
The photo transduction

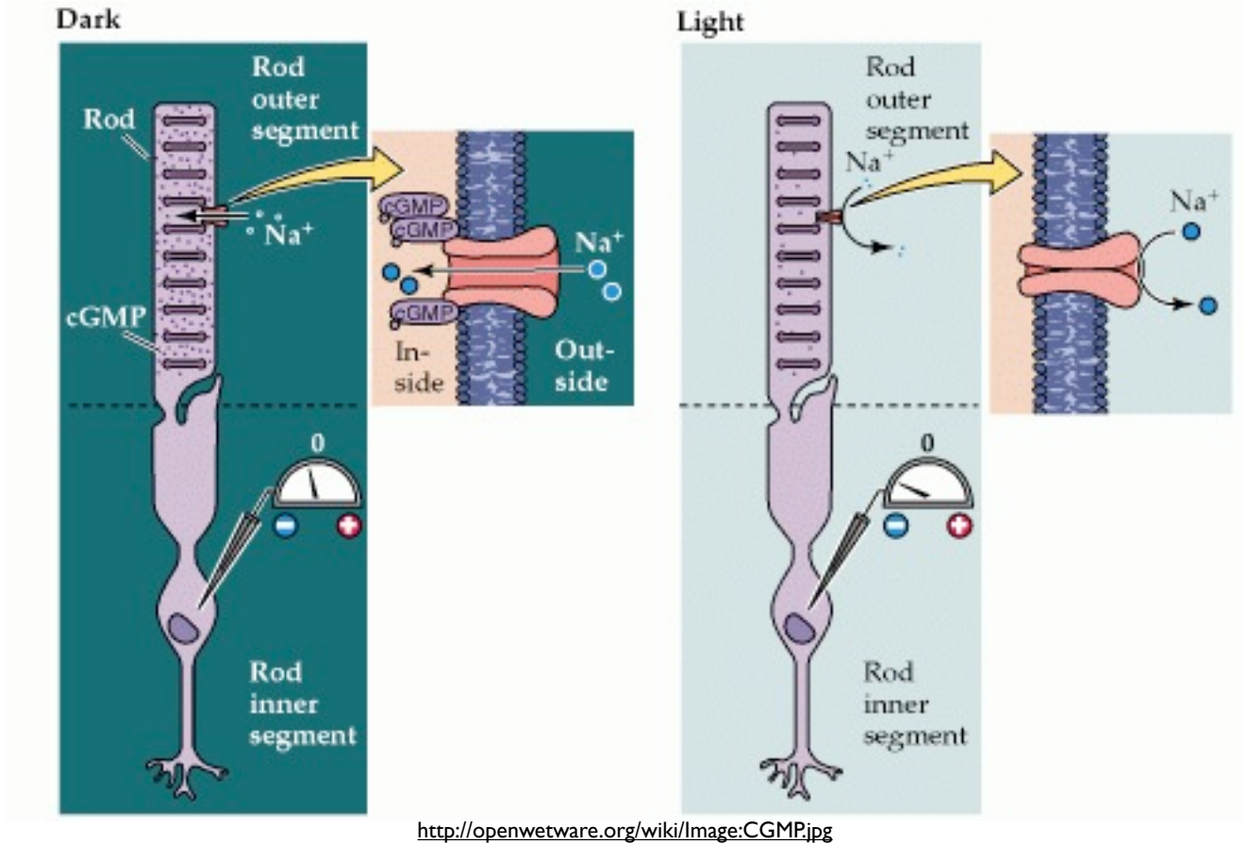
- So, in summary, the reduction in the cytoplasmic concentration of cGMP leads to closure of the cyclic nucleotide gated channels and blockage of the inward flux of Na^+, Ca^{2+} and Mg^{2+} thereby reducing the circulating electrical current.



http://openwetware.org/wiki/Image:CGMP.jpg

The photo transduction

- Closure of these channels has the dual effect of generating the photoreceptor's electrical response (by reducing the circulating current and hyperpolarizing the membrane voltage), and of causing a reduction in cytoplasmic calcium concentration.



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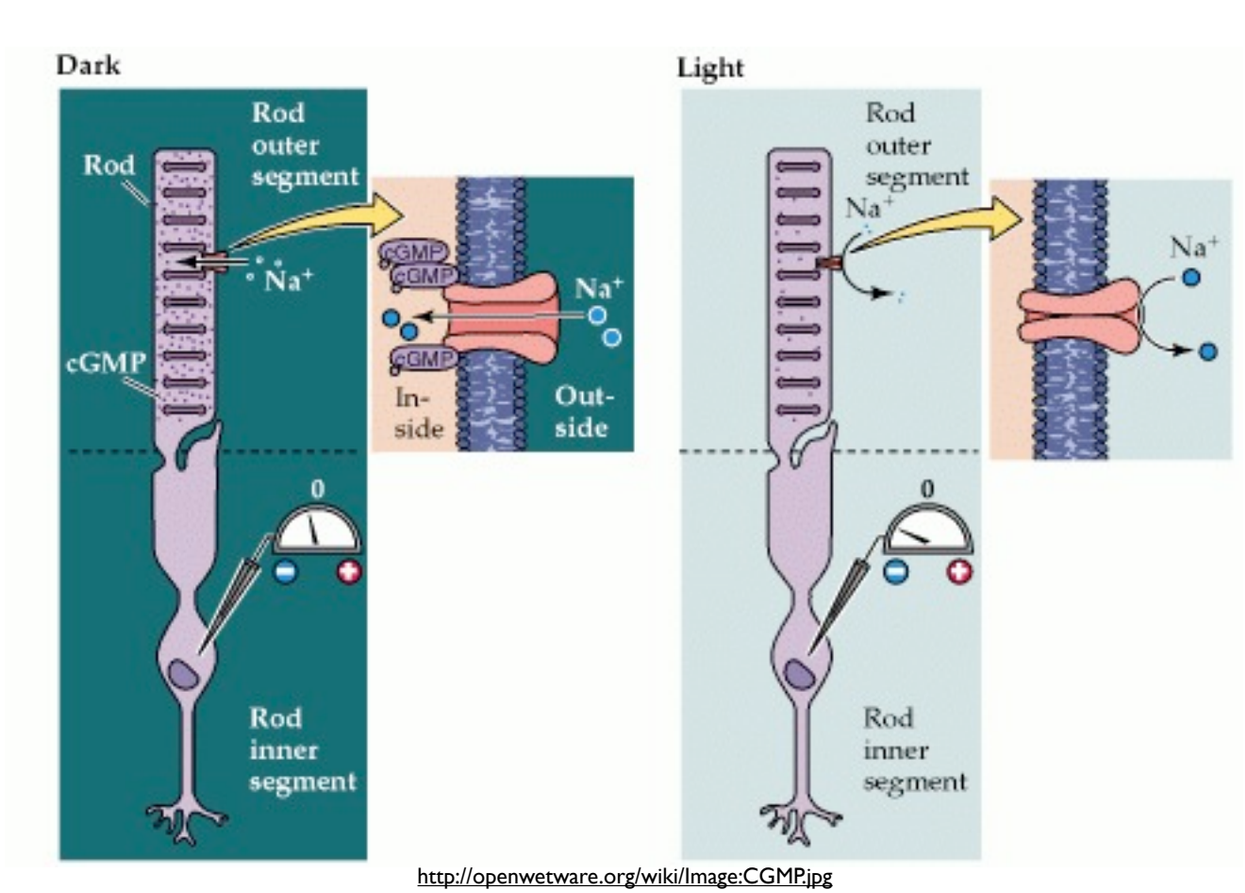
The photo transduction

generating the photoreceptor's electrical response



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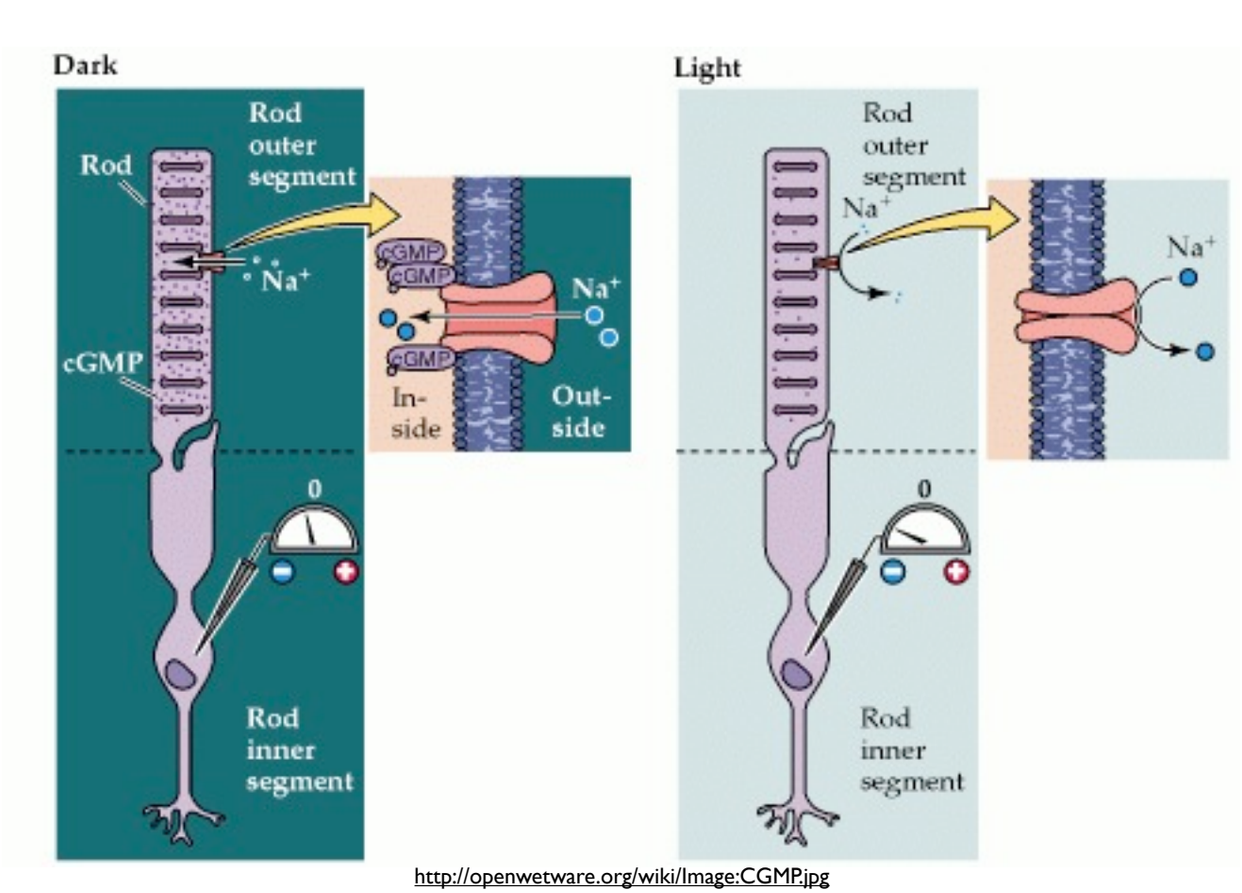
The photo transduction

generating the photoreceptor's electrical response

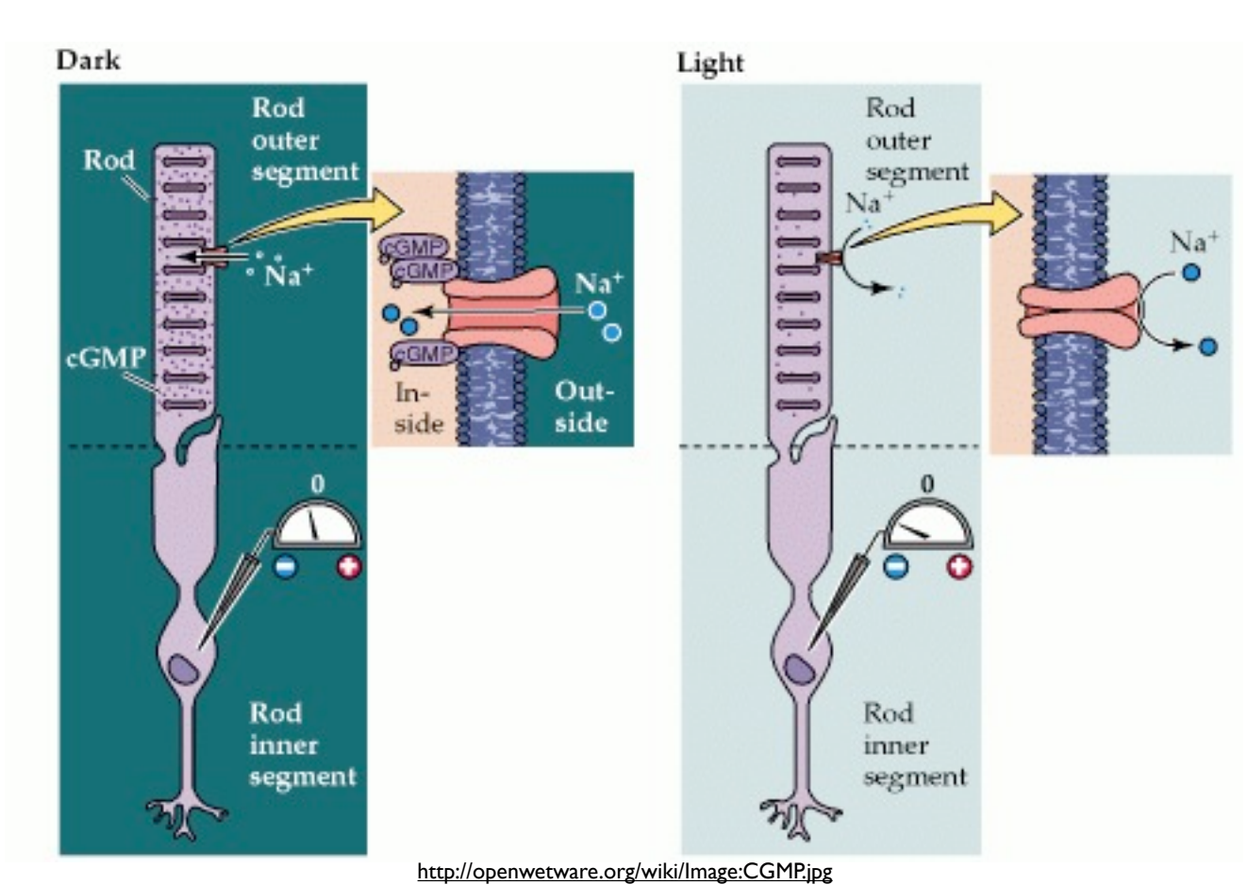
The ERG signal is born!



http://openwetware.org/wiki/Image:CGMP.jpg

The “dark current”

- In the absence of light, a "dark current" is present and is , as said before, composed mainly of the influx of the Na^+ component (80%). However, a Ca^{2+} component (15%) and a Mg^{2+} component (5%) are also present (Yau, 1994)

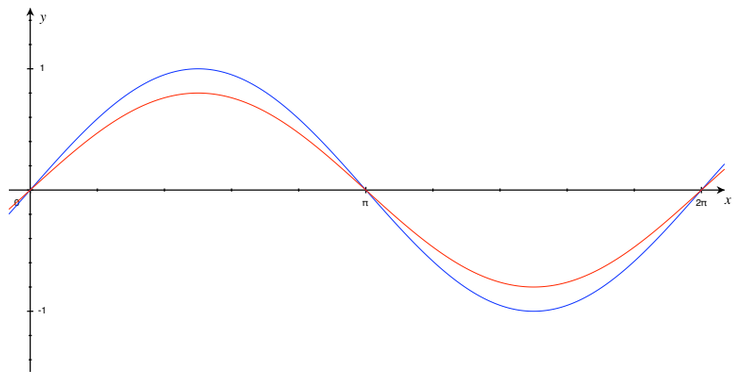


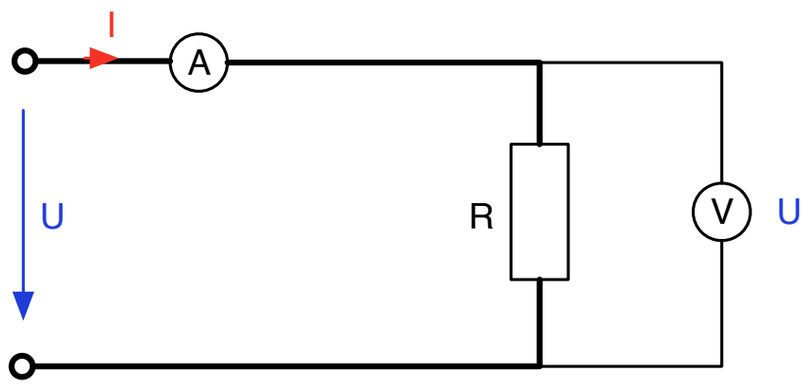
http://openwetware.org/wiki/Image:CGMP.jpg

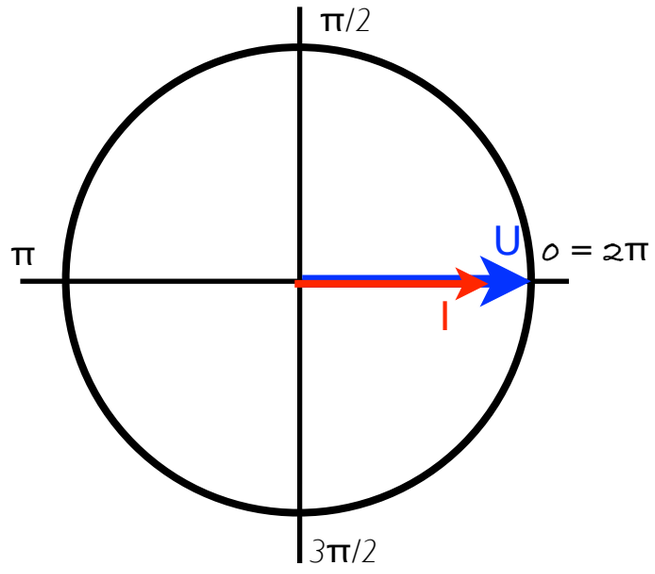
The electrical basis

of ERG recordings

- Either the resting current (when photoreceptors are depolarized) or the reduced current (when light hyperpolarizes the plasma membrane of the photoreceptor) are not directly measured with an ammeter but rather will be derived from the relationships between the current and the voltage given by the Ohm's law: $U = R * I$

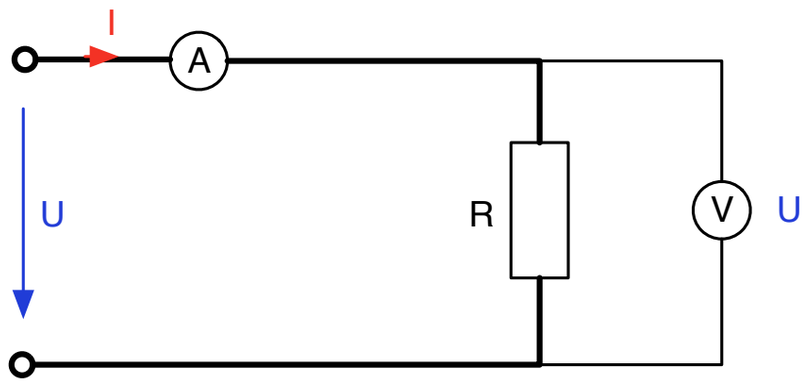






The electrical basis

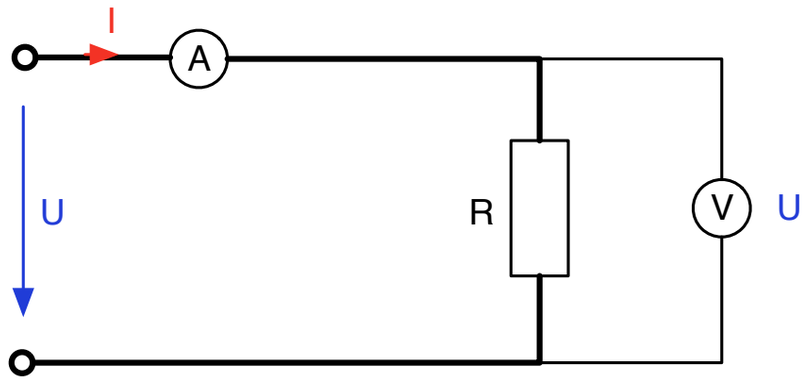
of ERG recordings



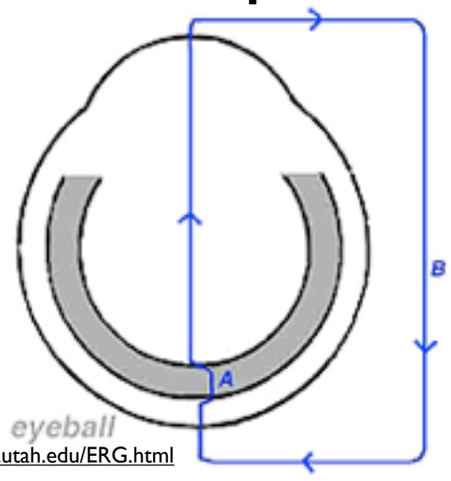
The electrical basis

of ERG recordings

- When an electrical current flows through a resistor, a potential difference at the terminals of the resistance occurs.



- If we thought to the photoreceptor has a source of an electrical current and the retina, respectively the eyeball as a resistor, a potential difference can be measured.



http://webvision.med.utah.edu/ERG.html

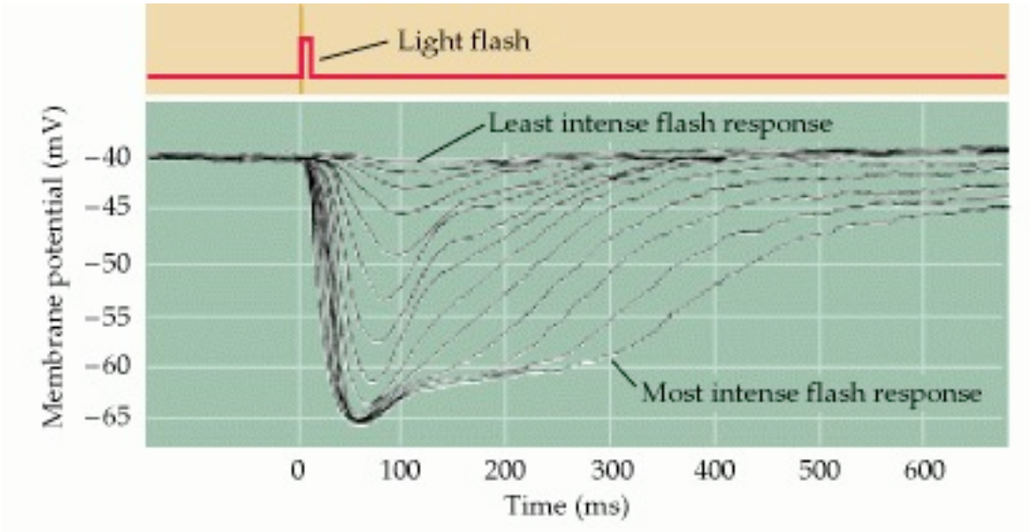
The current in pathway A, flows through a local route remaining entirely within the retina, while the current flowing through pathway B leaves the retina through the vitreous and anterior ocular tissue and returns to the retina through the sclera, the choroid and the pigment epithelium layer.

The light-induced current flowing through pathway B can be recorded in a noninvasive manner, with extra-ocular electrodes.

The electrical basis

of ERG recordings

- If the retina was constituted only of photoreceptors, the ERG signal would be a simple decrease of the resting current.



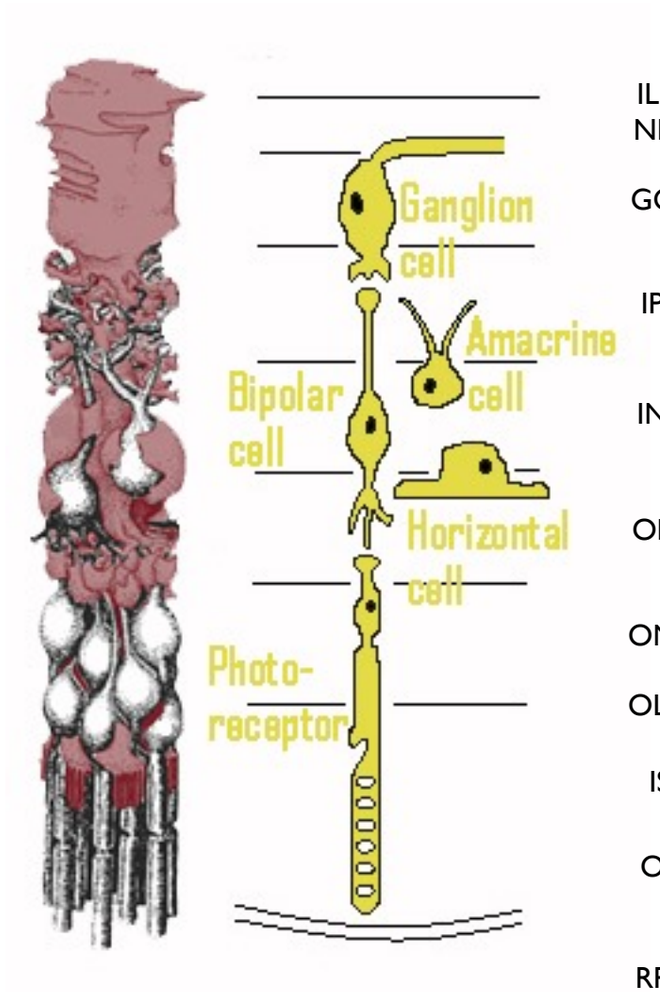
http://openwetware.org/wiki/Image:Photoreceptors_hyperpolarize.jpg

An intracellular recording from a single cone stimulated with different amounts of light. Each trace represents the response to a brief flash that was varied in intensity. At the highest light levels, the response amplitude saturates. (Neuroscience, Purves et al., 2001)

The electrical basis

of ERG recordings

- But in reality, the retina is much more complexe and this leads to an also more complexe ERG signal.



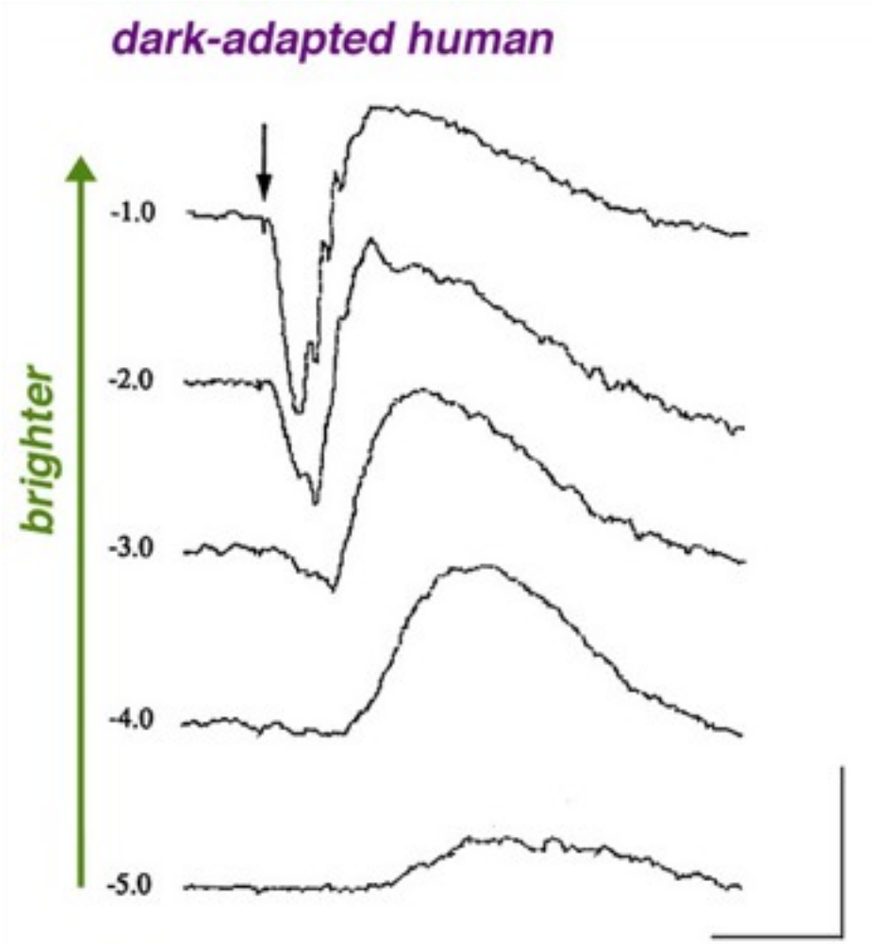
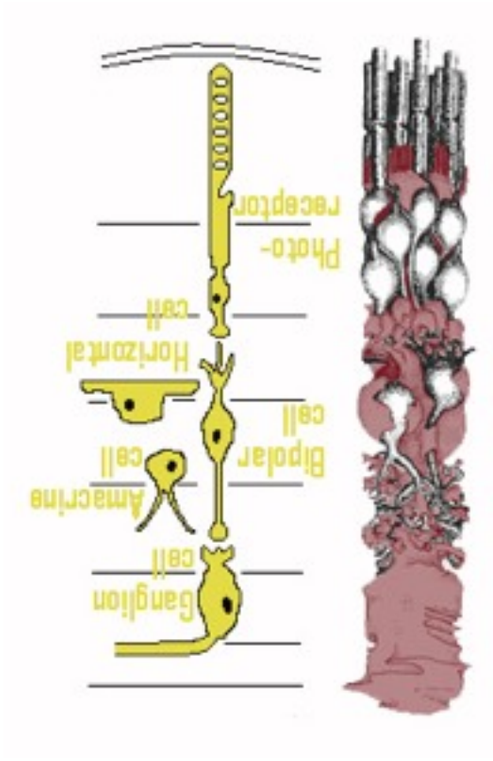


Fig. 17. ERG responses that were recorded from one subject with corneal electrode in the dark-adapted state. Several intensities were used covering a range of 4 log units.

http://webvision.med.utah.edu/ERG.html

The electrical basis

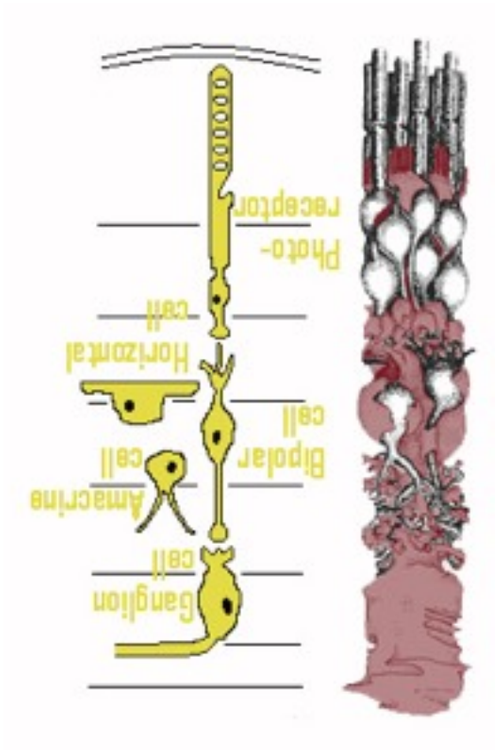
of ERG recordings



The electrical basis

of ERG recordings

- The idea that part of the ERG signal results from changes in the membrane potential of the Müller cells due to light-induced changes of extracellular potassium concentration, underlies the basis for the "Müller-cell Hypothesis".
- Since first proposed by Faber (1969), this idea has been tested by many investigators using intracellular recordings from Müller cells, measurements of extracellular concentrations of potassium and recording the ERG at different retinal depths.



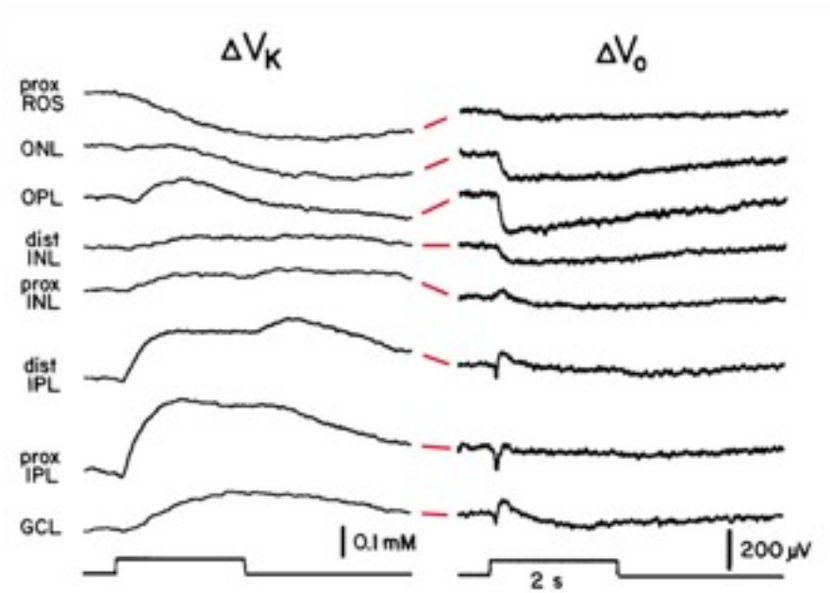


Fig. 7a. The Muller cell hypothesis of the ERG b-wave. Depth profile of light-induced changes in the extracellular concentration of potassium ions (_VK) and of local field potential (_V0) (Karwoski et al., 1985).

http://webvision.med.utah.edu/imageswv/ERGFig7A.jpg

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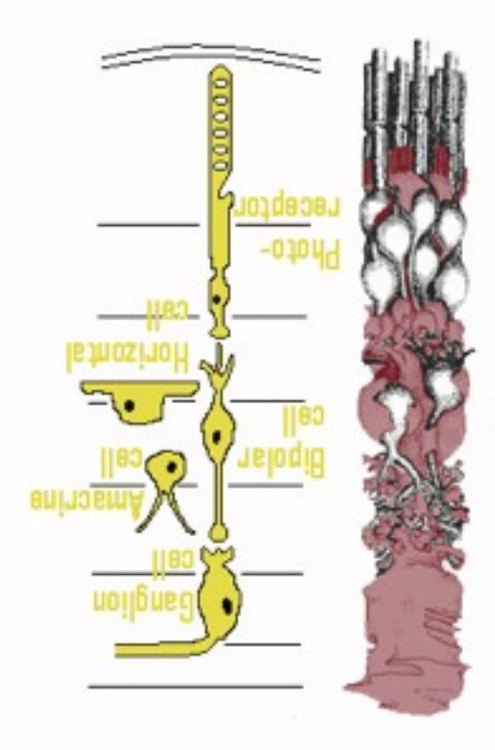


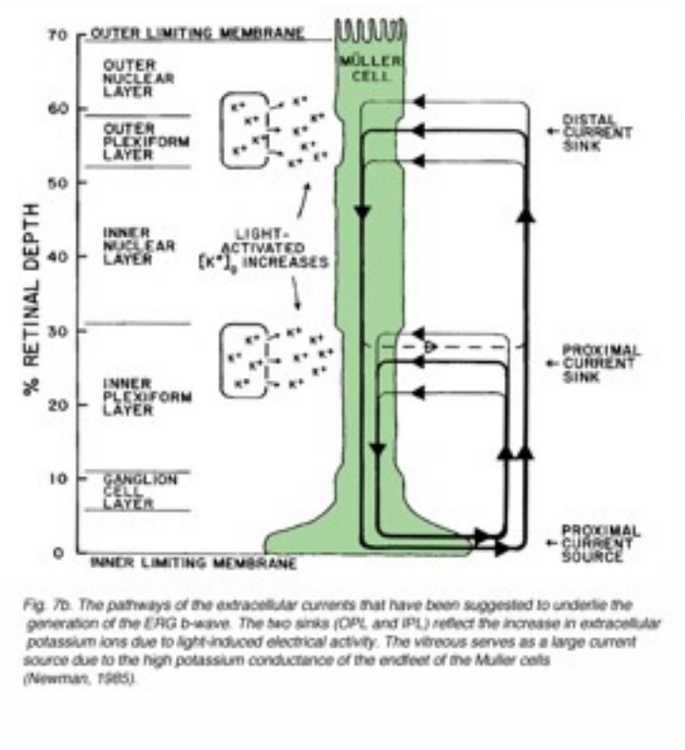
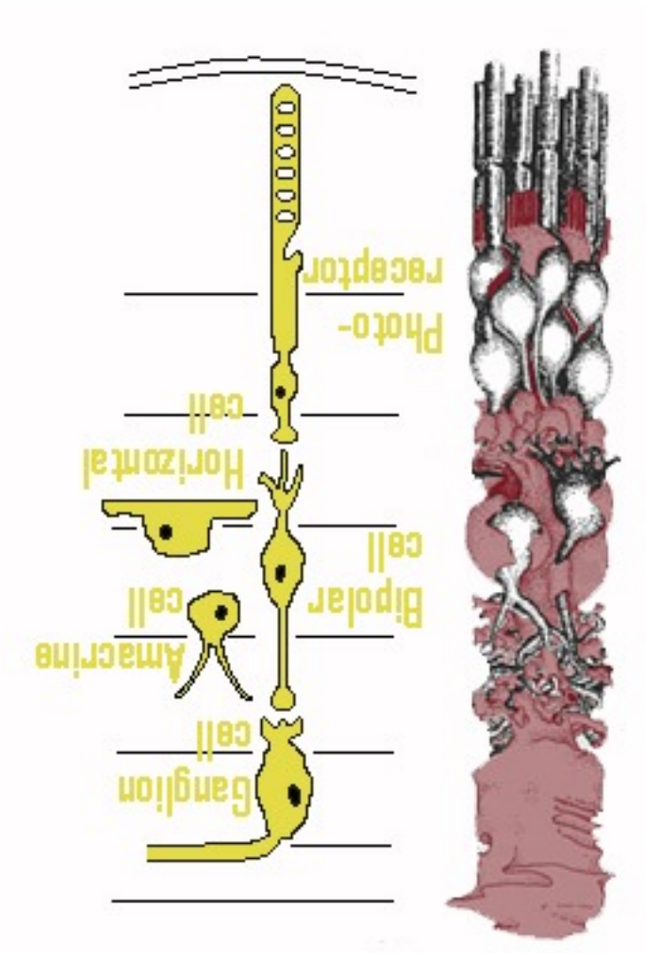


Fig. 7b. The pathways of the extracellular currents that have been suggested to underlie the generation of the ERG b-wave. The two sinks (OPL and IPL) reflect the increase in extracellular potassium ions due to light-induced electrical activity. The vitreous serves as a large current source due to the high potassium conductance of the endfeet of the Muller cells (Newman, 1985).

The electrical basis

of ERG recordings



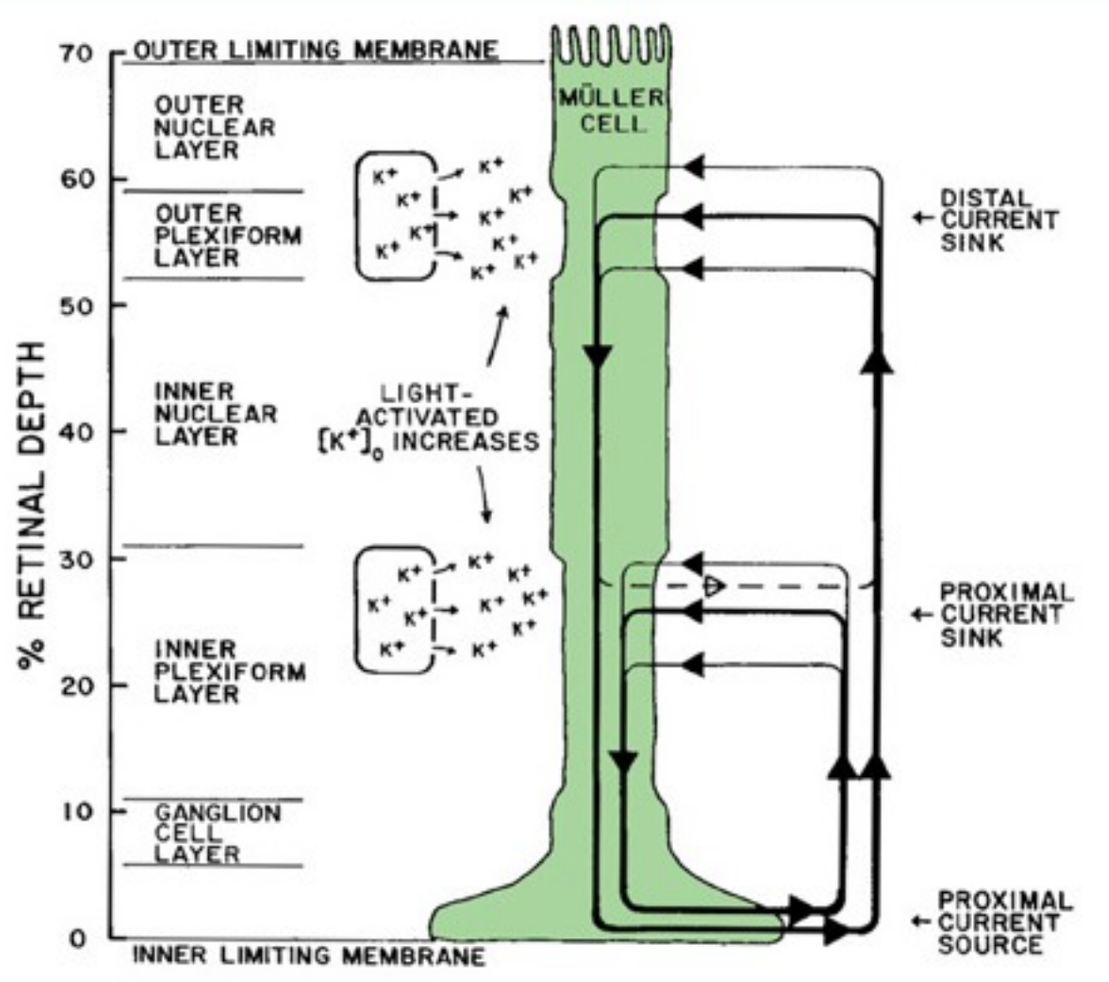


Fig. 7b. The pathways of the extracellular currents that have been suggested to underlie the generation of the ERG b-wave. The two sinks (OPL and IPL) reflect the increase in extracellular potassium ions due to light-induced electrical activity. The vitreous serves as a large current source due to the high potassium conductance of the endfeet of the Muller cells

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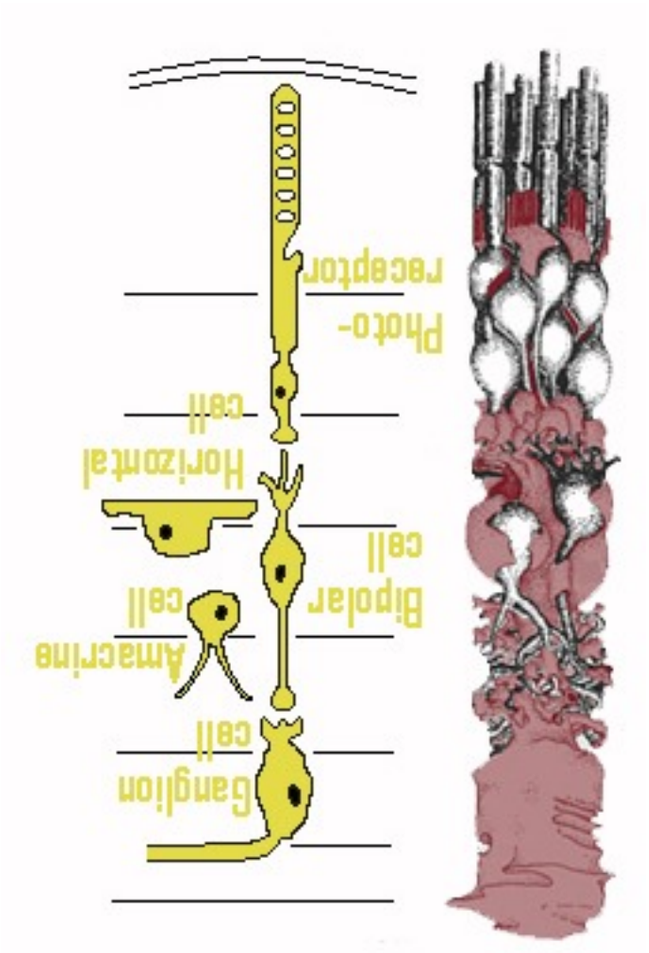
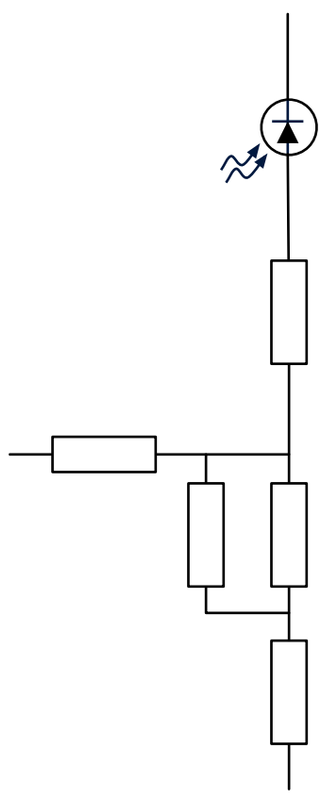
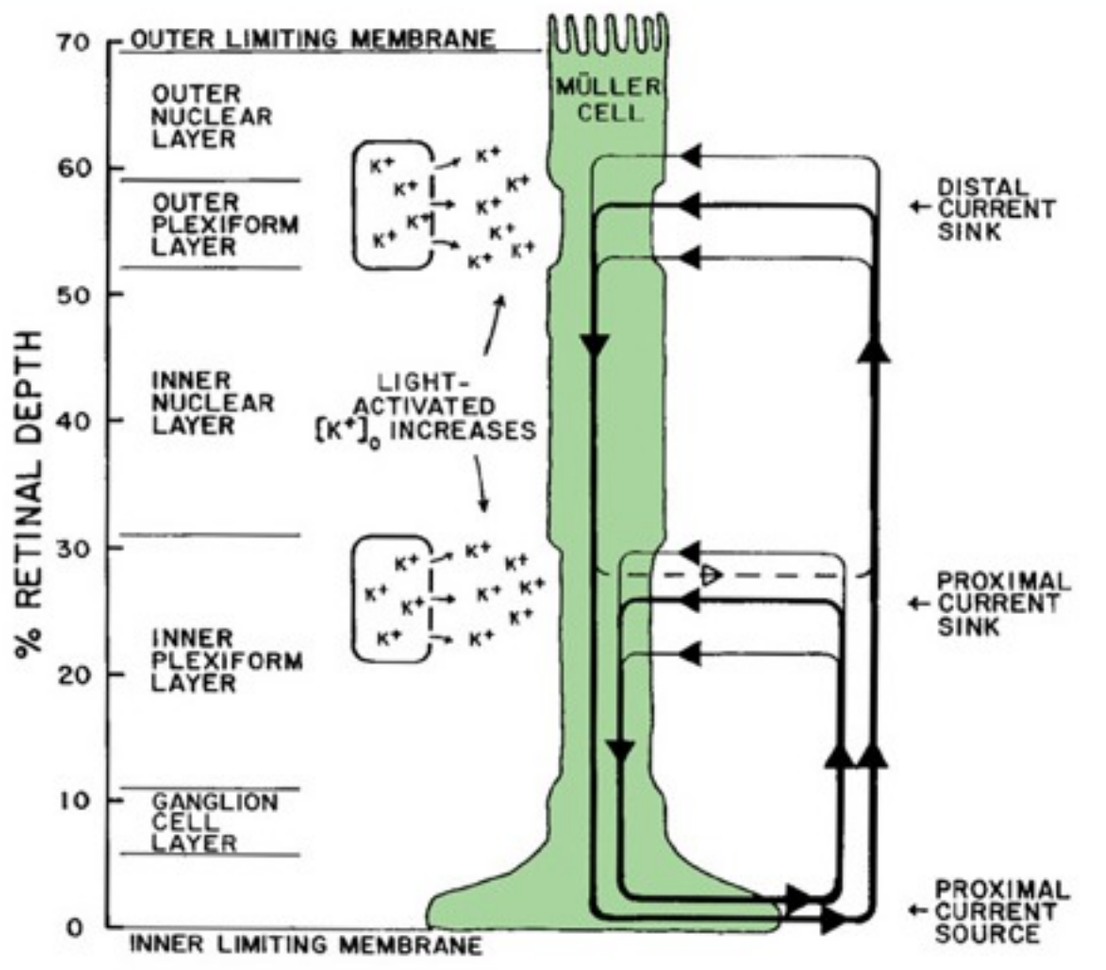
- Although if we know that it is not correct, in a first approximation, we can modelize the retina as a complexe serial/parallel resistive circuit. This simplify the understanding of the divers potential that take place in the several retinal levels.







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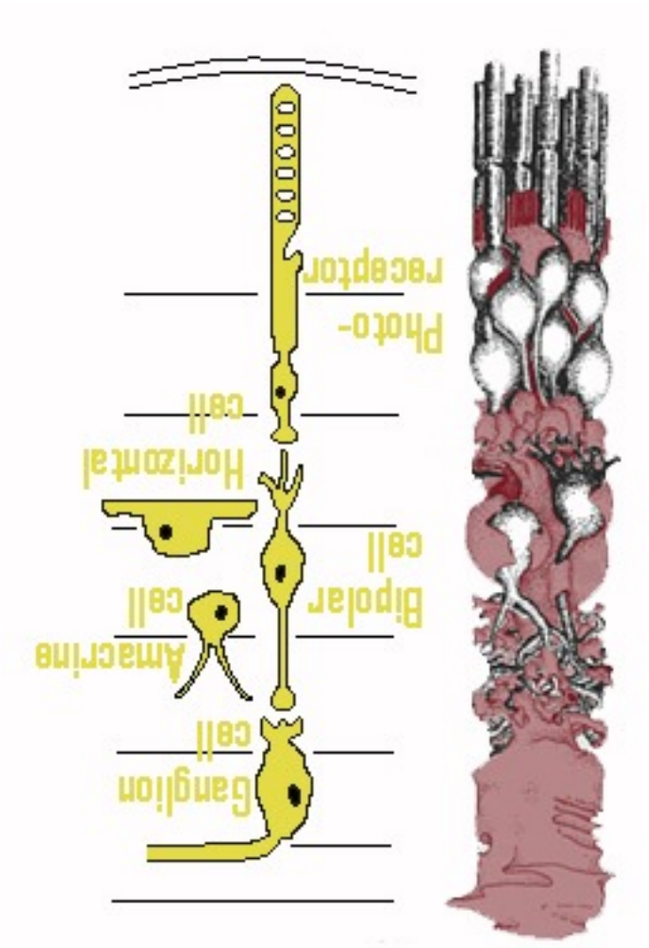
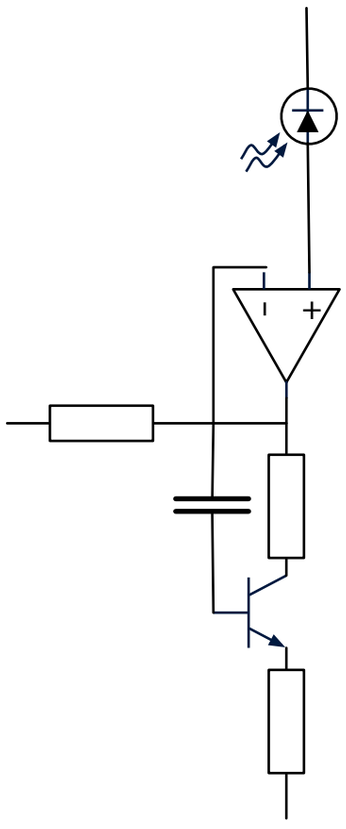
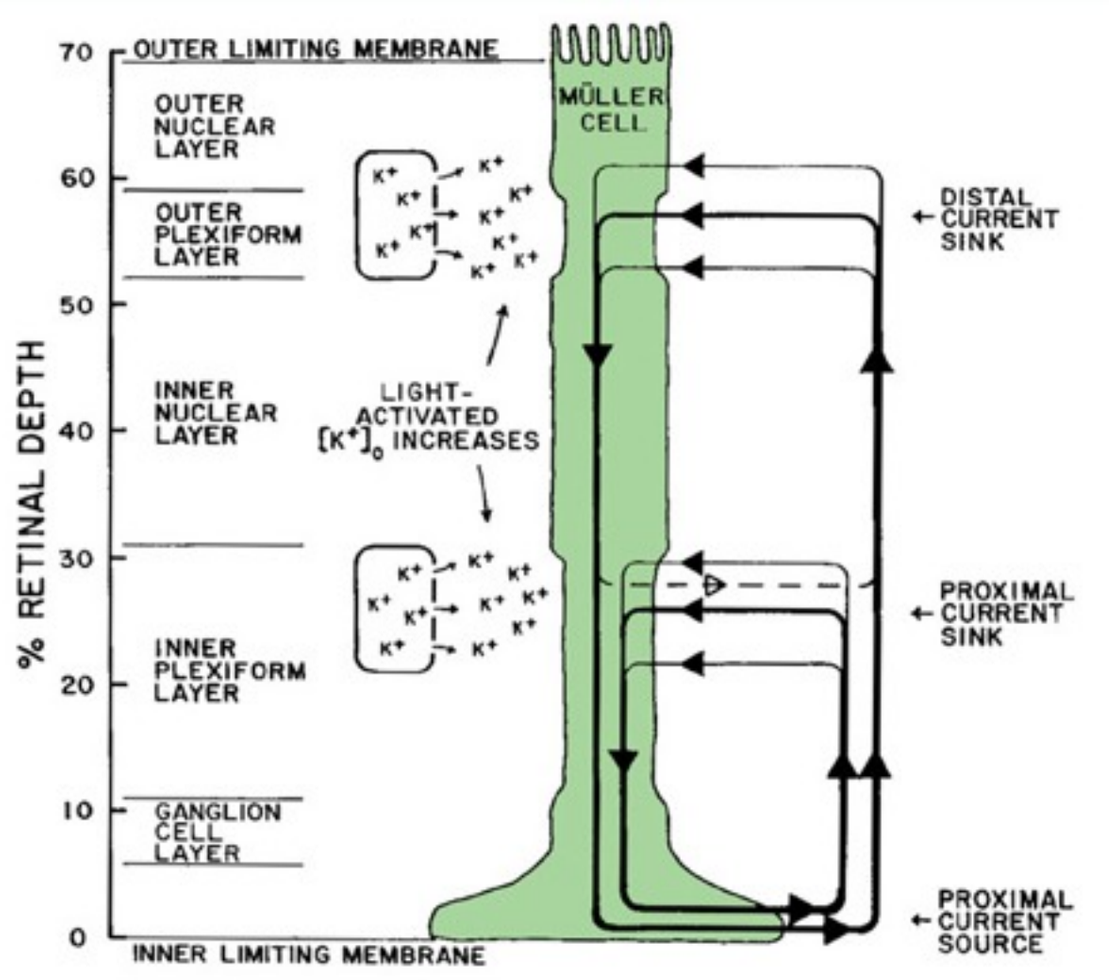




Example of what could be the electrical retinal circuit equivalence.



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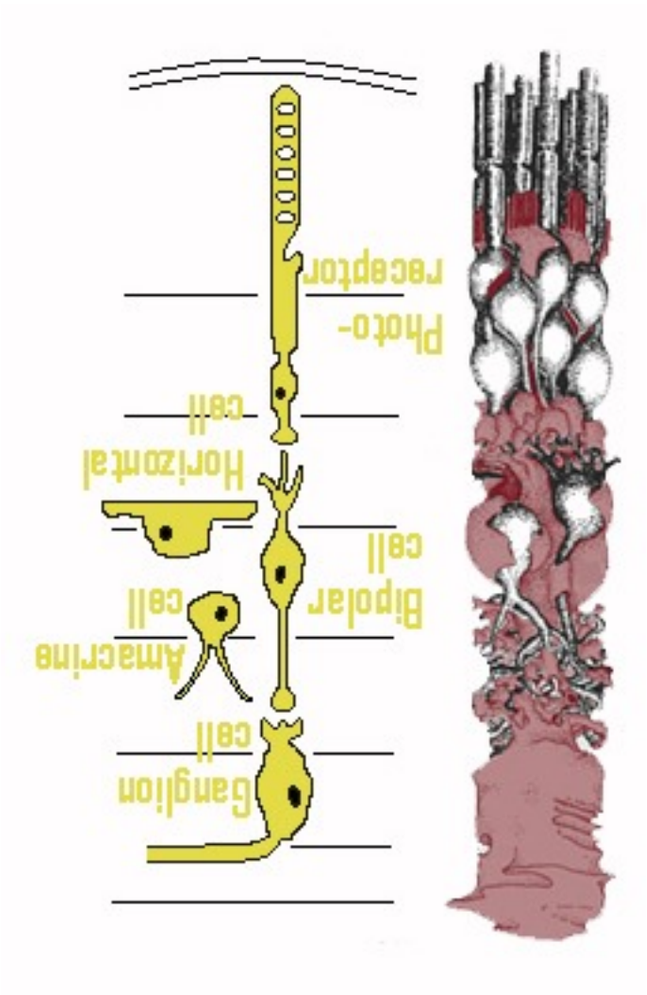

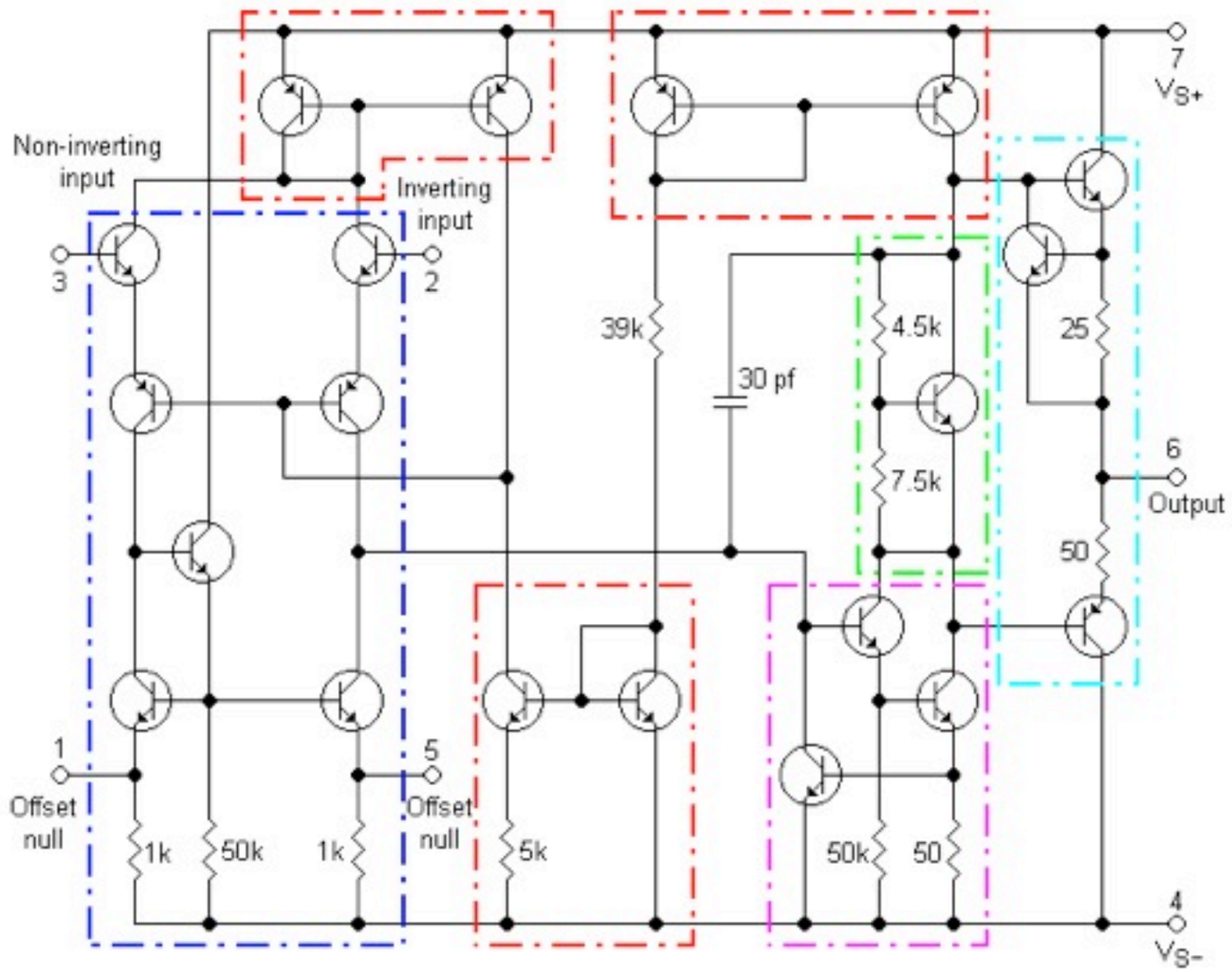

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http://commons.wikimedia.org/wiki/File:Opamptransistorlevelcolored.png