The architecture of the eye

Whose eye is this?
Tapetum can be found in raccoons, cats, dogs, cows

Retina -- it's a layer of light-sensitive cells

* Rod cells sense brightness
* Cone cells sense color

More rod and cone cells than citizens in the US!
Retina -- only attached to the eye in one spot

* All the nerves from the retina join to form optic nerve at the blind spot

* There are no light-sensitive cells at the blind spot

* Cannot see anything that lands on blind spot

Blind Spot Test

1. Hold the blind spot test paper at arm’s length
2. Close your right eye
3. Look at the “+” symbol with your left eye
4. Slowly move the paper closer and closer, until the “•” symbol disappears.
Rods and Cones

Distribution of Rods and Cones

Why do humans have color vision? What’s the evolutionary advantage?
The Eye is a Photonreceptor

Photophysics of Vision

\[ h\nu = E \]
Retina $\rightarrow$ Rod cell $\rightarrow$ Rhodopsin

Retina $\rightarrow$ Rod cell $\rightarrow$ Rhodopsin
Photoisomerization of Retinal

Quantum Biology of Retinal mechanism of retinal has been fascinating experimental and theoretical researchers over many decades until today. In this chapter, the quantum processes involved in the photoactivation of retinal in Rh and related proteins are presented.

Figure 11.1 Visual receptors. (a) Cross section of the eye with lens and iris on the left and the retina with nerve cells highlighted on the right. (b) The retinas of animals contain millions of rod and cone receptor cells. Shown are shapes and arrangement of rod and cone cells. (c) Discs in the cone and rod cells. The discs are hollow and made of membranes that are saturated with the light receptor protein, rhodopsin (Rh), in case of rods, and several types of proteins, iodopsins, in case of cones. In the figure Rhs are highlighted. (d) Light is absorbed by retinal (red), the chromatophore molecule situated inside Rh (blue tube and grey surface), which in turn is located inside a lipid (brown) membrane. Light excited retinal undergoes an isomerization reaction triggering the visual signal; this chapter describes the quantum mechanical nature of retinal’s light absorption characteristics and photo reactions.

11.2 Retinal in Rhodopsin and Bacteriorhodopsin

Figure 11.2 depicts the chemical structure of the retinal chromophore, mainly a polyene chain with six conjugated double bonds. One end of the polyene Visual Receptor Protein Rhodopsin

Visual Receptor Protein Rhodopsin
Quantum Biology of Retinal

In case of bR, the changes in the protein interior brought about by retinal photoisomerization induce the vectorial transfer of a proton from the interior to the exterior of the bacterial cell wall, in which bR resides, charging the bacterial cell energetically.

As shown in Fig. 11.1, Rh is a visual pigment responsible in animal eyes for monochromic vision in the dark. In the human eye, three other visual pigments, iodopsins, also exist in the retina, namely in the so-called cone cells, and are responsible for color vision. The visual pigments are members of the protein family of G-protein coupled receptors (GPCRs); photoactivation of the receptors leads to binding of G-protein to initiate a signaling transduction cascade (Shichida and Imai, 1998). Figures 11.1d, 11.3a depict the protein structure of Rh. In the resting dark state of Rh and the three human iodopsins, retinal is found in an 11-cis configuration. The primary photoreaction is a photoisomerization of retinal from its 11-cis state to its all-trans state as shown in Fig. 11.3b. The photoisomerization reaction in Rh is one of the fastest molecular reactions in nature; it completes within 200 fs (Kochendoerfer and Mathies, 1996; Polli et al., 2010; Schoenlein et al., 1991).

Figure 11.3 (a) Structure and photodynamics of rhodopsin. Seven trans-membrane helices of the protein embed a retinal (red). (b) Photoreaction in Rh. Upon photoabsorption, retinal undergoes isomerization from 11-cis to all-trans. Retinal is shown bound as a protonated Schiff base to a lysine residue.

Photoabsorption spectra of Rh and of the three iodopsins reach over a wide range of the visible spectrum: the photoabsorption maximum of Rh is at 500 nm, i.e., at a wavelength where sun light has maximum intensity on the surface of Earth. Photoabsorption of the three human iodopsins covers 400-500 nm, 450-630 nm, and 500-700 nm with absorption maxima around 430, 550, and 570 nm. The absorption characteristics permit the iodopsins to...
Interaction between the chromophore and side groups of amino acids determines color sensitivity of the visual pigments.
Deficiency

(Example: mutant in the side group Ala164S (Phe261Y, Ala269T) leads to weakness in sensitivity to green; deuteranopia)

Normal

Deutan (M-cone)

Boys are afflicted more often than girls! Why?

Alignment of Rh, bR, and sRII
Spectral Tuning in Archaeal Retinal Proteins


**Sensory rhodopsin I (sRI):**
- attractant (repellent) to orange (near UV) light

**Sensory rhodopsin II (sRII):**
- repellent to blue-green light

- Absorption maximum of sRII (vs. bR) is blue-shifted (70 nm) despite close homology
- sRII spectrum exhibits a prominent sub-band.

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**Sequences of bR and sRII**

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<td>BACT_HAPF241</td>
</tr>
</tbody>
</table>
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*br, Halobacterium halobium*
*bact_HAPF5*, *Marinobacterium pharaonis*

- Helical region
- Identical residues
- Binding pocket
X-ray Structures of bR and sRII

- X-ray crystallography shows structures are homologous.

X-ray QM/MM

Note helix shift!

Homology: computational errors cancel when comparing spectra

But there is also a significant difference in overall structure!

orange, red: sRII (Natronobacterium pharanois)

purple, blue: bR (Halobacterium salinarum)

Binding Sites of bR and sRII

Similar structure
- Aromatic residues.
- Hydrogen-bond network.
  (counter-ion aspartates, internal water molecules)

Mutagenic substitutions
(Shimono, Kamo et al.)

T204A/V108M/G130S of sRII produces only 20 nm (30%) spectral shift.

What is missing? What are the main determinants of spectral tuning: side groups or protein structure? Both!