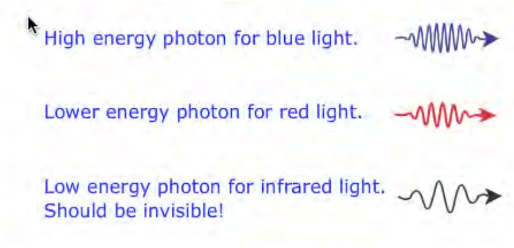
photon

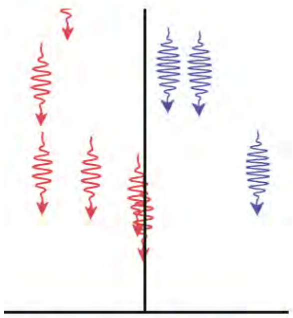
The value of sight in a light-filled world led eventually to the evolution of complex eyes. Trilobites, that appeared on earth over 521,000,000 years ago, had compound eyes with lenses composed of calcium carbonate (calcite) crystals. The clusters of prisms which formed the eyes of these early arthropods focused ambient light onto cells containing photopigment at the base of each lens. Within these cells, the stimulus of photon impact was converted into a response of membrane depolarization, beginning the path to neural processing and recognition of shape and form**:** ***sight***.

Color vision, the ability of an organism to differentiate among wavelengths of light within the visible spectrum, allows crisp *discrimination of marking boundaries* that would be invisible otherwise. In typical human fashion, anthropocentric beliefs about the universe led us to assume that prized abilities, such as seeing the world in glorious color, must be a special gift for *Homo sapiens* alone. As we began to understand the physics of light and the physiology of vision, we learned otherwise.

In the case of *Apis mellifera*, Karl von Frisch, who later was awarded the Nobel Prize for Physiology or Medicine for decoding the *language* of honeybees, started his work investigating color vision in bees. He began his 1973 Nobel Lecture with these words**:** "*Some 60 years ago, many biologists thought that bees and other insects were totally color-blind animals. I was unable to believe it. For the bright colors of flowers can be understood only as an adaptation to color-sensitive visitors. This was the beginning of experiments on the color sense of the bee*."

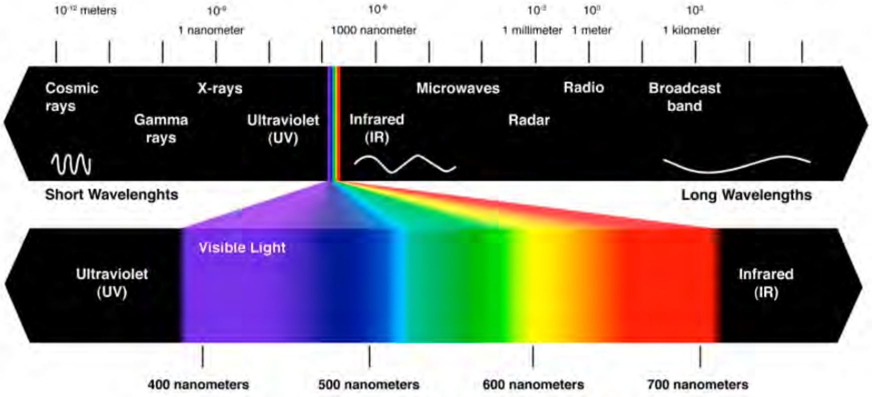
As we ask, "*What is color*?", we must first answer the question, " *What is light*?" Definitive answers to those questions have come only in the last century. Democritus, a Greek atomist (whose work was popularized by Epicurus and – much later – recorded by Lucretius in his 50 BC didactic poem *De rerum natura*), proposed in 400 BC that light was made of tiny particles. Isaac Newton also explained light as particles. Light was later understood as a wave function, with good mathematical descriptions provided by James Clerk Maxwell in the 1860's. In 1905, Albert Einstein revolutionized our thinking by precisely describing the quantum nature of light energy**:** the photon. He contemplated the *wave/particle duality of light*: "*It seems as though we must use sometimes the one theory and sometimes the other, while at times we may use either. We are faced with a new kind of difficulty. We have two contradictory pictures of reality; separately neither of them fully explains the phenomena of light, but together they do."*

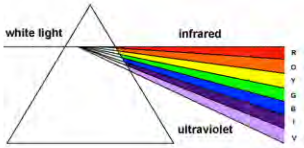


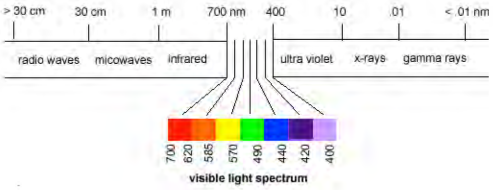


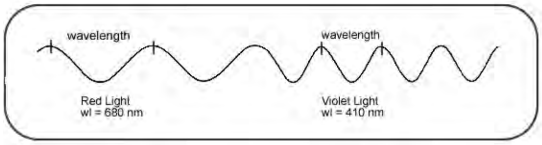
For the same light intensity, blue light requires fewer photons since the energy content of each photon is greater.

Only a small portion of the electromagnetic spectrum is able to be sensed by any living cells on earth, however, because _photoreceptor pigments_ - which absorb photons and convey this interaction to the organism - _only absorb light energy of very specific wavelengths_. Without ability to detect a wavelength (which is the case for most of the spectrum), organisms are totally blind to it.









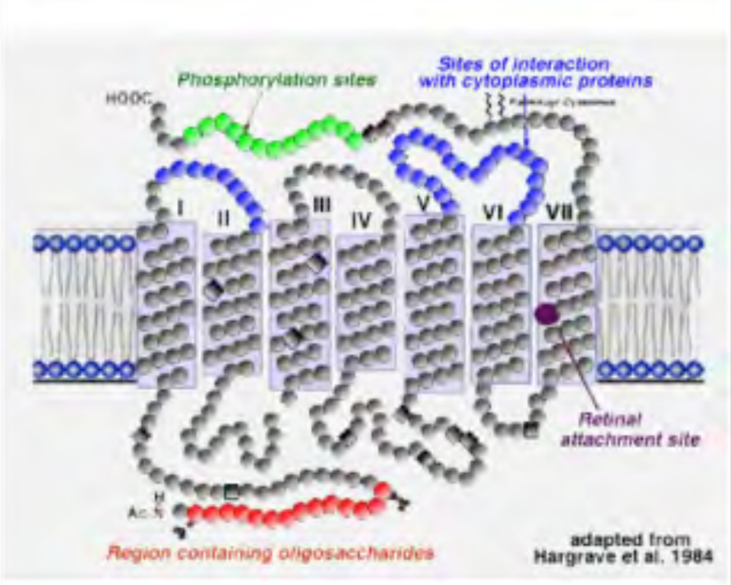


Fig. 9. Structural model of Rhodopsin showing seven transmembrane components and the attachment site for retinal

In honeybees and humans, the _ability to discriminate differences in reflected light within the visible spectrum_ (_i.e._, ***color vision***) arises from the _simultaneous input from three different sets of light-sensitive cells_, each with a slightly different light-absorbing (photoreceptor) pigment. As _information regarding the relative intensity of each of the three different frequencies of light_ is integrated in the central nervous system - of bees or of humans - an assignment of "color" is made.

***Without a brain, there is no color*.**

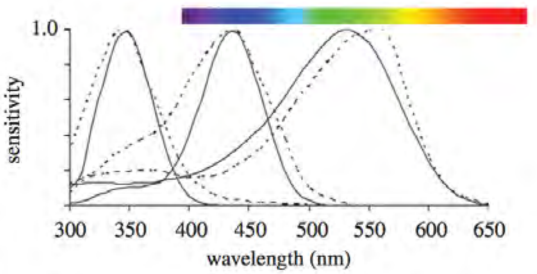


Figure 1. Many hymenopteran species are trichromatic, with an ultraviolet-sensitive (SWS, 300–400 nm), blue-sensitive (MWS, 400–500 nm) and green-sensitive (LWS, 500–600 nm) photoreceptor [5], while human vision perceives longer-wavelength radiation (as indicated by the visible light spectral bar above the graph). The plots show representative sensitivity of the three photoreceptors of honeybees (dotted line [2]) and bumblebees (solid line [3]).

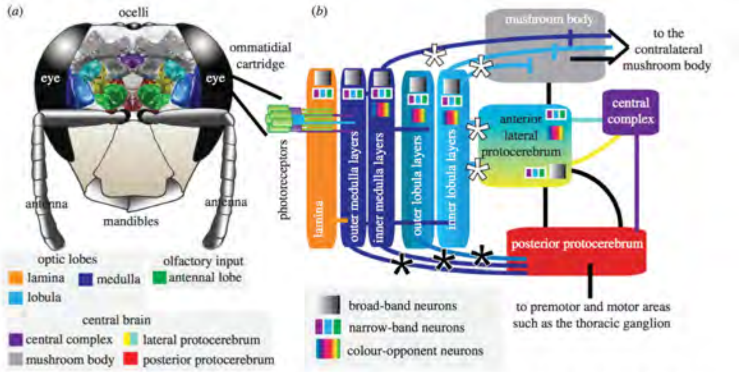
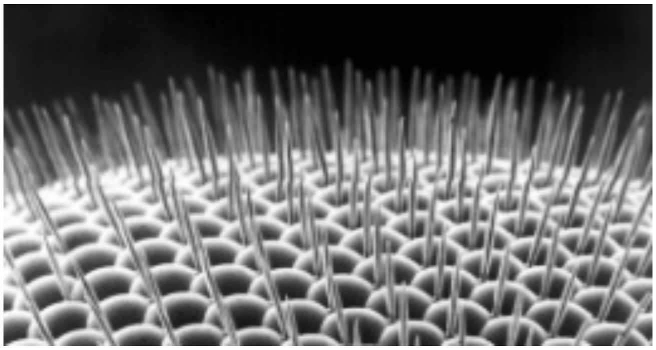


Figure 2. Visual pathways in the bee brain. (a) The brain occupies much of the bee head capsule, shown here in three-dimensional reconstruction inside a cutaway view of the bumblebee (*B. terrestris*). (b) Simplified diagram of the different colour-processing pathways in the optic lobe and central brain structures as currently understood from the photoreceptors to the central brain [16,17,25]. The neurons found within the different brain regions can be divided into broad-band, narrow-band and colour-opponent neurons, which send their inputs to the central brain via several pathways. However, two major colour pathways can be outlined: (i) neurons from the outer layers of the medulla and lobula to the posterior protocerebrum, which generally exhibit less adaptation and lower spike time precision (black asterisks); and (ii) neurons from the inner layers of the medulla and lobula to the lateral protocerebrum and mushroom bodies, which exhibit stimulus adaptation and increased spike time precision (white asterisks).

Honeybees have eyes assembled of 5,000 separate units called ommatidia ... and there are three different types of photoreceptor cells that are associated with each ommatidia. Their difference lies in the *specific wavelength sensitivities of the three different opsin molecules catching the light*: short-, medium-, and long-wave sensitive opsins (SWS: 300-400nm; MWS: 400-500nm; LWS: 500-600nm) ... trichromatic vision, it's called. When a photon of just the right wavelength strikes an opsin molecule, its energy knocks an electron out of place, causing a twitch in the rhodopsin complex and depolarizing the membrane of the photoreceptor cell. As you may know, membrane depolarization is an important way in which information and messaging is conducted in living cells, and is the basis of nervous tissue function. As the composite signals of incoming light are processed in the brain, discrimination of color boundaries is possible and the world is seen in living color.



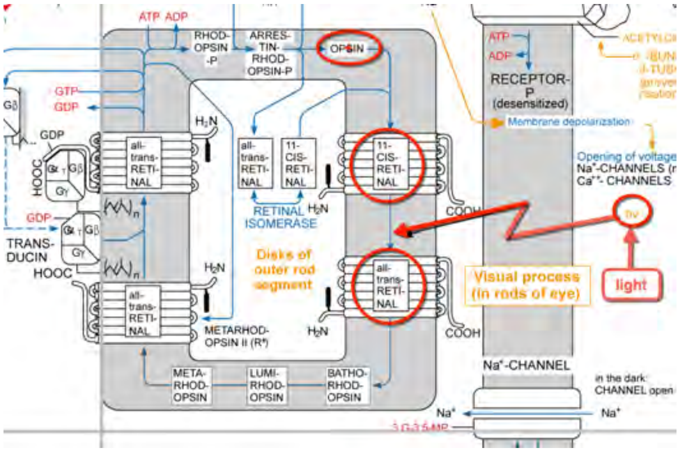


Fig1b. Scanning electron micrograph of the rods and cones of the primate retina. Image adapted from one by Ralph C. Eagle/Photo Researchers, Inc.

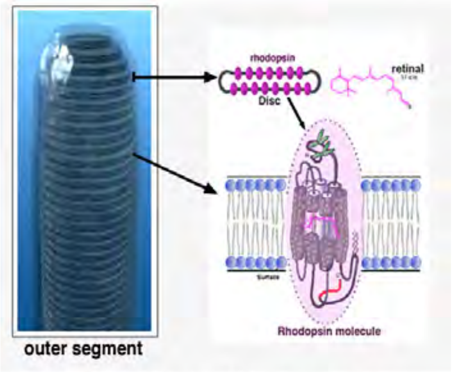


Fig 8. Schematic diagram of Rhodopsin in the outer segment discs

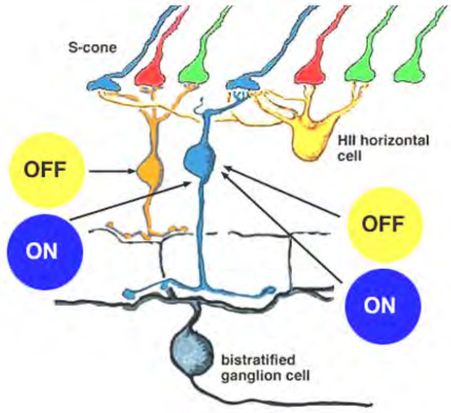
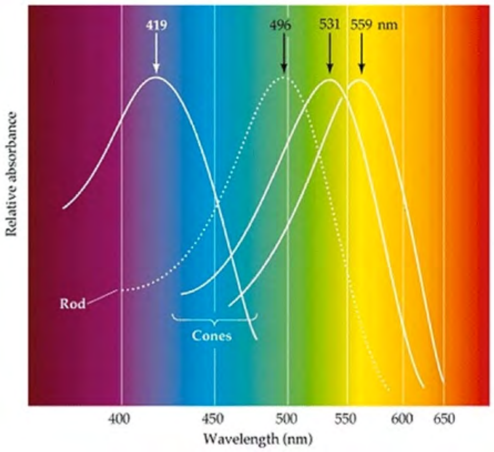
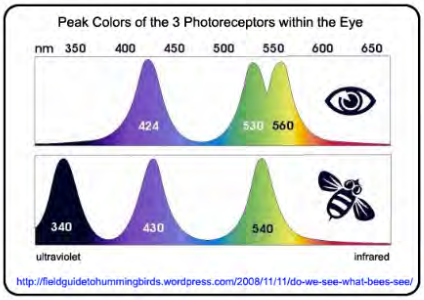
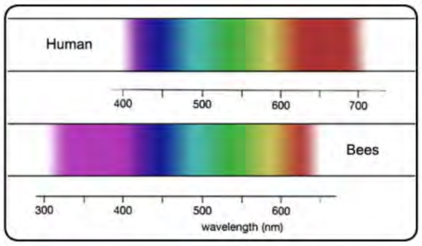


Fig. 9. Neurons of the S-cone pathways.







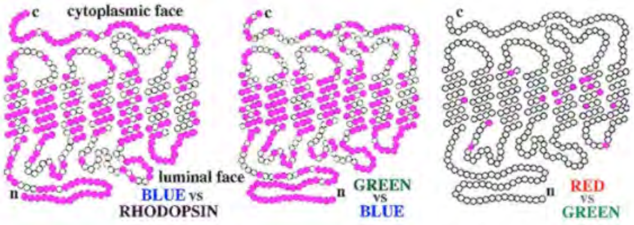


Fig. 14b. The closely related molecular structure of the cone opsins. The blue-cone opsin compared with rhodopsin. The blue-cone opsin compared with the green opsin and the minimal difference between the red- and green-cone opsins. The pink-filled circles represent amino acid substitutions between these molecules. The open circles indicate identical amino acids. Adapted from Nathans et al. (1986)

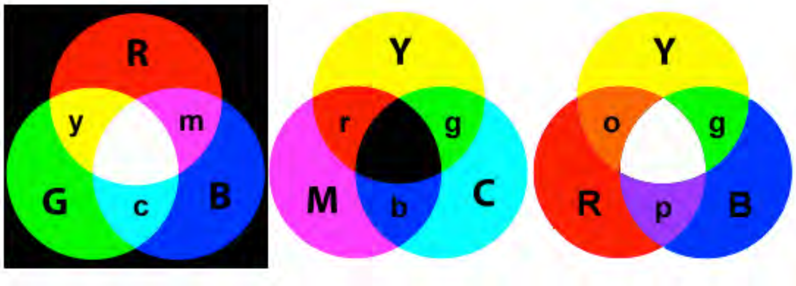


image sources:

pveducation.org
http://westmtnapiary.com
Dyer et al.: Colour processing in complex environments: insights from the visual system of bees
http://webvision.med.utah.edu

For more information regarding color vision,
including links to additional references, go to **imagessays.com -> photon**