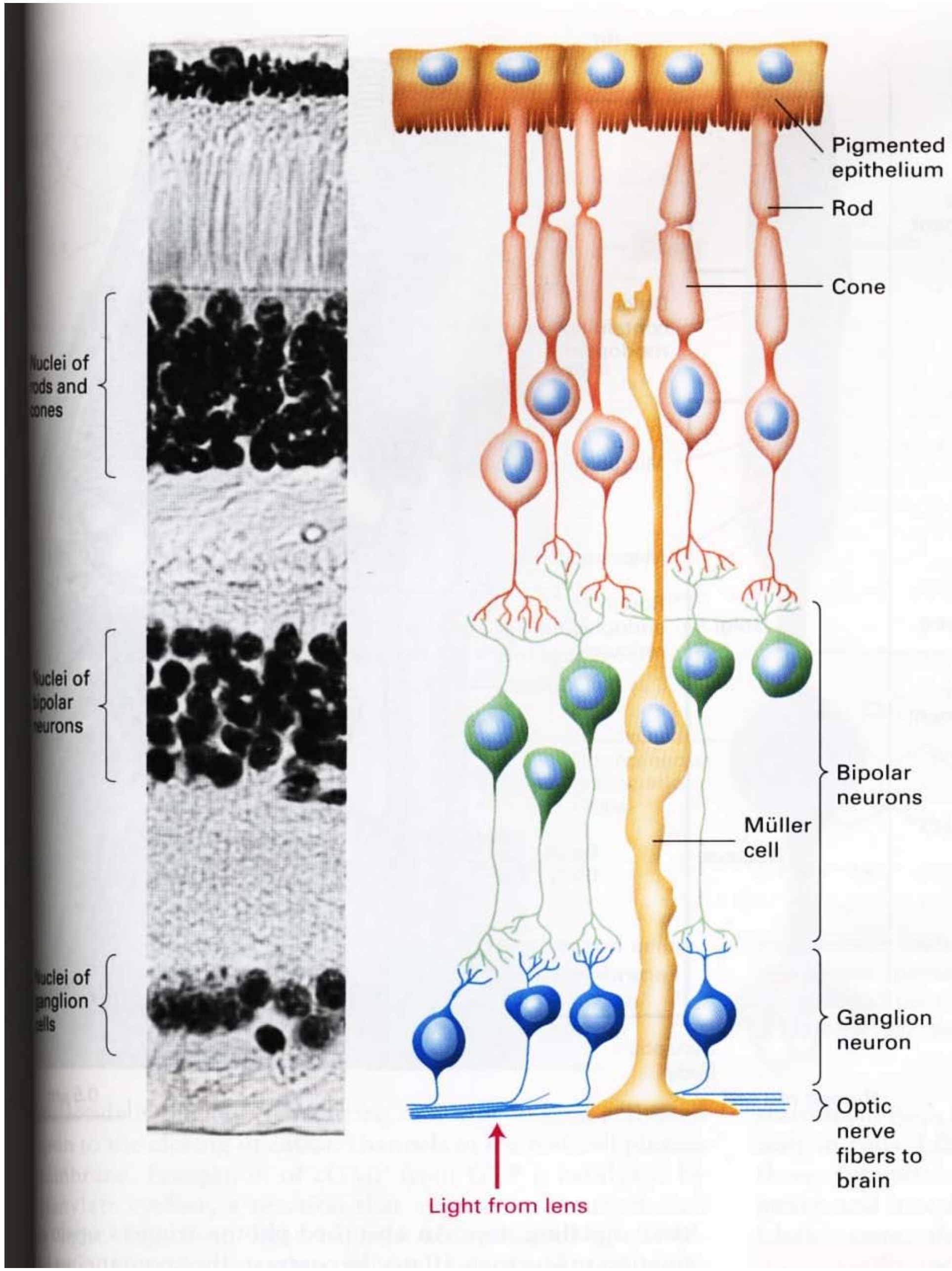
Nägemine

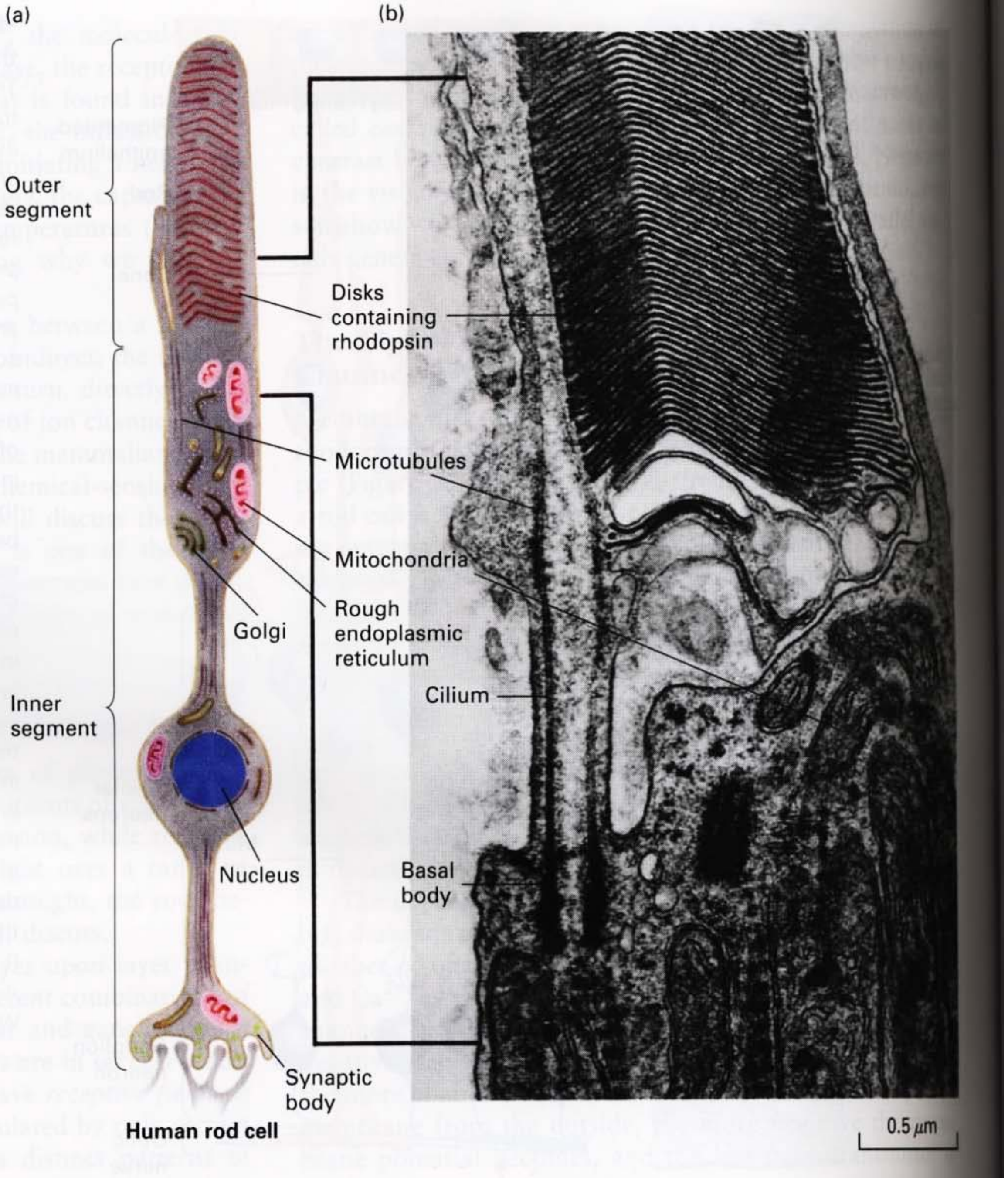
Silmalääts projekteerib silmapõhjale välismaailma pildi. Silma võrkkesta rakud reageerivad erinevatele valgustugevustele ja värvidele erinevate närvi-impulssidega, mis aju kompuutris ühtseks pildiks töödeldakse



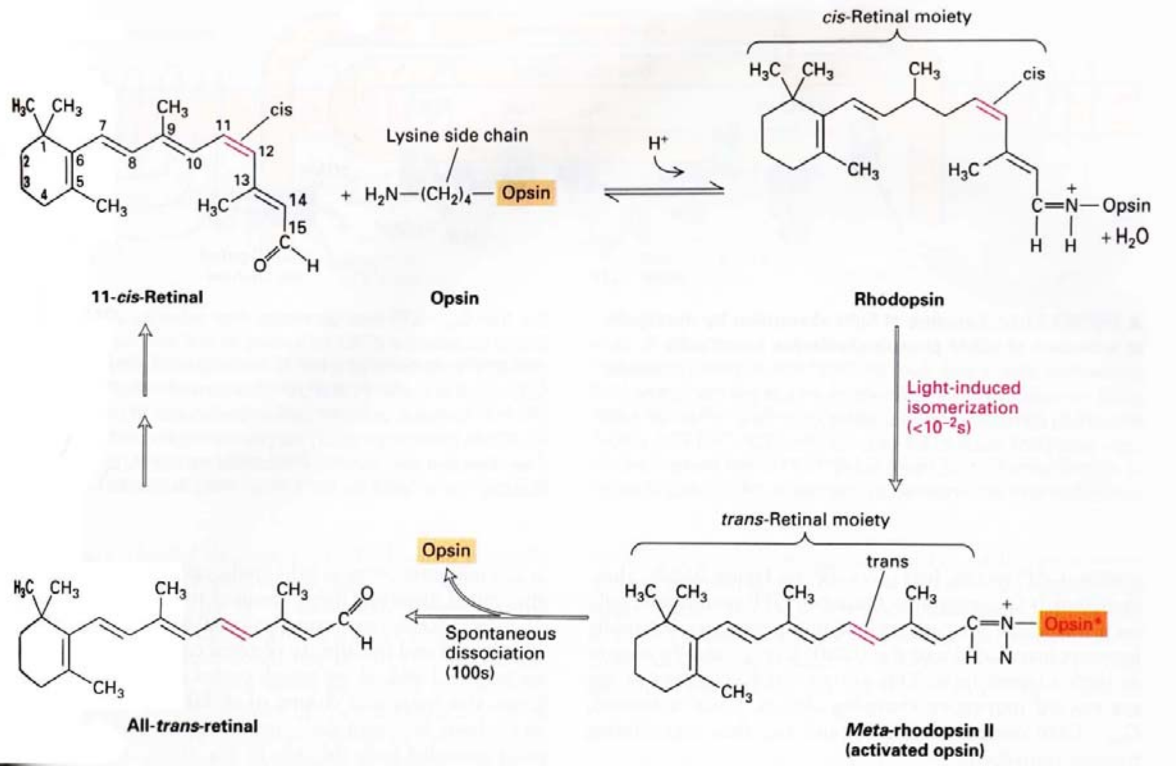
◀ FIGURE 21-43 Some of the cells in the neural layer of the human retina. The outermost layer of cells (in the rear of the eyeball) forms a pigmented epithelium in which the tips of the rod and cone cells are buried. Light focused from the lens passes through all of the cell layers of the retina and is absorbed by light-sensitive proteins in the rods and cones. The pigmented epithelium also absorbs light and prevents light reflection back to the cones and rods. The axons of each rod and cone synapse with many bipolar neurons, which integrate the responses of many photoreceptors. Some are involved in recognizing patterns of light that fall on the retina—for instance, a band of light that excites a set of rod cells in a straight line. Others respond to characteristics of visual images such as color, movement, and depth. Bipolar cells, in turn, synapse with cells in the ganglion layer that send axons—optic nerve fibers—through the optic nerve to the brain and that transmit distinct visual characteristics in multiple parallel pathways. Müller cells are supportive non-neural cells that fill much of the retinal spaces. Other types of cells are not depicted; all of the cells depicted here make many more synapses than are shown. [From R. G. Kessel and R. H. Kardon, 1979, *Tissues and Organs: A Text-Atlas of Scanning Electron Microscopy*, W. H. Freeman and Company, p. 87.]

Valgustundlik pigment on retiina kõige tagumine kiht, enne läbib valgus kolvid-kepikesed, bipolaarsed neuronid ja ganglionid. Kolvid-kepikesed on neuronitega ühendatud suure arvu sünapsite kaudu, samuti neuronid ganglionitega

▶ FIGURE 21-44 (a) Diagram of the structure of a human rod cell. At the synaptic body, the rod cell forms a synapse with one or more bipolar neurons. Rhodopsin is a light-sensitive transmembrane protein located in the flattened membrane disks of the outer segment. (b) Electron micrograph of the region of the rod cell indicated by the bracket in (a); this region includes the junction of the inner and outer segments. [Part (b) from R. G. Kessel and R. H. Kardon, 1979, *Tissues and Organs: A Text-Atlas of Scanning Electron Microscopy*, W. H. Freeman and Company, p. 91.]

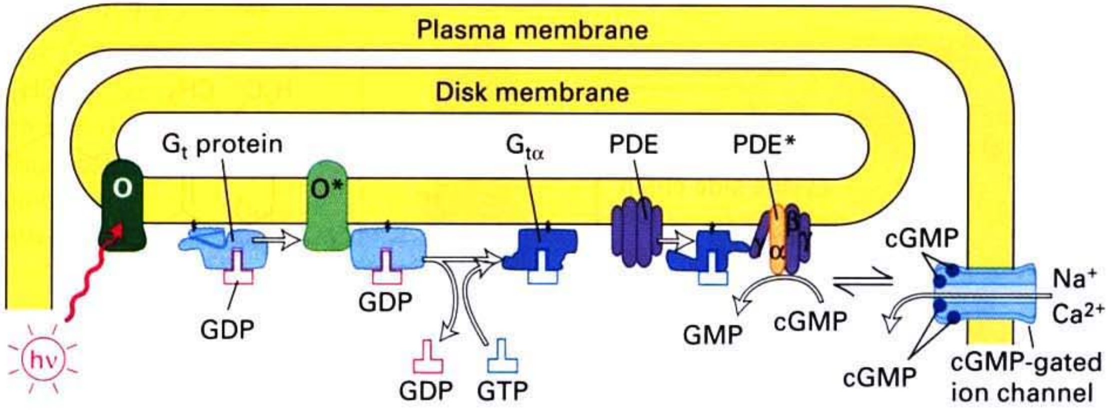


Silma valgustundlik pigment on rodopsiin, mis asetseb kepikeste (kolvikeste) kaugeimas osas paiknevates membraanides. Rodopsiin on tegelikult pigmendi *retinaali* ja valgu *opsiini* kompleks, mis valguse mõjul laguneb, põhjustab närviimpulsi ja jälle tagasi ühineb.



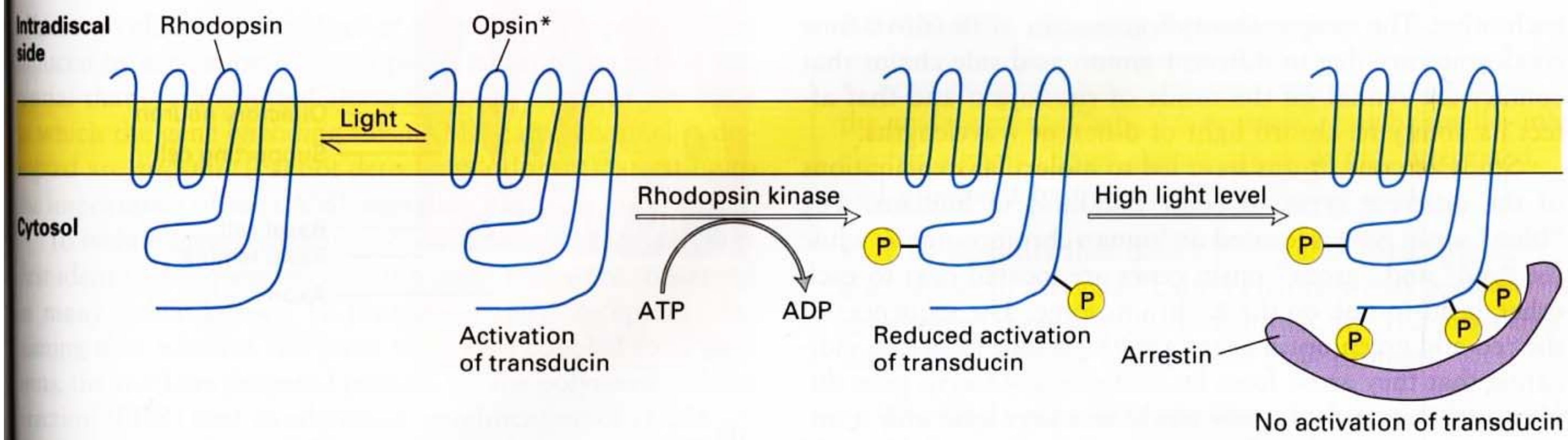
▲ FIGURE 21-46 Rhodopsin, the photoreceptor in rod cells, is formed from 11-*cis*-retinal and opsin, a transmembrane protein. Absorption of light causes rapid photoisomerization of the *cis*-retinal to the *trans* isomer, forming the unstable intermediate *meta*-rhodopsin II, or activated opsin. The latter dissociates spontaneously to give opsin and all-*trans*-retinal, which is converted back to the *cis* isomer by enzymes in rod cells. [See J. Nathans, 1992, *Biochemistry* **31**:4923.]

Silma valgustundlikkus põhineb retinaali tsis-trans isomerisatsioonil. Algseisus on 11-cis-retinaal opsiiniga kompleksis. Valguse neeldumine ergastab π-sideme, see hetkeks katkeb, lubades ahelal pöörduda sigma-sideme telje ümber. Suure tõenäosusega peatub pöörlemine trans-seisundis (sirge ahel). Nüüd on rodopsiin aktiveerunud ja edastab signaali mebraani Na-kanalitele. Trans-retinaal eraldub opsiinist, ensüümi abil pöördub cis-vormi tagasi ja liitub uuesti popsiiniga, oles valmis järgmiseks impulsiks.



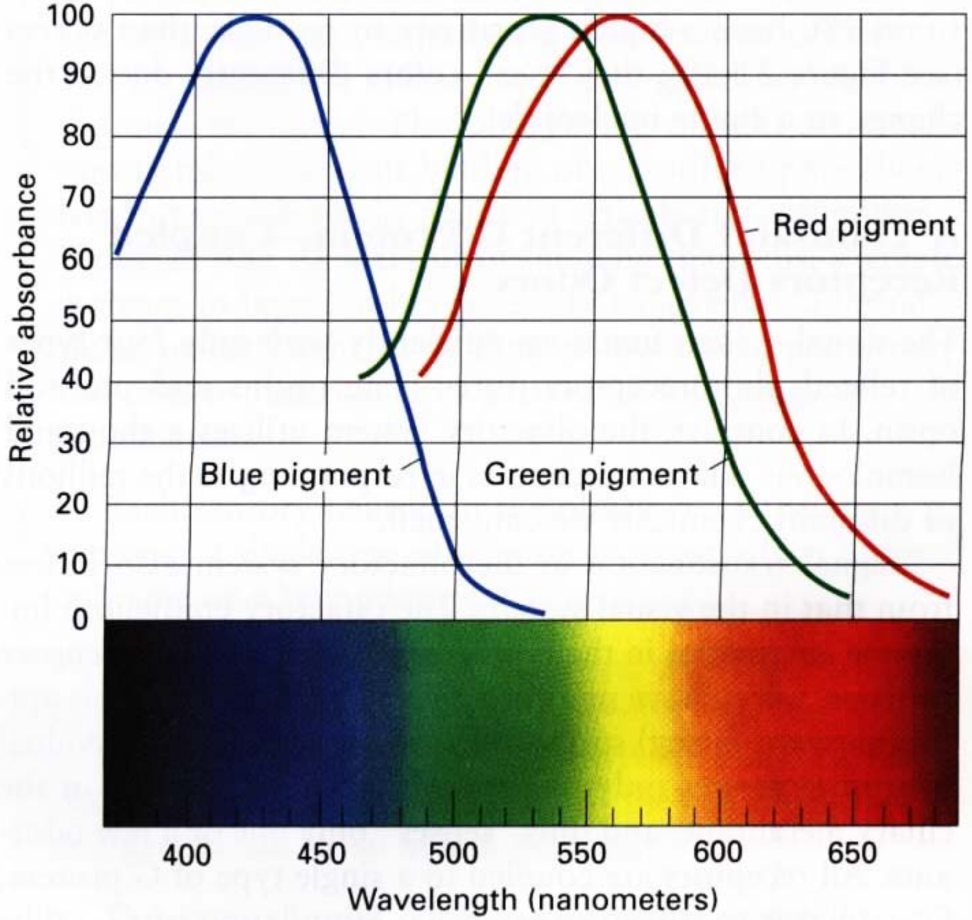
▲ **FIGURE 21-47 Coupling of light absorption by rhodopsin to activation of cGMP phosphodiesterase in rod cells.** In dark-adapted rod cells, a high level of cGMP acts to keep nucleotide-gated nonselective cation channels open and the membrane depolarized compared with the resting potential of other cell types. Light absorption leads to activation of opsin (O*) and conversion of inactive transducin (G_t) with bound GDP to the active state with bound GTP accompanied by dissociation of $G_{\beta\gamma}$ (not shown). The free $G_{\tau\alpha}$ · GTP thus generated then activates cGMP phosphodiesterase (PDE) by binding to and dissociating its two inhibitory γ subunits; as a result, the released catalytic α and β subunits of activated PDE (PDE*) can convert cGMP to GMP. The resultant decrease in cGMP causes dissociation of cGMP from the nucleotide-gated channels in the plasma membrane; the channels then close and the membrane becomes transiently hyperpolarized. [Adapted from V. Arshavsky and E. Pugh, 1998, *Neuron* **20:**11.]

Tava(pime)seisus on kepikese rakumembraanis suhteliselt palju avatud Na kanaleid, mis osaliselt depolariseerib rakumembraani (-30mV, mitte 80 mV nagu tavaliselt). Na kanaid hoiab avatud cGMP, mis on kanalitega seotud. Aktiveeritud rodopsiin algatab GTP hüdrolüüsiga seotud ahela, mis lõppkokkuvõttes katalüüsib cGMP ülemineku lihtsaks GMP ks. See põhjustab Na kanali juhtivuse vähenemise ja K kanali üleoleku suurenemise tõttu membraani polarisatsiooni suurenemise kuni -35 mV. Paistab, et see väike potentsiaali muutus ongi nägemise närvisignaali algus, mis sünaptilise ülekande kaudu võimendub juba normaalse närvisimpulsi tasemeni.



▲ **FIGURE 21-48 Role of opsin phosphorylation in adaptation of rod cells to changes in ambient light levels.** Light-activated opsin (opsin*), but not dark-adapted rhodopsin, is a substrate for rhodopsin kinase. The extent of opsin* phosphorylation is directly proportional to the ambient light level, and the ability of an opsin* molecule to catalyze activation of transducin (see Figure 21-47) is inversely proportional to the number of sites phosphorylated. Thus the higher the ambient light level, the larger the increase in light level needed to activate the same number of transducin molecules. At very high light levels, arrestin binds to the completely phosphorylated opsin, forming a complex that cannot activate transducin at all. [See L. Lagnado and D. Baylor, 1992, *Neuron* **8**:995.]

Silmade harjumine valgusega on nende rodopsiini valgustundlikkuse vähenemine, mis on seotud os rodopsiini fosforüülimisega.



▲ **FIGURE 21-49 The absorption spectra of the three human opsins responsible for color vision.** Individual cone cells express one of the three cone opsins. The spectra were determined by measuring in a microspectrophotometer the light absorbed by individual cone cells obtained from cadavers. [From J. Nathans, 1989, *Sci. Am.* **260(2)**:44.]

Värviline nägemine toimub kolvikestes, kus sellesama retinaali tundlikkuse spekter on nihutatud erinevate valkseoste abil (nii nagu klorofüllil). Kolm liiki kolvikesi, sinisele, rohelisele ja punasele valgusele tundlikud, tegutsevad nii nagu kolmevärvi süsteem televisioonitorus. Loomulikult jääb signaalide analüüs aju ülesandeks, kus asub spetsiaalne ala, nn. *visual cortex* (inglise keeles).