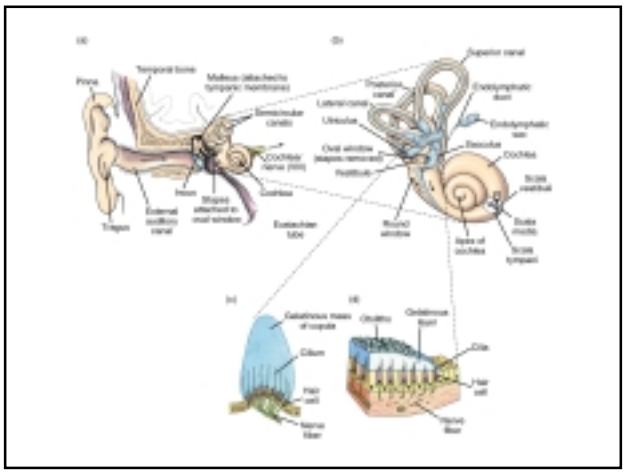
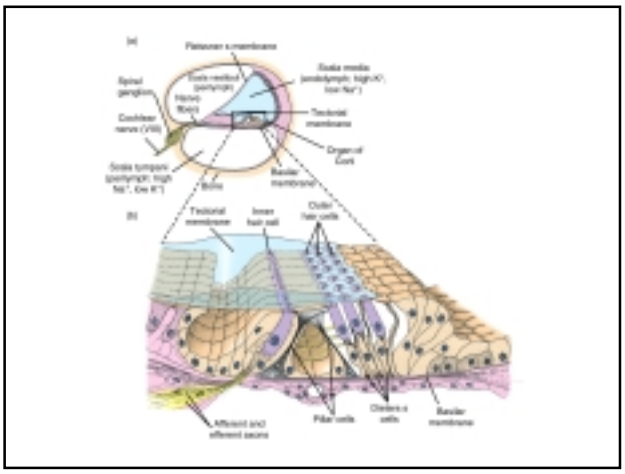
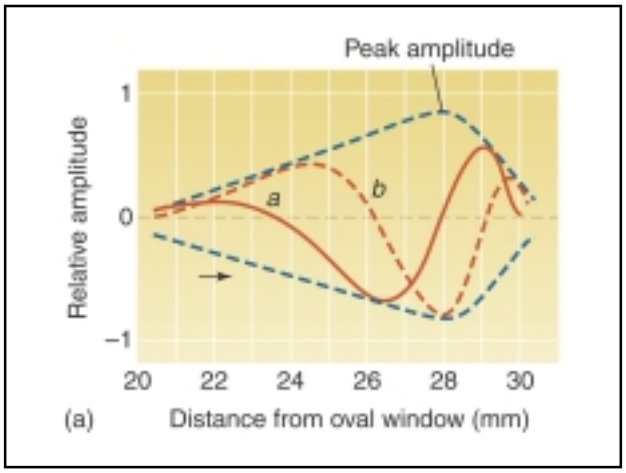
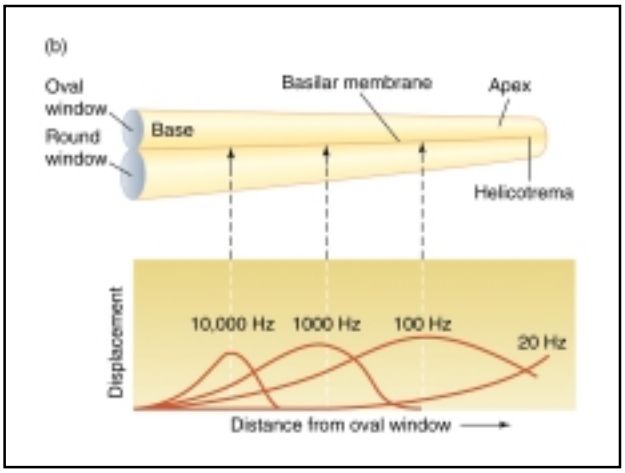
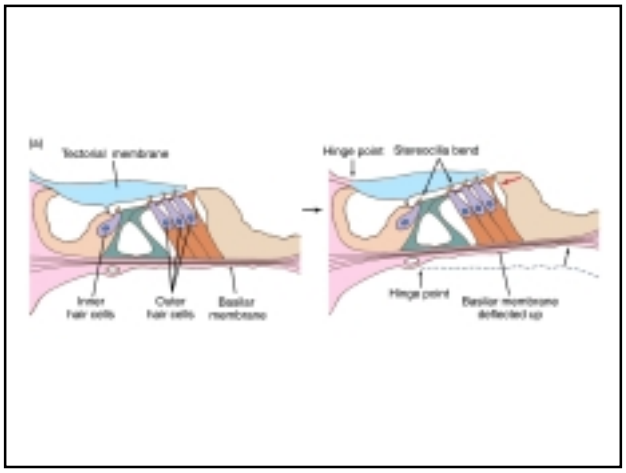
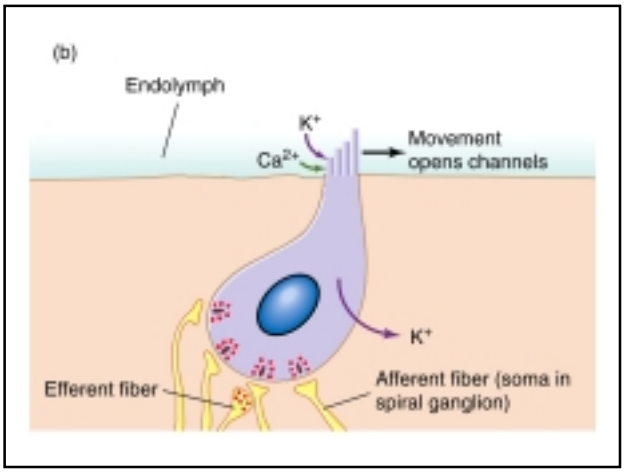


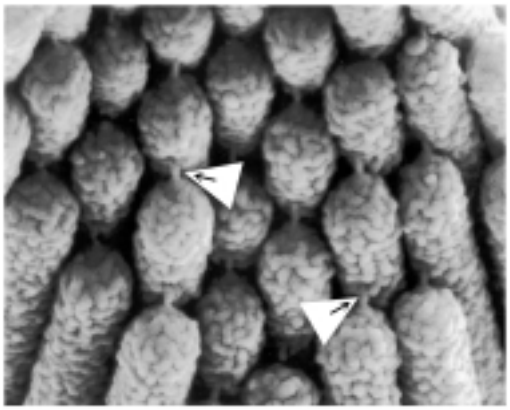


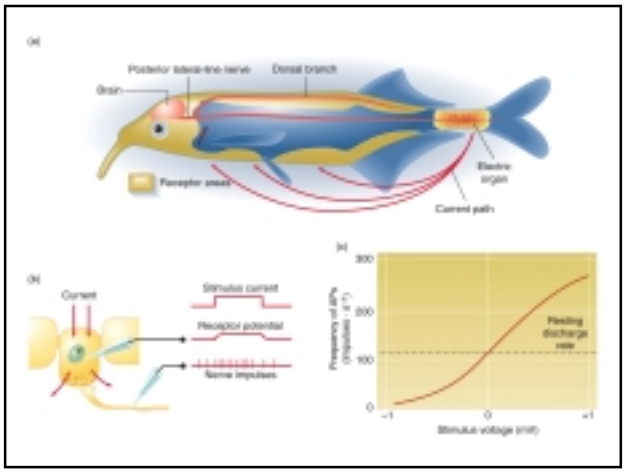

Peak amplitude
Relative amplitude
1
0
−1
a
b
20
22
24
26
28
30
(a)
Distance from oval window (mm)

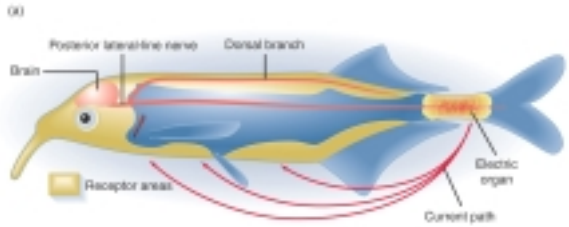

(b)
Oval window
Round window
Base
Basilar membrane
Apex
Helicotrema
Displacement
10,000 Hz
1000 Hz
100 Hz
20 Hz
Distance from oval window

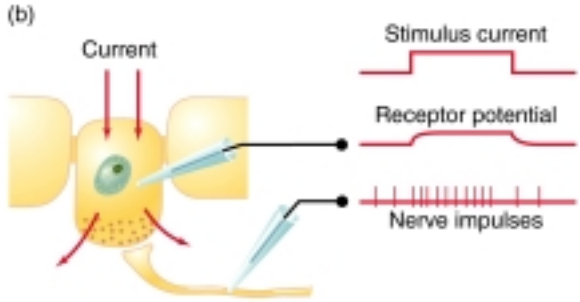

Tectorial membrane
Hinge point
Stereocilia bend
Inner hair cells
Outer hair cells
Basilar membrane
Hinge point
Basilar membrane deflected up

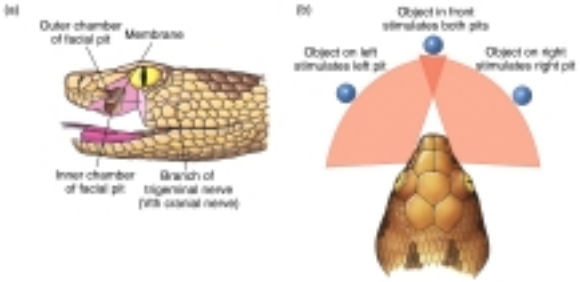

(b)
Endolymph
K+
Ca2+
Movement opens channels
K+
Efferent fiber
Afferent fiber (soma in spiral ganglion)

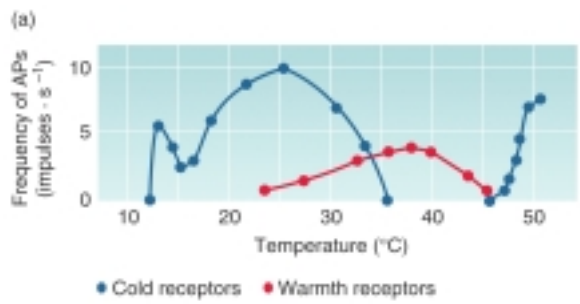


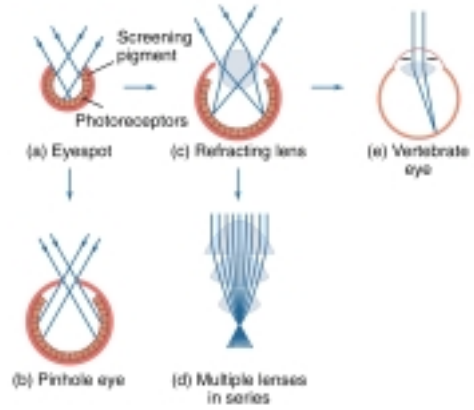

(a)
Posterior lateral-line nerve
Dorsal branch
Brain
Electric organ
Current path
(b)
Current
Stimulus current
Receptor potential
Nerve impulses
(c)
Resting discharge rate
Stimulus voltage (mV)

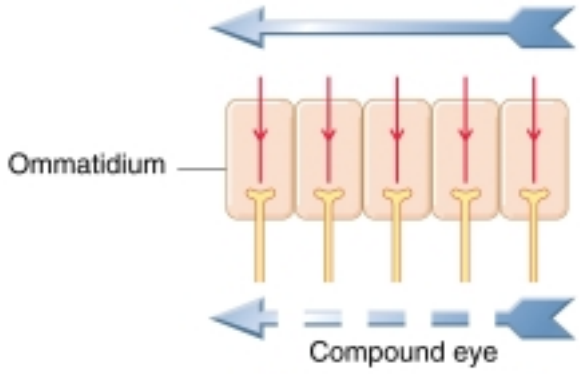

(a)
Posterior lateral-line nerve
Dorsal branch
Brain
Receptor areas
Electric organ
Current path

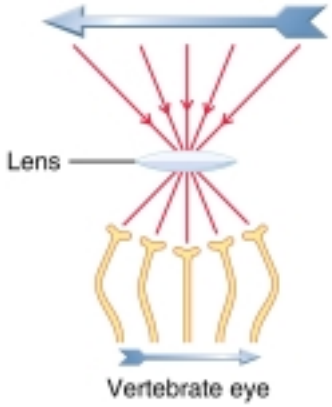

(b)
Current
Stimulus current
Receptor potential
Nerve impulses

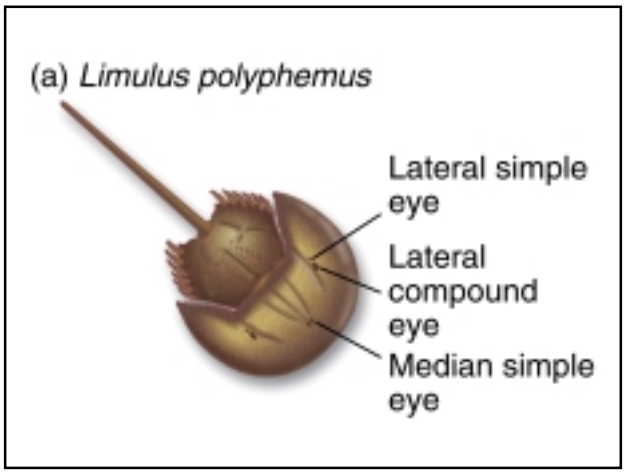

(a)
Outer chamber of facial pit
Membrane
Inner chamber of facial pit
Branch of trigeminal nerve (with ocular nerve)
(b)
Object in front stimulates both pits
Object on left stimulates left pit
Object on right stimulates right pit

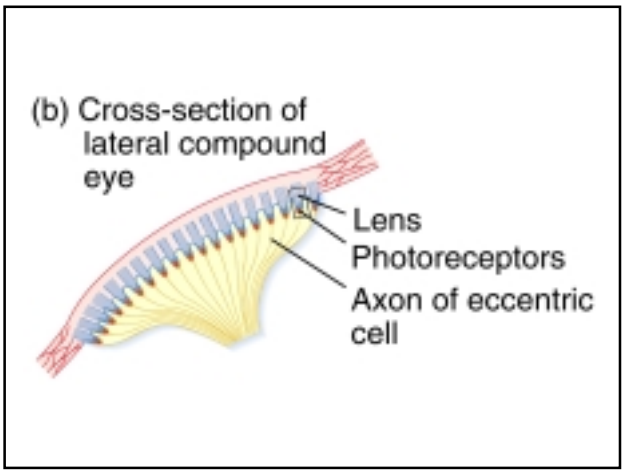

(a)
Frequency of APs (impulses · s⁻¹)
10
5
0
10
20
30
40
50
Temperature (°C)
Cold receptors
Warmth receptors

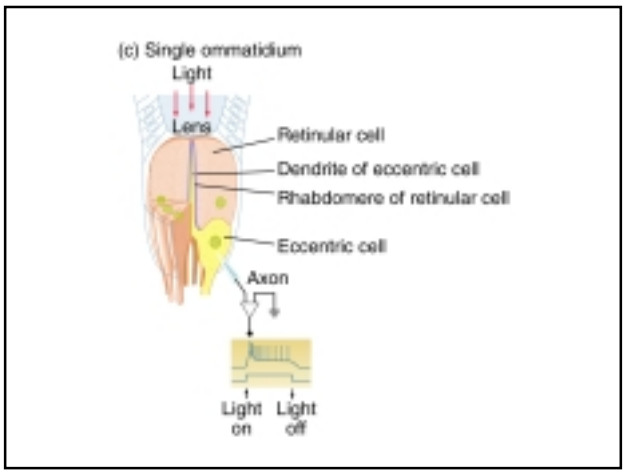

Screening pigment
Photoreceptors
(a) Eyespot
(c) Refracting lens
(e) Vertebrate eye
(b) Pinhole eye
(d) Multiple lenses in series

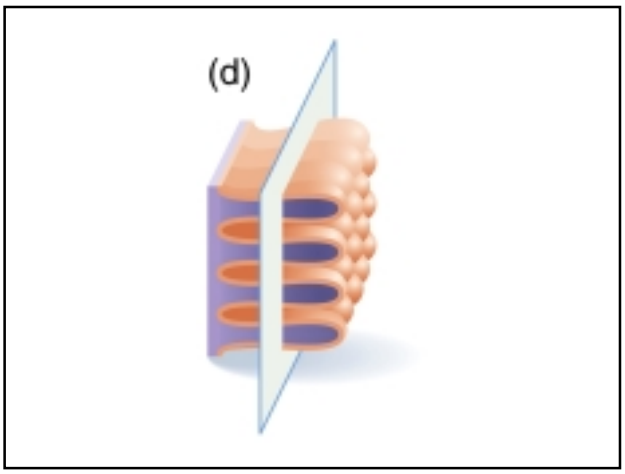

Ommatidium
Compound eye

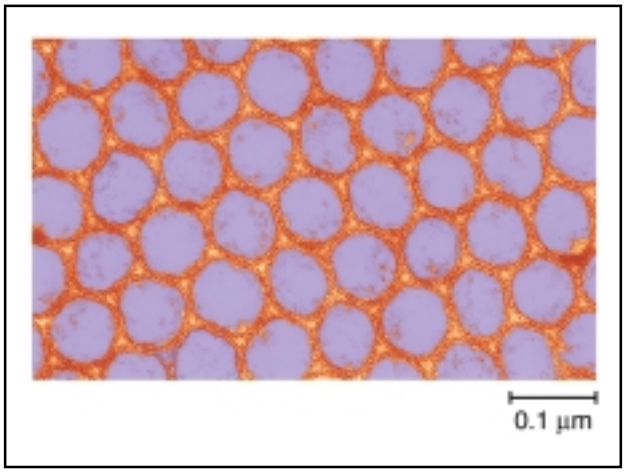

Lens
Vertebrate eye

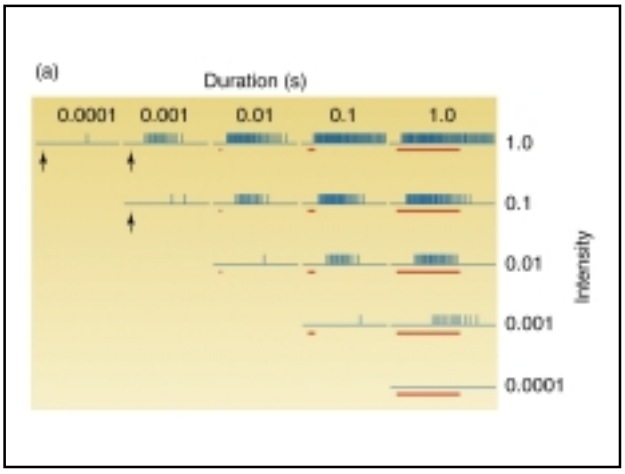

(a) *Limulus polyphemus*
Lateral simple eye
Lateral compound eye
Median simple eye

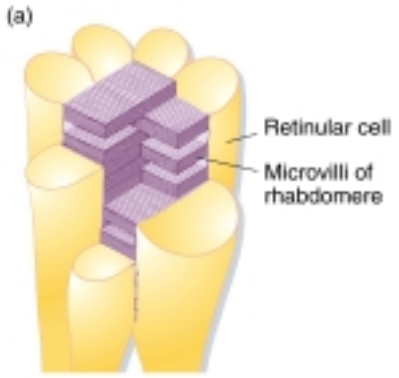

(b) Cross-section of lateral compound eye
Lens
Photoreceptors
Axon of eccentric cell

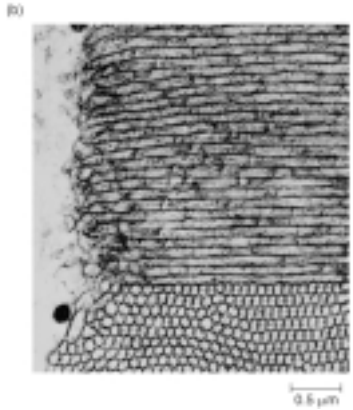

(c) Single ommatidium
Light
Lens
Retinular cell
Dendrite of eccentric cell
Rhabdomere of retinular cell
Eccentric cell
Axon
Light on
Light off

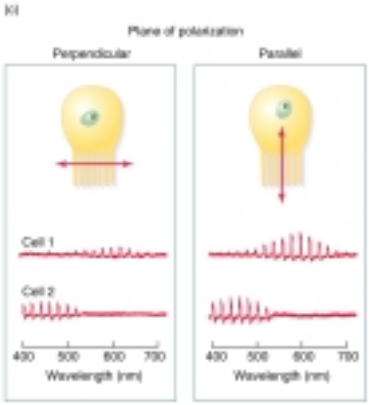

(d)

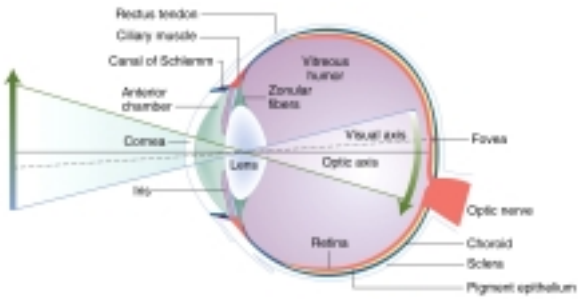

0.1 µm

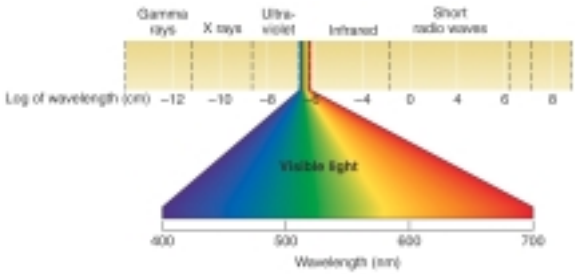

(a)
Duration (s)
0.0001
0.001
0.01
0.1
1.0
Intensity
1.0
0.1
0.01
0.001
0.0001

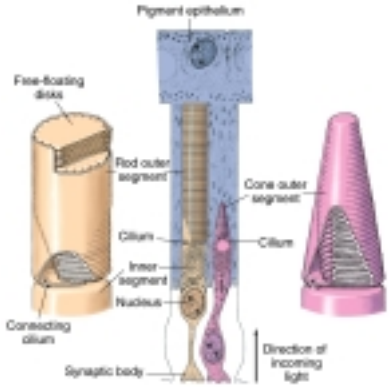

(a)
Retinular cell
Microvilli of rhabdomere

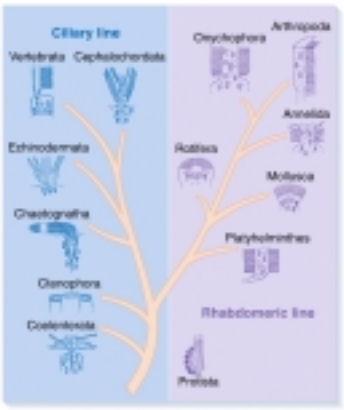

(b)
0.5 μm

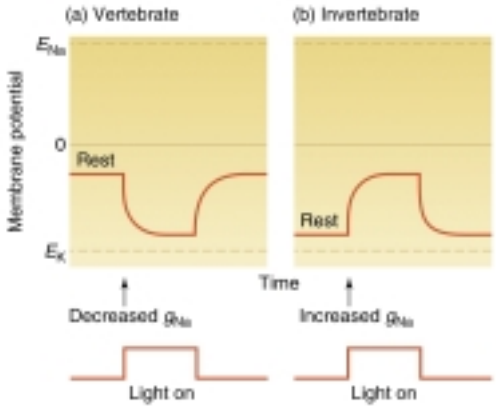

(c)
Plane of polarization
Perpendicular
Parallel
Cell 1
Cell 2
400 500 600 700
Wavelength (nm)
400 500 600 700
Wavelength (nm)

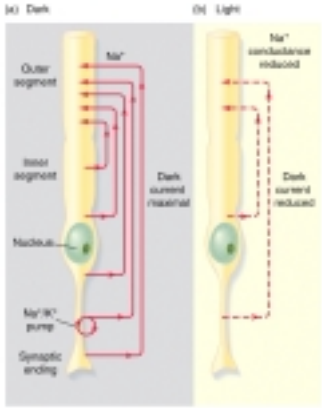

Rectus tendon
Ciliary muscle
Canal of Schlemm
Anterior chamber
Vitreous humor
Zonular fibers
Cornea
Visual axis
Fovea
Lens
Optic axis
Iris
Optic nerve
Retina
Choroid
Sclera
Pigment epithelium

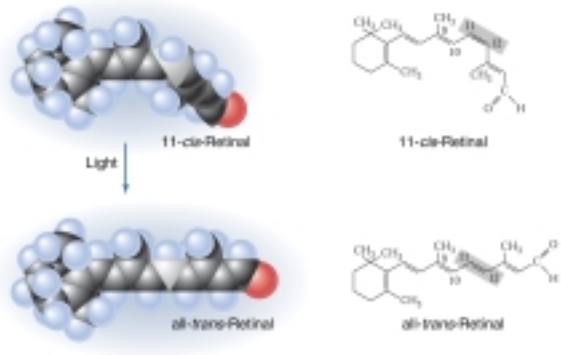

Gamma rays
X rays
Ultra-violet
Infrared
Short radio waves
Log of wavelength (cm) −12 −10 −8 −6 −4 0 4 6 8
Visible light
400 500 600 700
Wavelength (nm)

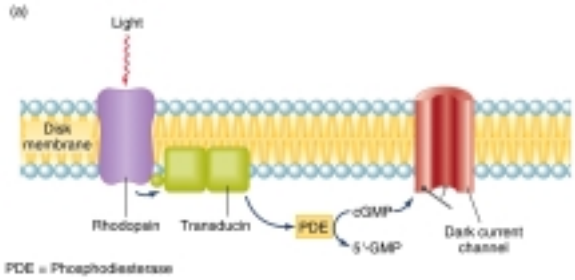

Pigment epithelium
Free-floating disks
Rod outer segment
Cone outer segment
Cilium
Cilium
Inner segment
Nucleus
Connecting cilium
Synaptic body
Direction of incoming light

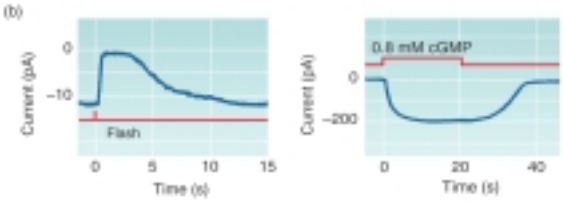

Ciliary line
Vertebrata
Cephalochordata
Echinodermata
Chaetognatha
Ctenophora
Coelenterata
Onychophora
Arthropoda
Annelida
Rotifera
Mollusca
Platyhelminthes
Rhabdomeric line
Protista

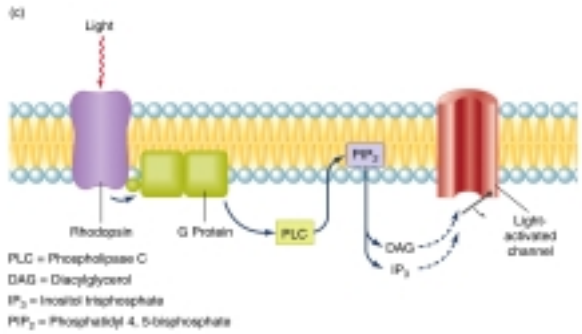

(a) Vertebrate
(b) Invertebrate
Membrane potential
E_{Na}
0
E_K
Rest
Rest
Time
Decreased g_{Na}
Increased g_{Na}
Light on
Light on

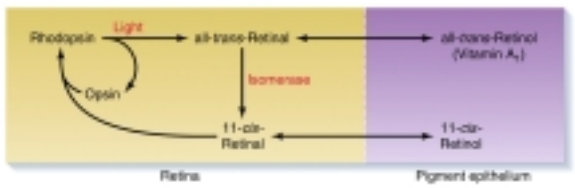

(a) Dark
(b) Light
Outer segment
Inner segment
Nucleus
Na⁺/K⁺ pump
Synaptic ending
Dark current maximal
Dark current reduced

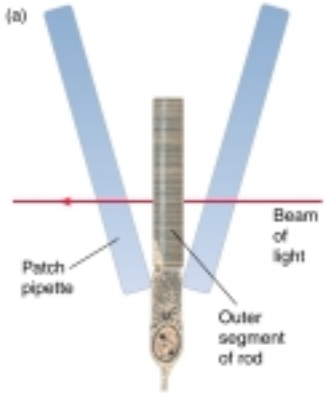

11-cis-Retinal
Light
all-trans-Retinal
11-cis-Retinal
all-trans-Retinal

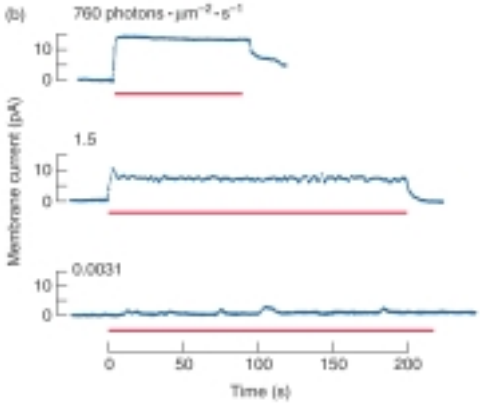

(a)
Light
Disk membrane
Rhodopsin
Transducin
PDE
cGMP
5'-GMP
Dark current channel
PDE = Phosphodiesterase

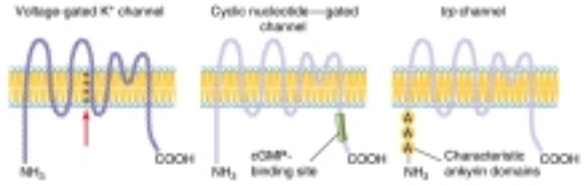

(b)
Current (pA)
0
−10
Flash
0
5
10
15
Time (s)
0.8 mM cGMP
Current (pA)
0
−200
0
20
40
Time (s)

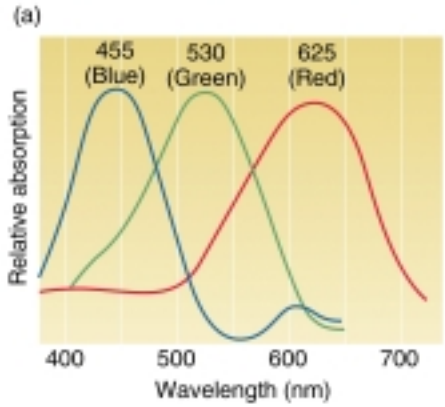

(c)
Light
Rhodopsin
G Protein
PLC
PIP2
DAG
IP3
Light-activated channel
PLC = Phospholipase C
DAG = Diacylglycerol
IP3 = Inositol trisphosphate
PIP2 = Phosphatidyl 4, 5-bisphosphate


Rhodopsin
Light
all-trans-Retinal
all-trans-Retinol (Vitamin A1)
Opsin
Isomerase
11-cis-Retinal
11-cis-Retinal
Retina
Pigment epithelium


(a)
Beam of light
Patch pipette
Outer segment of rod


(b)
760 photons · μm⁻² · s⁻¹
1.5
0.0031
Membrane current (pA)
10
0
0
50
100
150
200
Time (s)


Voltage-gated K⁺ channel
Cyclic nucleotide—gated channel
Ion channel
NH3
COOH
cGMP-binding site
Characteristic ankyrin domains


(a)
455 (Blue)
530 (Green)
625 (Red)
Relative absorption
400
500
600
700
Wavelength (nm)