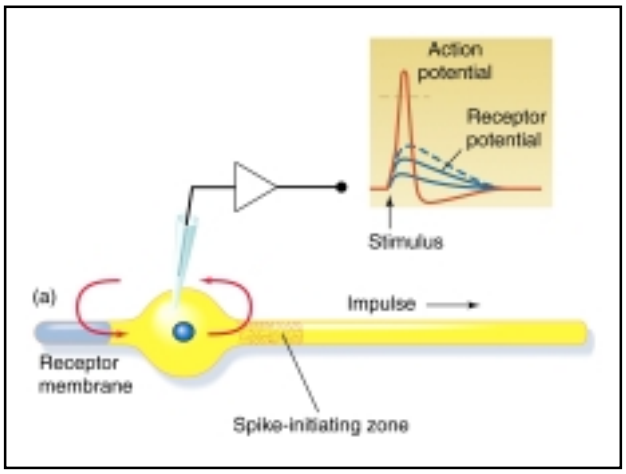
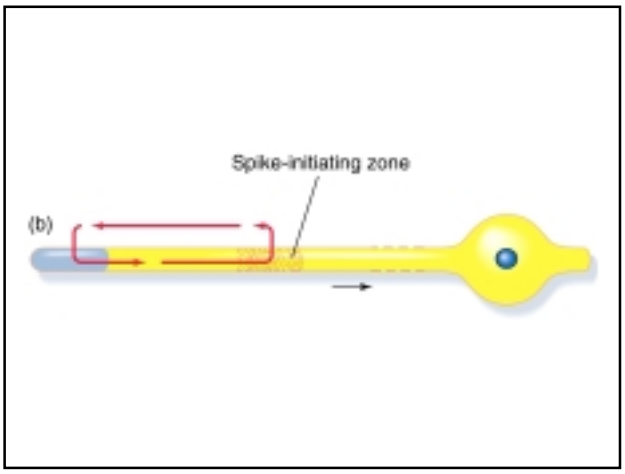
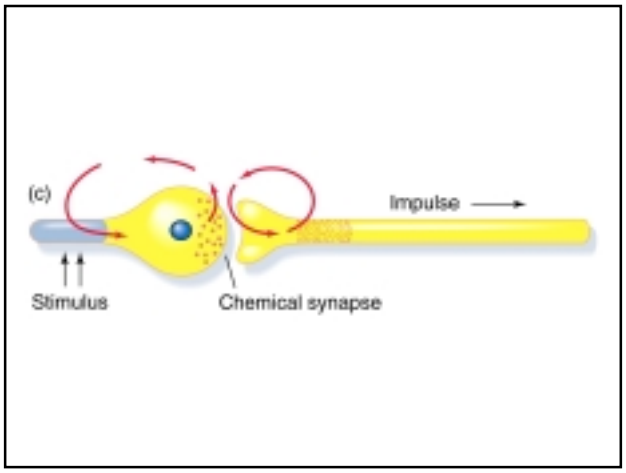
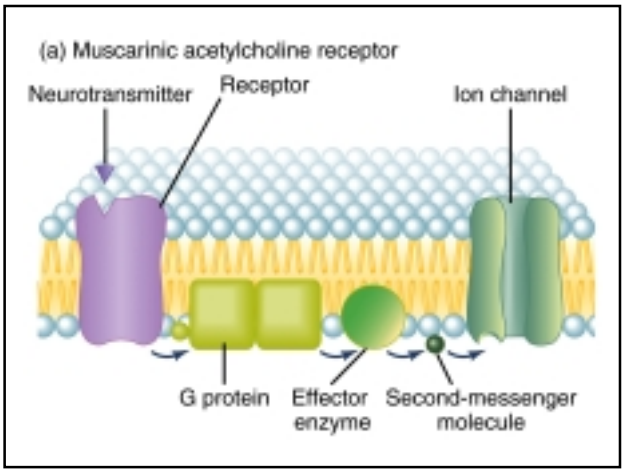
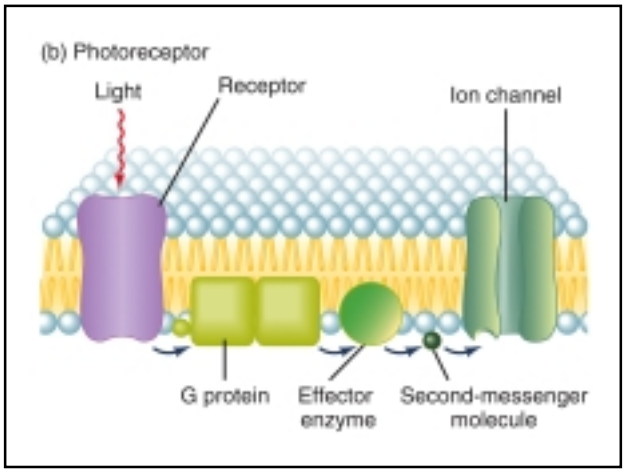
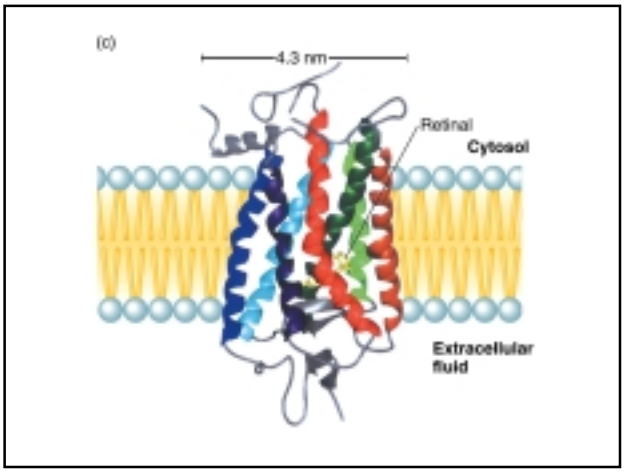

Action potential
Receptor potential
Stimulus
(a)
Impulse
Receptor membrane
Spike-initiating zone

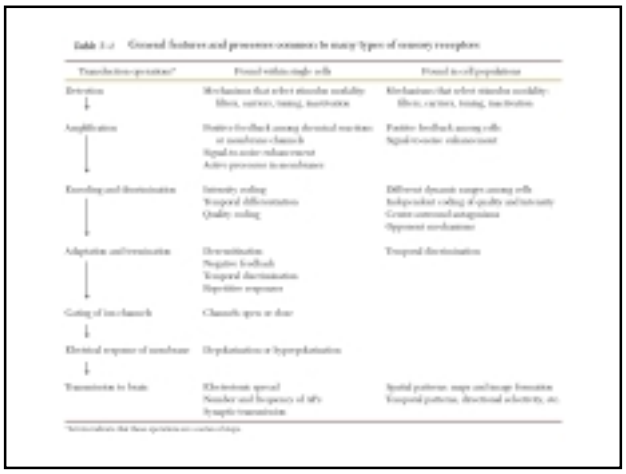

Spike-initiating zone
(b)


(c)
Impulse
Stimulus
Chemical synapse


(a) Muscarinic acetylcholine receptor
Neurotransmitter
Receptor
Ion channel
G protein
Effector enzyme
Second-messenger molecule

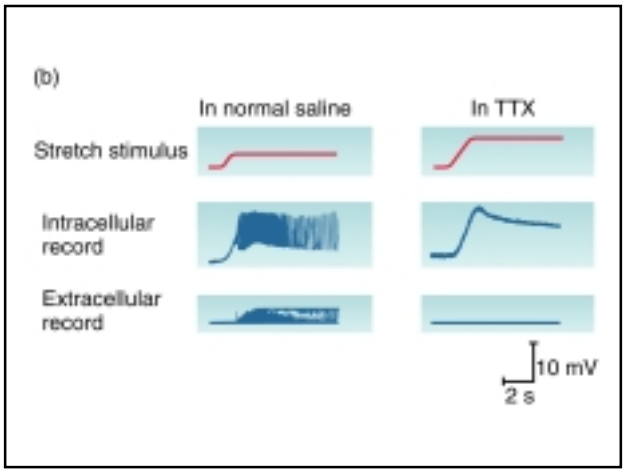

(b) Photoreceptor
Light
Receptor
Ion channel
G protein
Effector enzyme
Second-messenger molecule

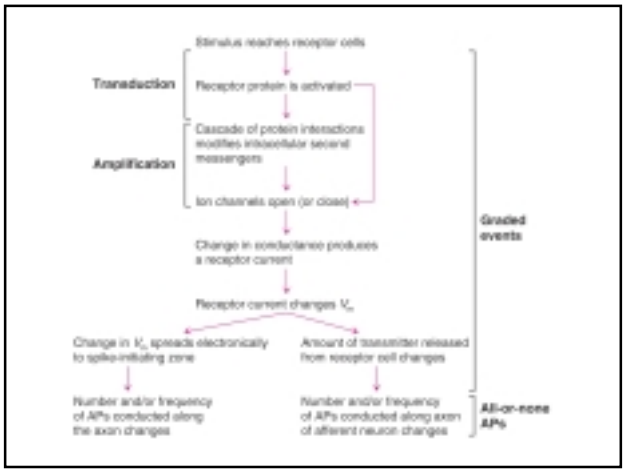

(c)
4.3 nm
Retinal
Cytosol
Extracellular fluid

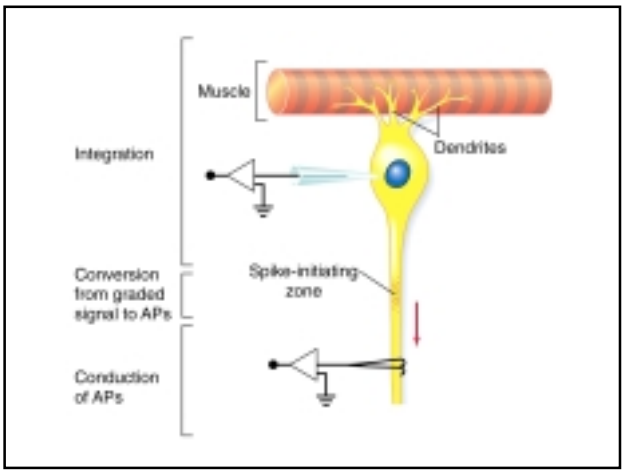


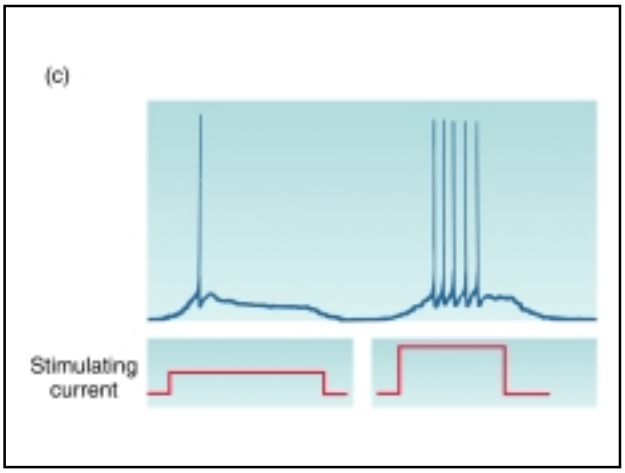
| Transduction operations* | Found within single cells | Found in cell populations |
|---|---|---|
| Detection | Mechanisms that select stimulus modality: filters, carriers, tuning, inactivation | Mechanisms that select stimulus modality: filters, carriers, tuning, inactivation |
| Amplification | Positive feedback among elevated reactions or membrane channels<br>Signal to noise enhancement<br>Active processes in membranes | Positive feedback among cells<br>Signal to noise enhancement |
| Encoding and discrimination | Intensity coding<br>Temporal differentiation<br>Quality coding | Different dynamic ranges among cells<br>Independent coding of quality and intensity<br>Center-surround antagonism<br>Opponent mechanisms |
| Adaptation and termination | Desensitization<br>Negative feedback<br>Temporal discrimination<br>Hyperbolic responses | Temporal discrimination |
| Gating of ion channels | Channels open or close | |
| Electrical response of membrane | Depolarization or hyperpolarization | |
| Transmission to brain | Electrotonic spread<br>Number and frequency of APs<br>Synaptic transmission | Spatial patterns, maps and image formation<br>Temporal patterns, directional selectivity, etc. |

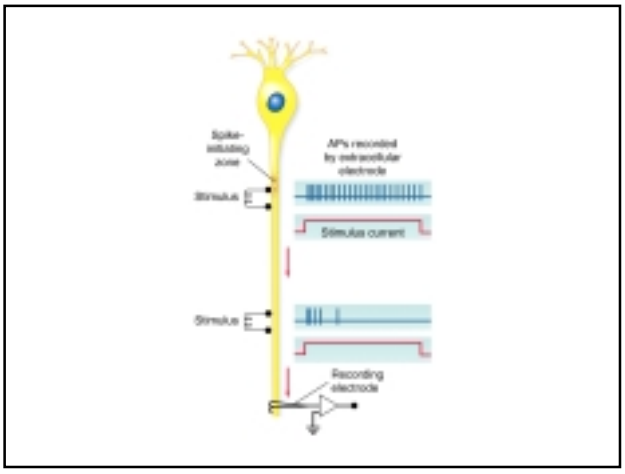
*It is unknown that these operations are cumulative.

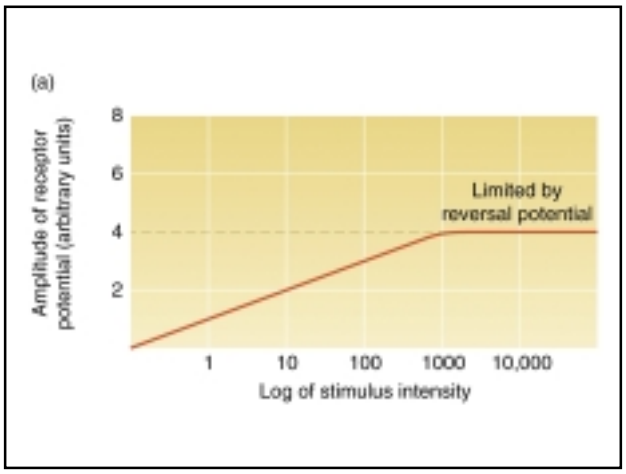


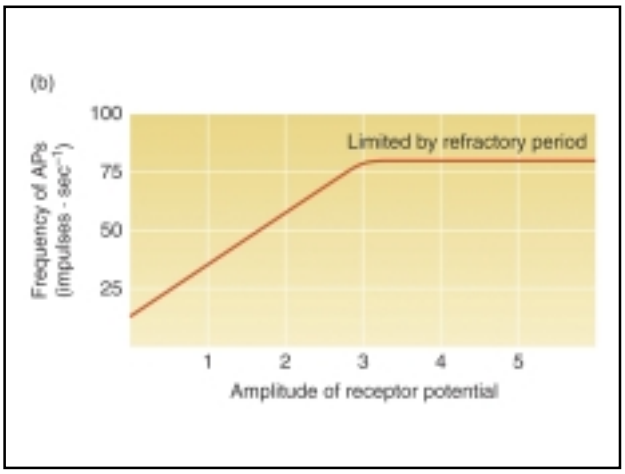



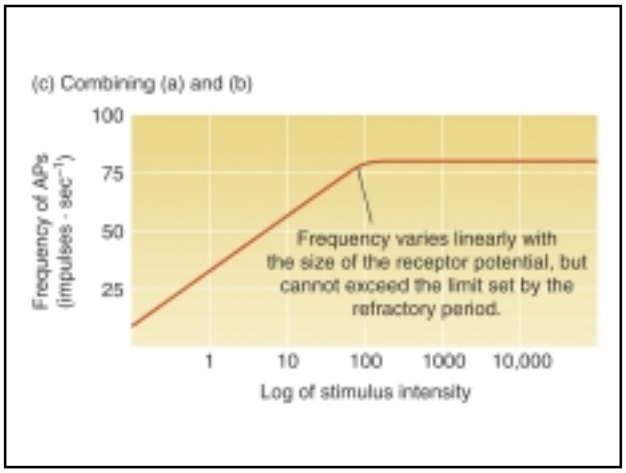



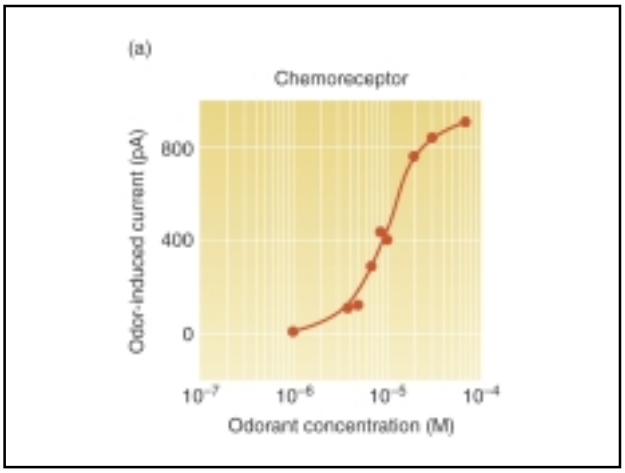



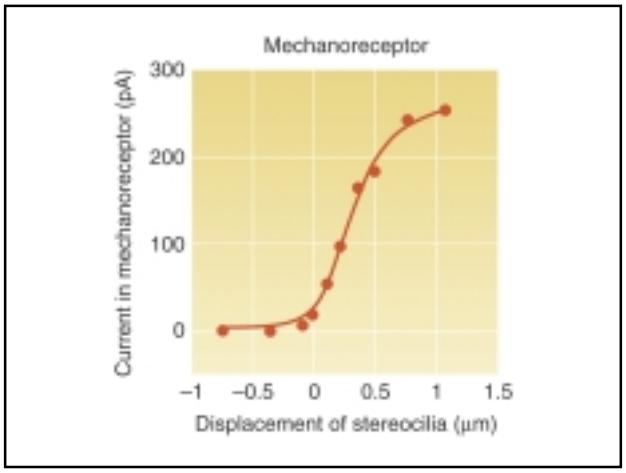



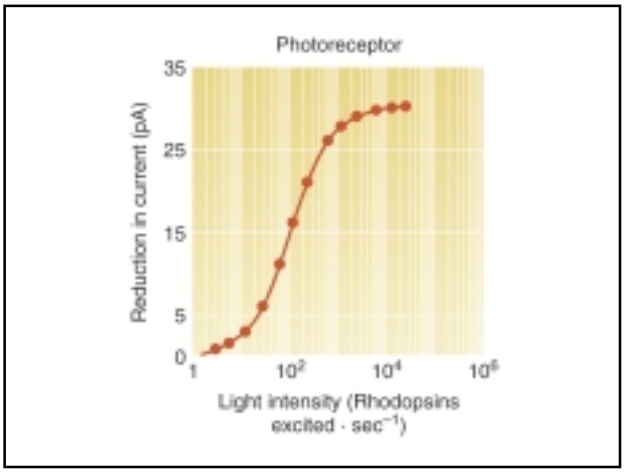

(a)
Amplitude of receptor potential (arbitrary units)
8
6
4
2
Limited by reversal potential
1
10
100
1000
10,000
Log of stimulus intensity

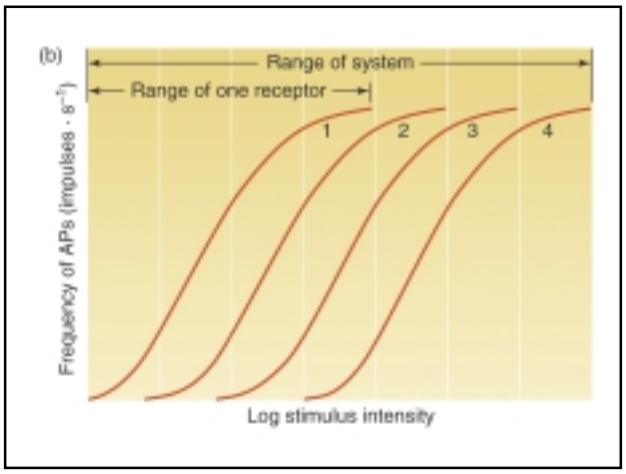

(b)
Frequency of APs (impulses · sec⁻¹)
100
75
50
25
Limited by refractory period
1
2
3
4
5
Amplitude of receptor potential

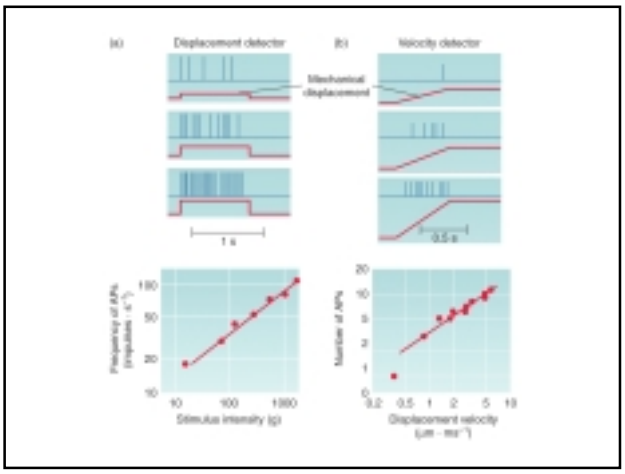

(c) Combining (a) and (b)
Frequency of APs (impulses · sec⁻¹)
100
75
50
25
Frequency varies linearly with the size of the receptor potential, but cannot exceed the limit set by the refractory period.
1
10
100
1000
10,000
Log of stimulus intensity

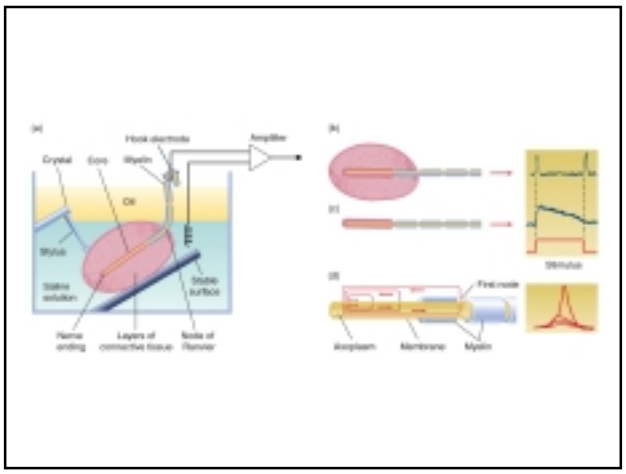

(a)
Chemoreceptor
Odor-induced current (pA)
800
400
0
10⁻⁷
10⁻⁶
10⁻⁵
10⁻⁴
Odorant concentration (M)

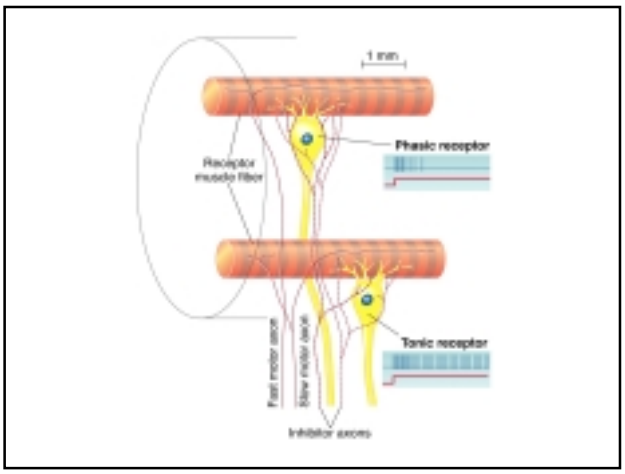

Mechanoreceptor
Current in mechanoreceptor (pA)
300
200
100
0
−1
−0.5
0
0.5
1
1.5
Displacement of stereocilia (μm)

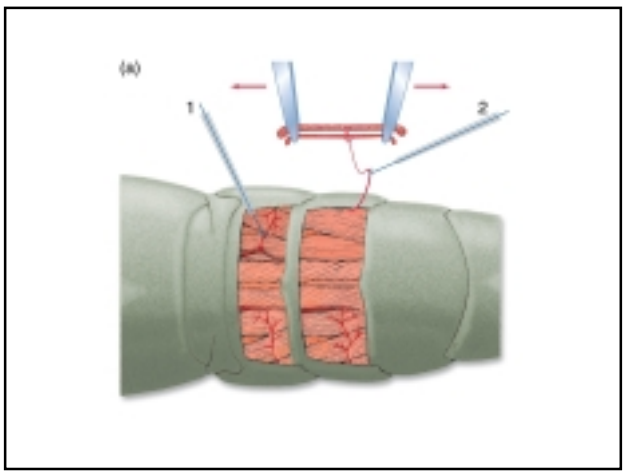

Photoreceptor
Reduction in current (pA)
35
25
15
5
0
1
10²
10⁴
10⁶
Light intensity (Rhodopsins excited · sec⁻¹)

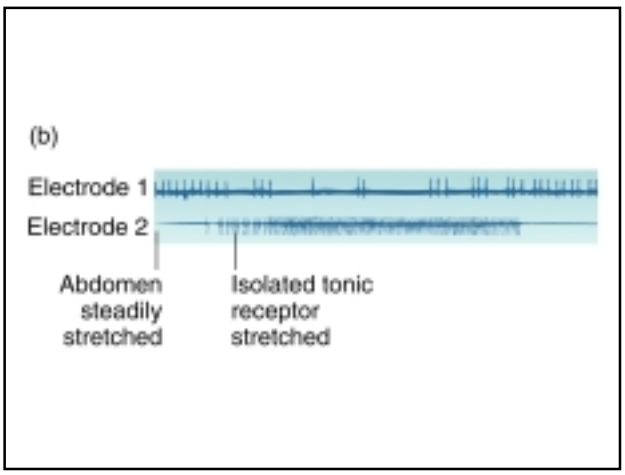

(b)
Range of system
Range of one receptor
1
2
3
4
Frequency of APs (impulses · s⁻¹)
Log stimulus intensity

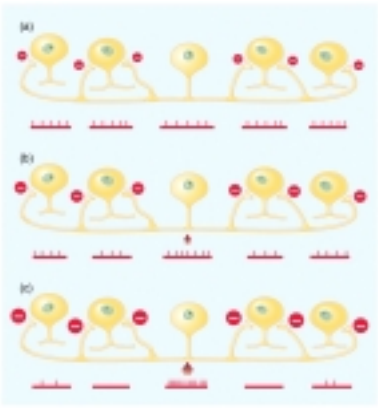

(a) Displacement detector
(b) Velocity detector
Mechanical displacement
1 s
0.5 s
Frequency of APs (impulses · s⁻¹)
Number of APs
Stimulus intensity (g)
Displacement velocity (μm · ms⁻¹)

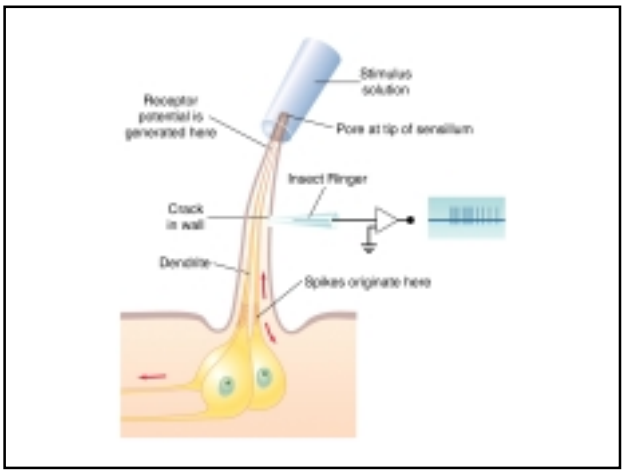

Hook electrode
Amplifier
Crystal
Cuticle
Myelin
Oil
Stylus
Saline solution
Stable surface
Nerve ending
Layers of connective tissue
Node of Ranvier
Stimulus
First node
Axoplasm
Membrane
Myelin

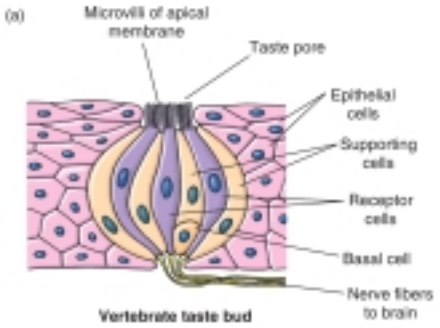

1 mm
Phasic receptor
Receptor muscle fiber
Tonic receptor
Fast motor axon
Slow motor axon
Inhibitor axons

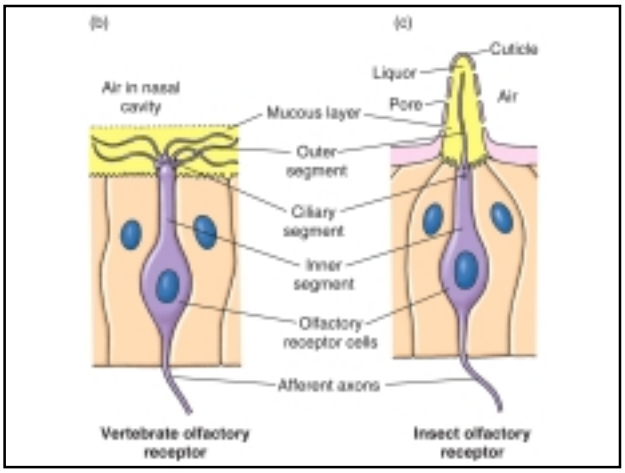

(a)
1
2

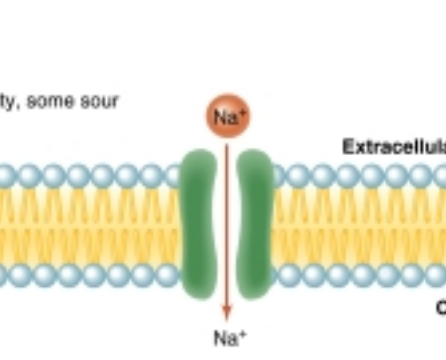

(b)
Electrode 1
Electrode 2
Abdomen steadily stretched
Isolated tonic receptor stretched

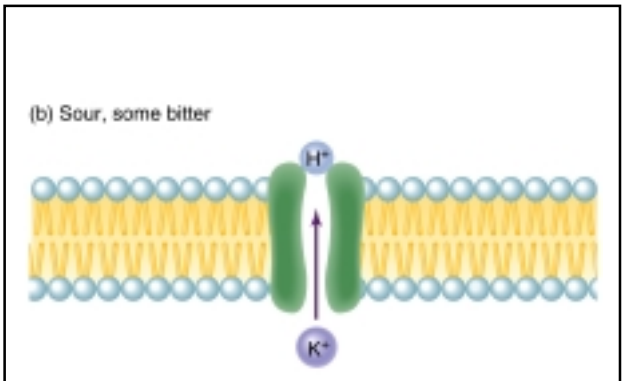

(a)
(b)
(c)

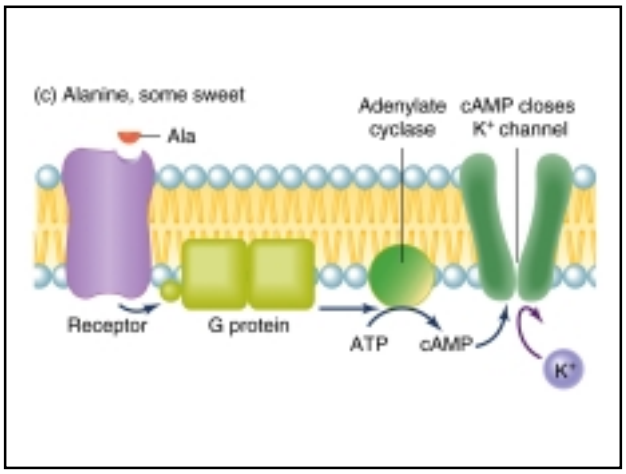

Stimulus solution
Receptor potential is generated here
Pore at tip of sensillum
Insect flinger
Crack in wall
Dendrite
Spikes originate here

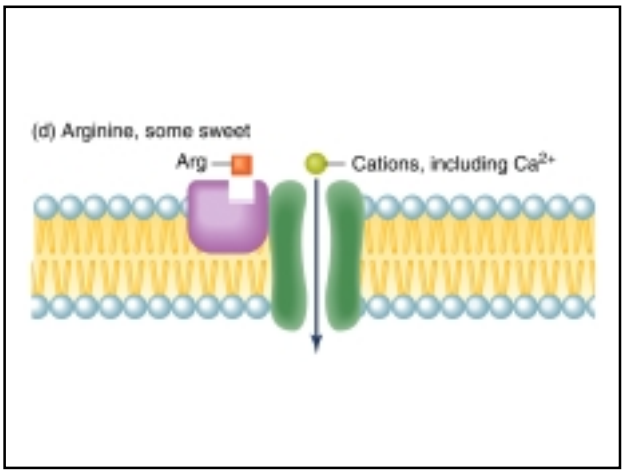

(a)
Microvilli of apical membrane
Taste pore
Epithelial cells
Supporting cells
Receptor cells
Basal cell
Nerve fibers to brain
Vertebrate taste bud

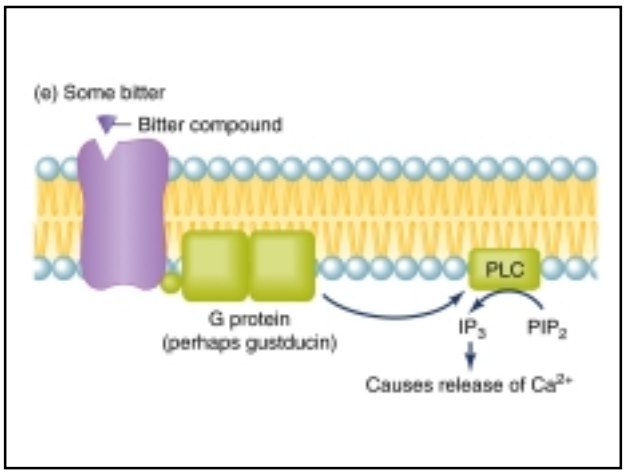

(b)
(c)
Air in nasal cavity
Cuticle
Liquor
Pore
Air
Mucous layer
Outer segment
Ciliary segment
Inner segment
Olfactory receptor cells
Afferent axons
Vertebrate olfactory receptor
Insect olfactory receptor

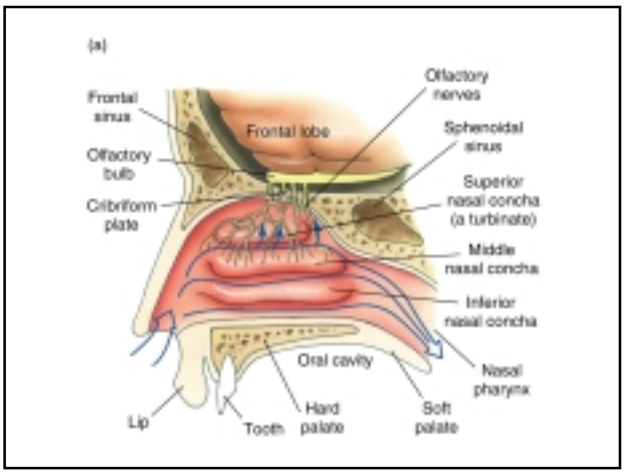

(a) Salty, some sour
Na+
Extracellular fluid
Cytosol
Na+

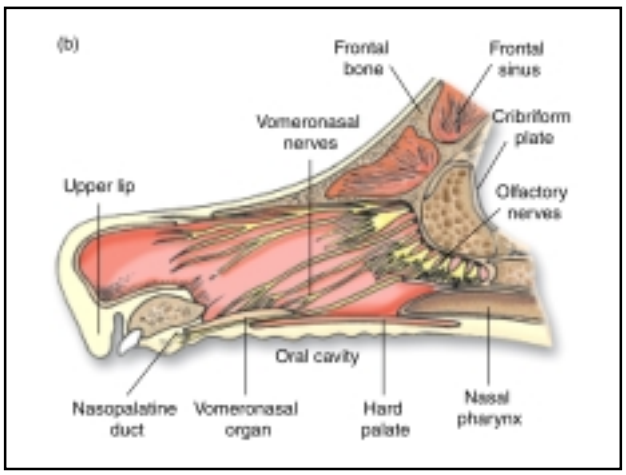

(b) Sour, some bitter
H+
K+

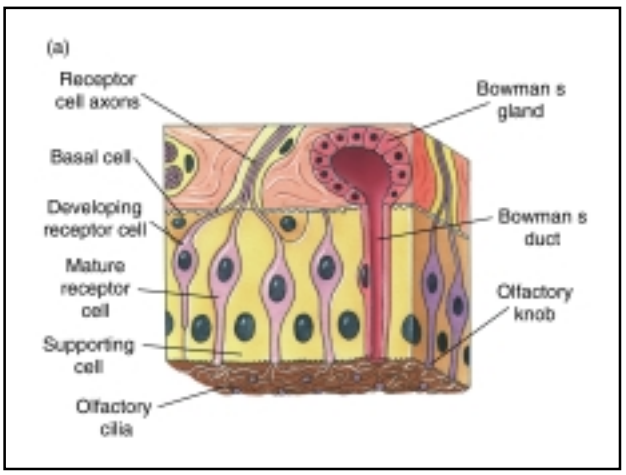

(c) Alanine, some sweet
Ala
Adenylate cyclase
cAMP closes K+ channel
Receptor
G protein
ATP
cAMP
K+

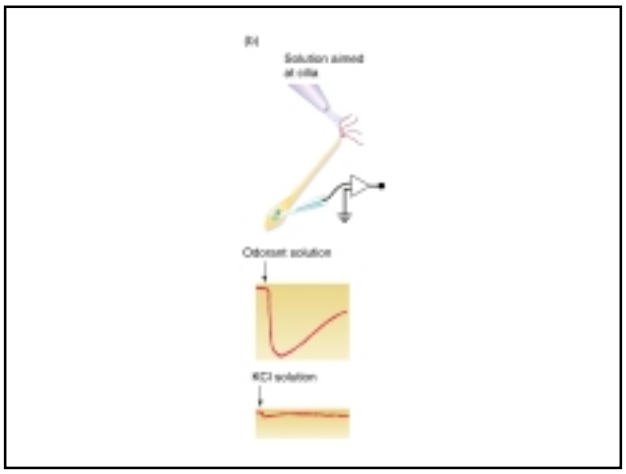

(d) Arginine, some sweet
Arg
Cations, including Ca2+

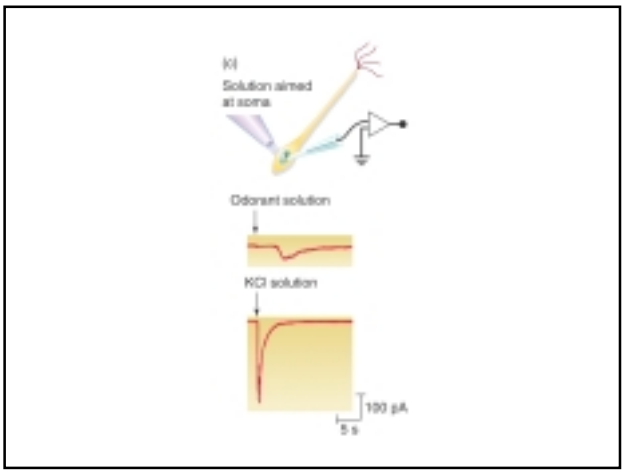

(e) Some bitter
Bitter compound
PLC
G protein
(perhaps gustducin)
IP3
PIP2
Causes release of Ca2+

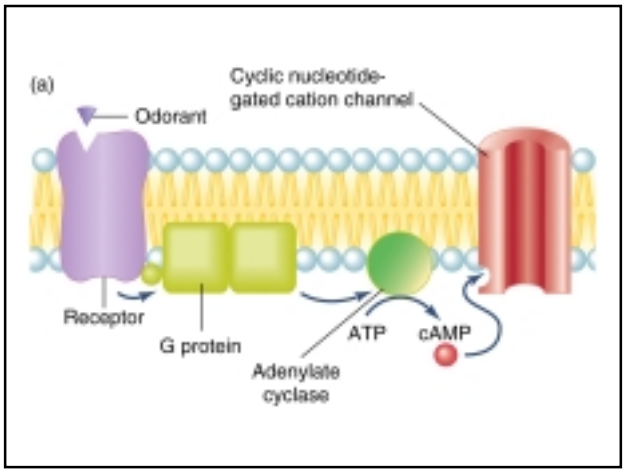

(a)
Frontal sinus
Olfactory nerves
Frontal lobe
Sphenoidal sinus
Olfactory bulb
Superior nasal concha (a turbinate)
Cribriform plate
Middle nasal concha
Inferior nasal concha
Oral cavity
Nasal pharynx
Lip
Tooth
Hard palate
Soft palate

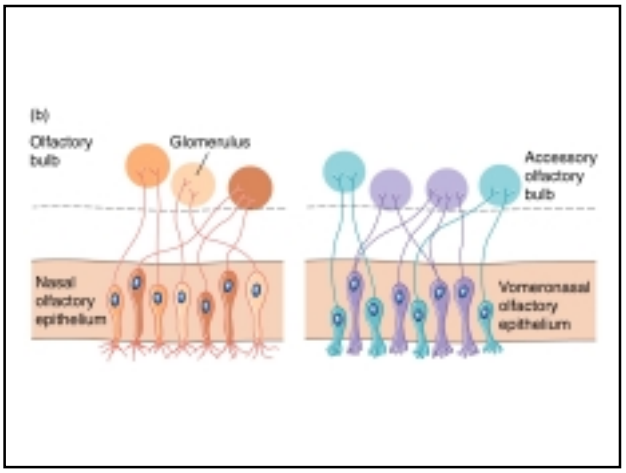

(b)
Frontal bone
Frontal sinus
Vomeronasal nerves
Cribriform plate
Upper lip
Olfactory nerves
Oral cavity
Nasopalatine duct
Vomeronasal organ
Hard palate
Nasal pharynx

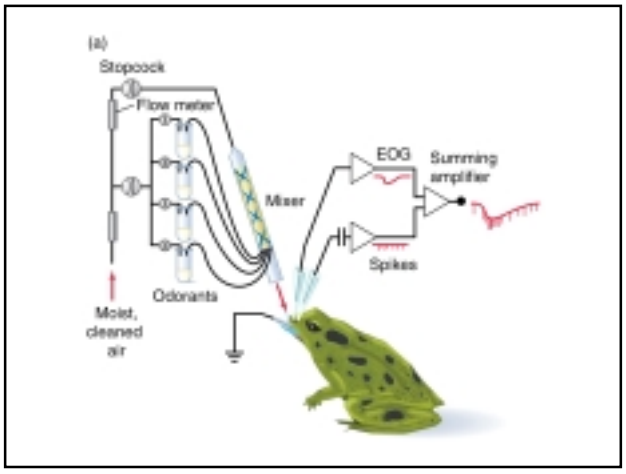

(a)
Receptor cell axons
Bowman s gland
Basal cell
Developing receptor cell
Bowman s duct
Mature receptor cell
Olfactory knob
Supporting cell
Olfactory cilia

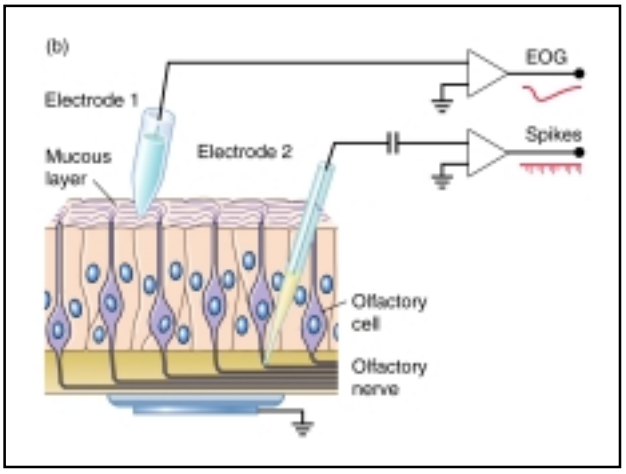

(a)
Solution aimed at cilia
Odorant solution
KCl solution

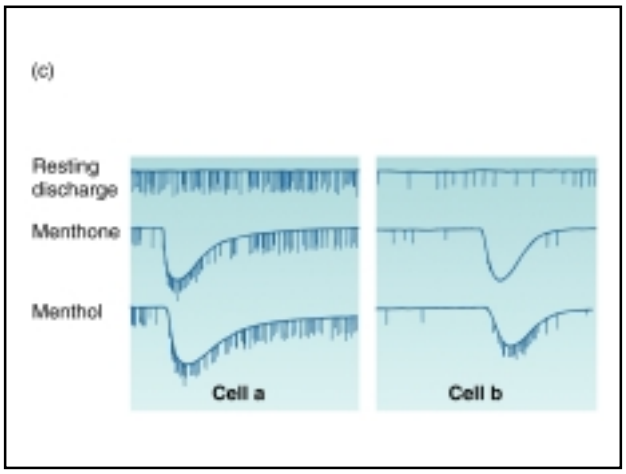

(c)
Solution aimed at soma
Odorant solution
KCl solution
100 pA
5 s

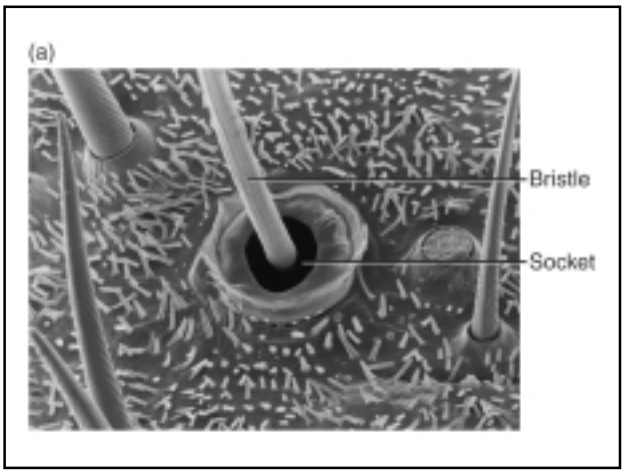

(a)
Cyclic nucleotide-gated cation channel
Odorant
Receptor
G protein
Adenylate cyclase
ATP
cAMP

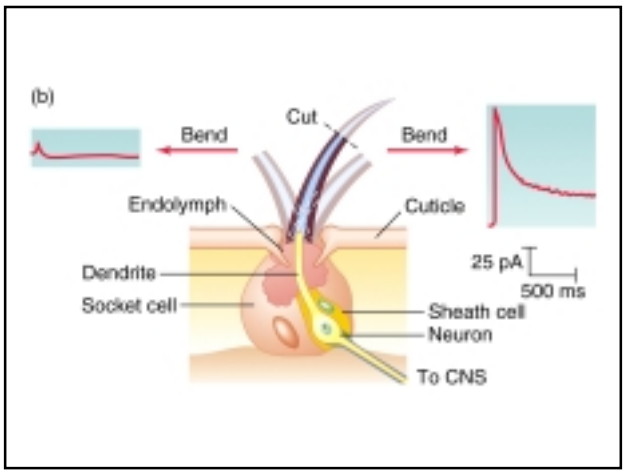

(b)
Olfactory bulb
Glomerulus
Accessory olfactory bulb
Nasal olfactory epithelium
Vomeronasal olfactory epithelium

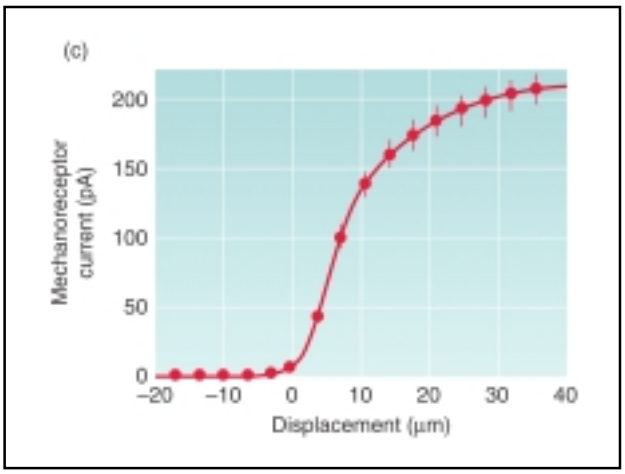

(a)
Stopcock
Flow meter
Mixer
EOG
Summing amplifier
Spikes
Odorants
Moist, cleaned air

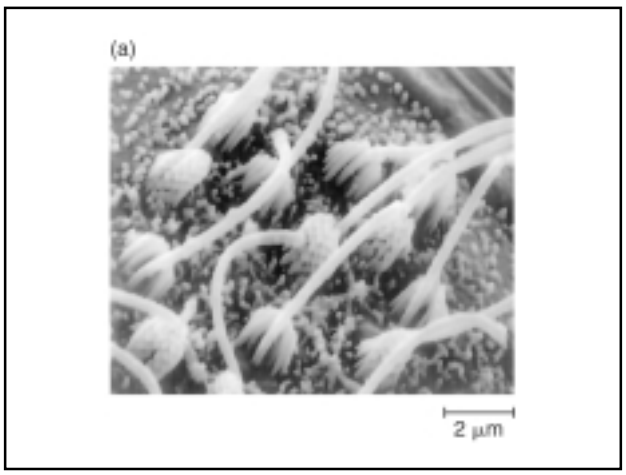

(b)
EOG
Electrode 1
Spikes
Mucous layer
Electrode 2
Olfactory cell
Olfactory nerve

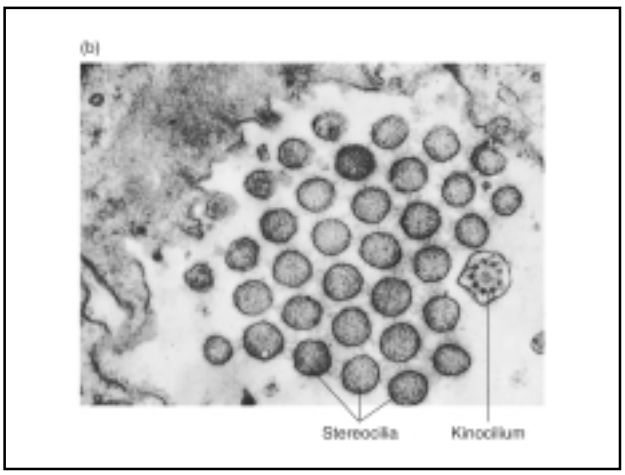

(c)
Resting discharge
Menthone
Menthol
Cell a
Cell b

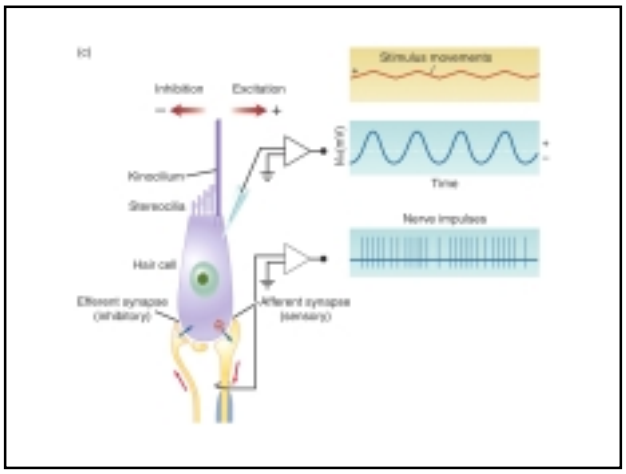

(a)
Bristle
Socket

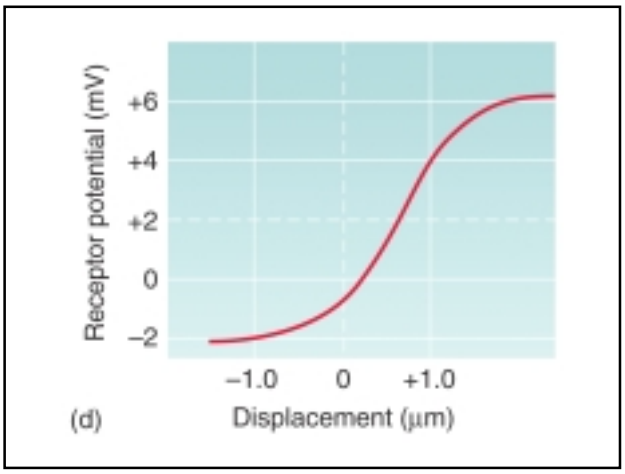

(b)
Bend
Cut
Bend
Endolymph
Cuticle
Dendrite
Socket cell
25 pA
500 ms
Sheath cell
Neuron
To CNS

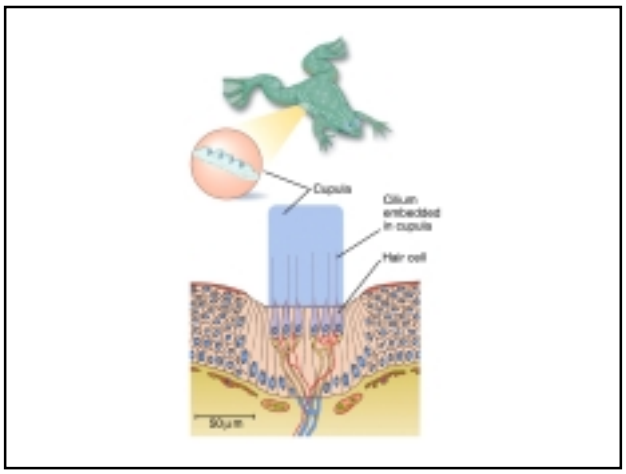

(c)
Mechanoreceptor current (pA)
200
150
100
50
0
−20
−10
0
10
20
30
40
Displacement (μm)

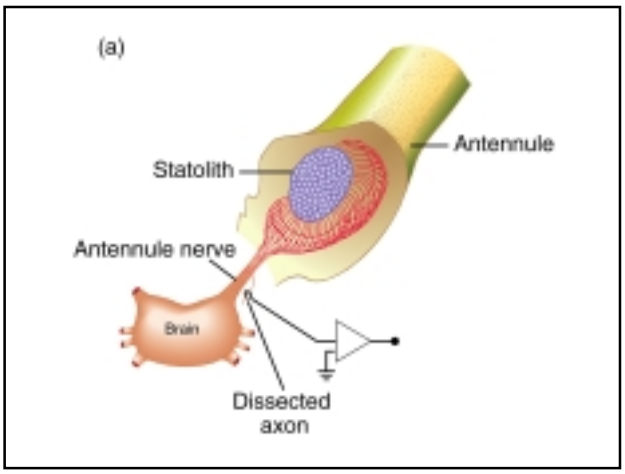

(a)
2 μm


(b)
Stereocilia
Kinocilium


(c)
Stimulus movement
Inhibition
Excitation
Kinocilium
Stereocilia
Hair cell
Efferent synapse (inhibitory)
Afferent synapse (sensory)
Time
Nerve impulses


Receptor potential (mV)
+6
+4
+2
0
−2
−1.0
0
+1.0
(d)
Displacement (μm)


Cupula
Cilium embedded in cupula
Hair cell
50 μm


(a)
Statolith
Antennule
Antennule nerve
Brain
Dissected axon