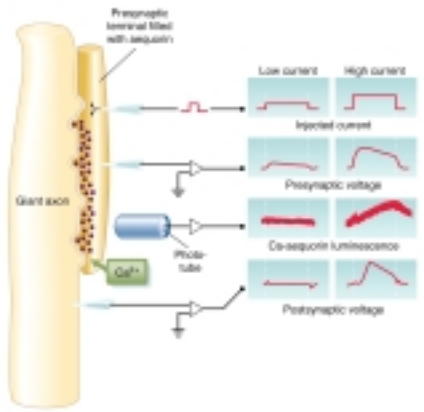
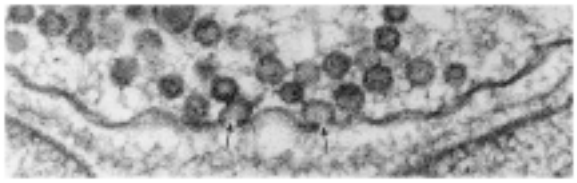
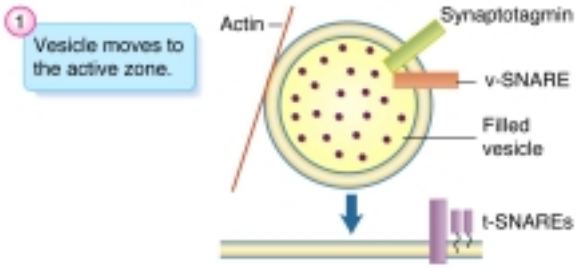
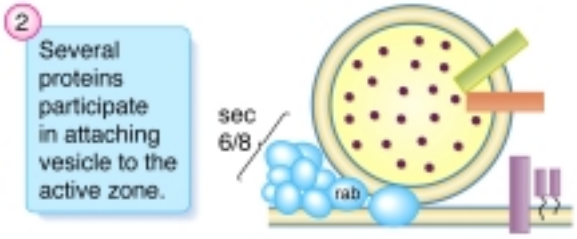
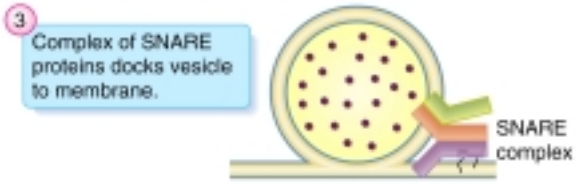

Low current
High current
Injected current
Presynaptic voltage
Giant axon
Ca-aequorin luminescence
Pipette-tube
Postsynaptic voltage




1
Vesicle moves to the active zone.
Actin
Synaptotagmin
v-SNARE
Filled vesicle
t-SNAREs


2
Several proteins participate in attaching vesicle to the active zone.
sec 6/8
rab


3
Complex of SNARE proteins docks vesicle to membrane.
SNARE complex

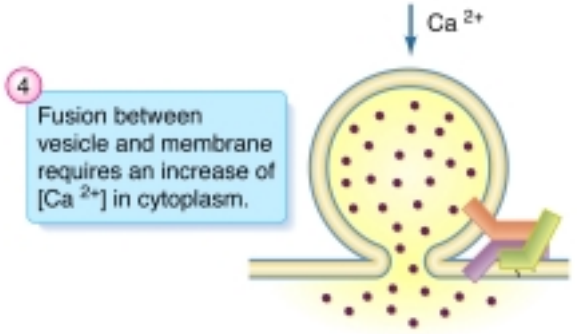
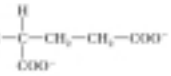
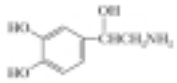
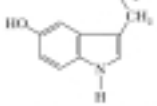

Ca 2+
4
Fusion between vesicle and membrane requires an increase of [Ca 2+] in cytoplasm.

Table 6-2 Typical small neurotransmitters, their structures, and functions

Neurotransmitter	Typical effects*	Structure
Acetylcholine (ACh)	Fast excitation; slow inhibition	
Glycine (Gly)	Fast inhibition	
γ-Aminobutyric acid (GABA)	Fast inhibition; slow inhibition	$^{+}H_3N-CH_2-CH_2-CH_2-COO^-$
Glutamate (Glu)	Fast excitation; slow change in postsynaptic metabolism	

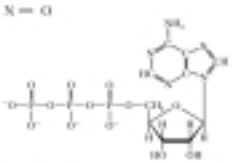
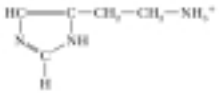
*Notice that the effect of a neurotransmitter depends on the properties of the postsynaptic cell. For most neurotransmitters, however, it is possible to identify their most probable effect.

Table 6-2 Typical small neurotransmitters, their structures, and functions

Neurotransmitter	Typical effects*	Structure
Norepinephrine (Nor-epi)	Slow excitation; slow inhibition	
Dopamine	Differs with location but causes slow postsynaptic effects	
Serotonin (5-HT = 5-hydroxytryptamine)	Slow excitation or slow inhibition	

*Notice that the effect of a neurotransmitter depends on the properties of the postsynaptic cell. For most neurotransmitters, however, it is possible to identify their most probable effect.

Table 6-2 Typical small neurotransmitters, their structures, and functions

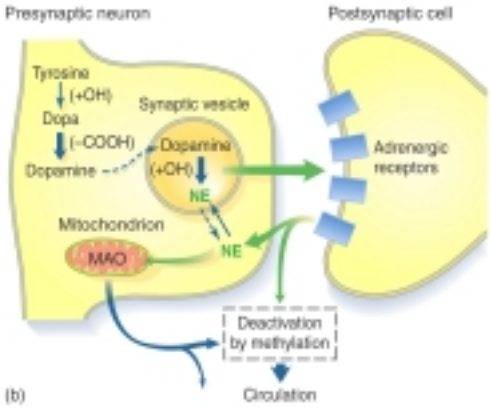
Neurotransmitter	Typical effects*	Structure
Nitrogen oxide (NO)	Synaptic modulation	$N=O$
Adenosine triphosphate (ATP)	Both fast and slow synaptic transmission	
Histamine	Slow modulation	

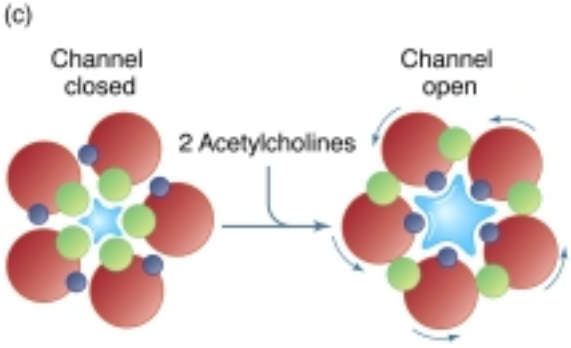
*Notice that the effect of a neurotransmitter depends on the properties of the postsynaptic cell. For most neurotransmitters, however, it is possible to identify their most probable effect.

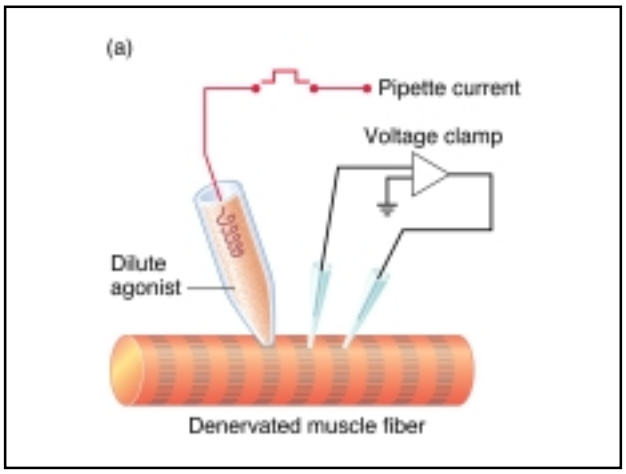
Acetylcholine (ACh)

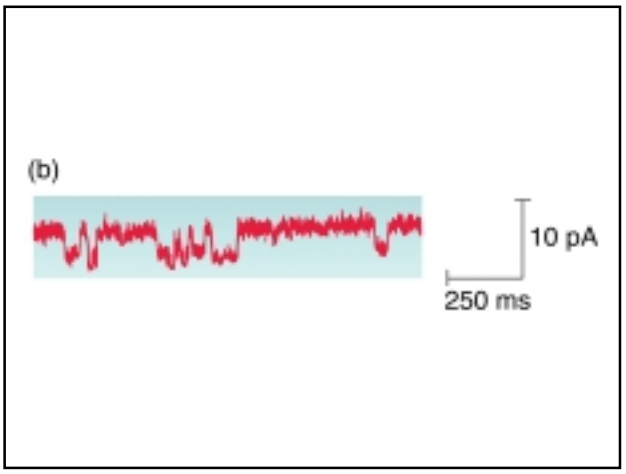
Carbachol, an ACh agonist

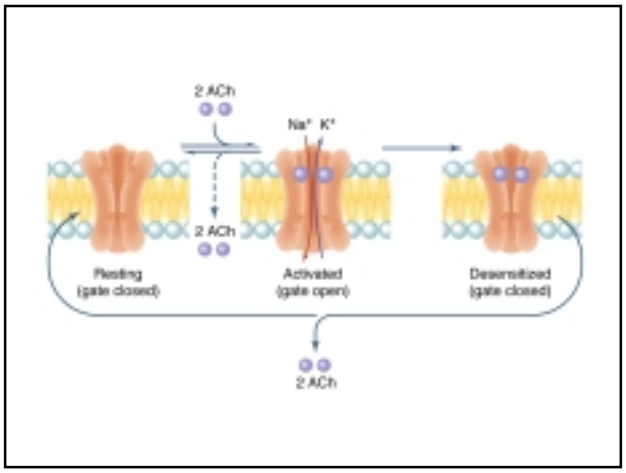
D-Tubocurarine, an ACh antagonist

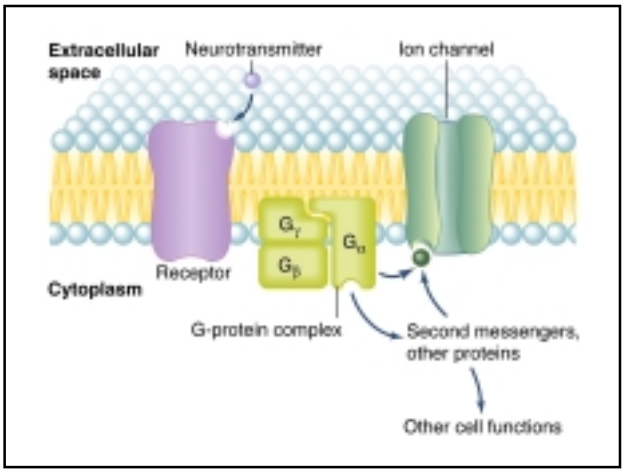


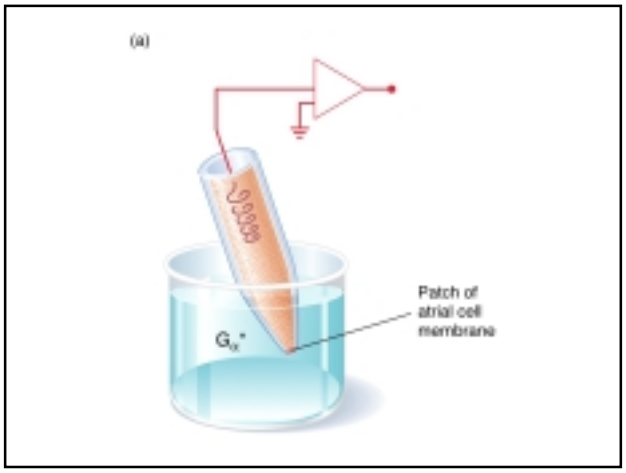


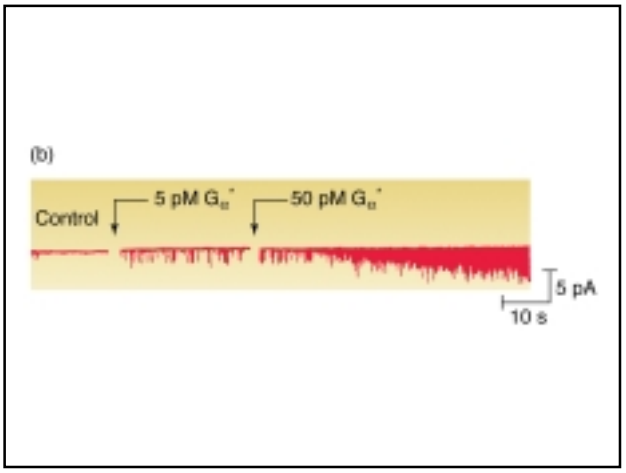

(a)
Pipette current
Voltage clamp
Dilute agonist
Denervated muscle fiber

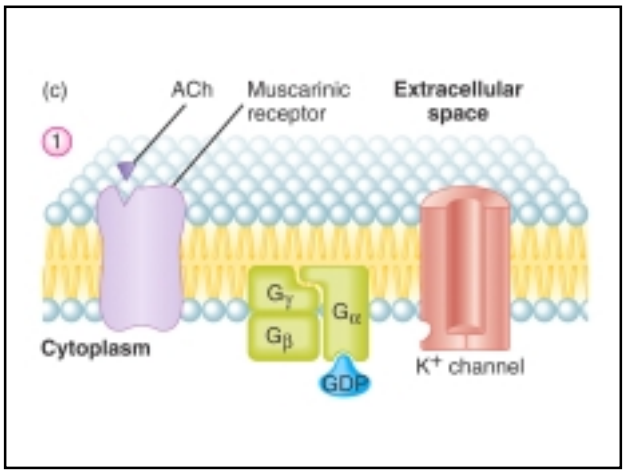

(b)
10 pA
250 ms

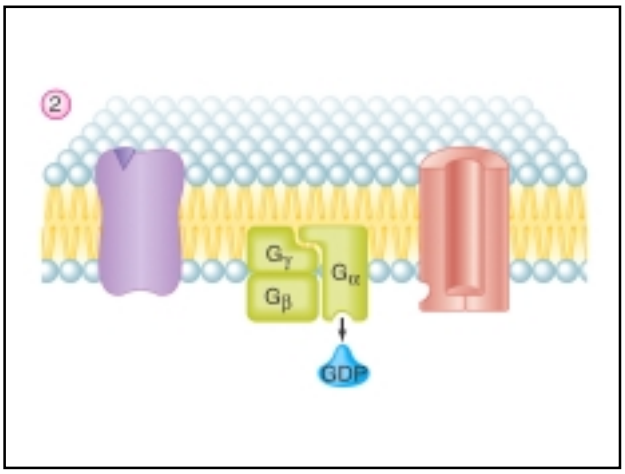

2 ACh
Na+ K+
2 ACh
Resting (gate closed)
Activated (gate open)
Desensitized (gate closed)
2 ACh

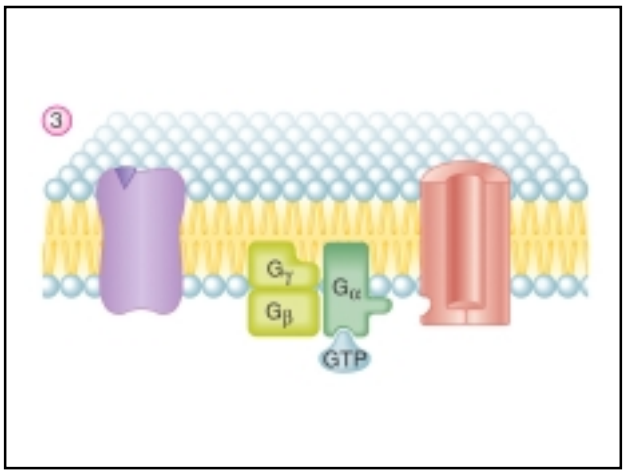

Extracellular space
Neurotransmitter
Ion channel
Receptor
Cytoplasm
G-protein complex
Second messengers, other proteins
Other cell functions

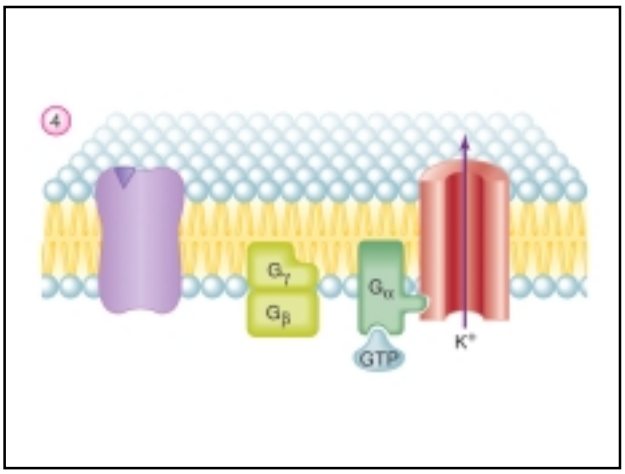

(a)
Patch of atrial cell membrane

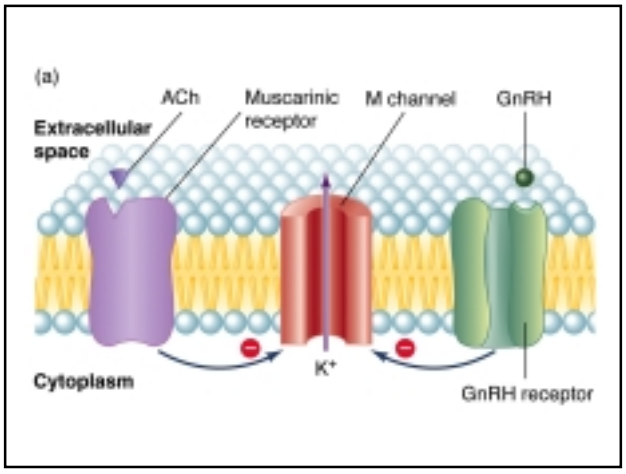

(b)
Control
5 pM
50 pM
5 pA
10 s

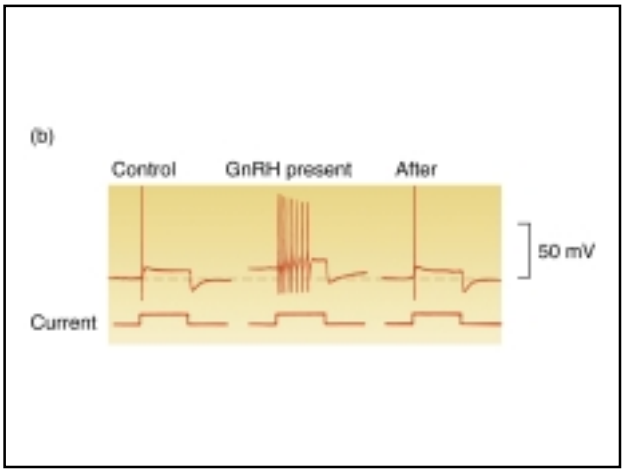

(c)
ACh
Muscarinic receptor
Extracellular space
1
Cytoplasm
Gγ
Gβ
Gα
GDP
K+ channel

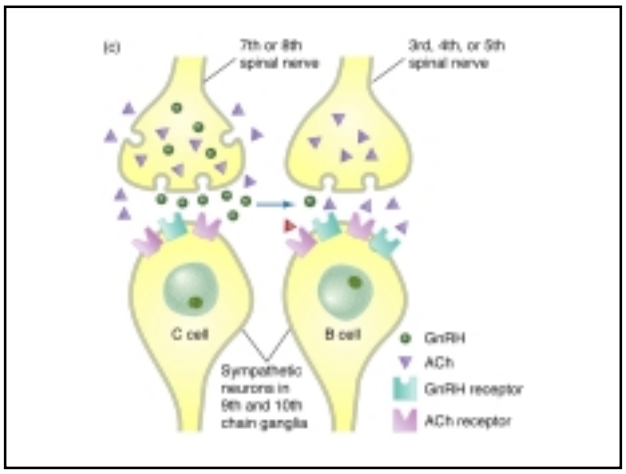

2
Gγ
Gβ
Gα
GDP

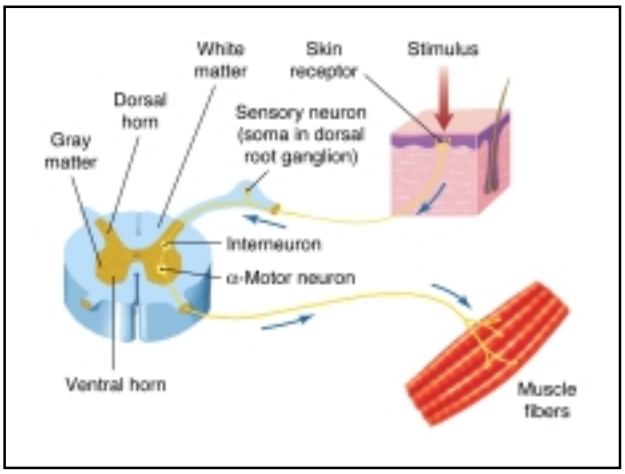

3
Gγ
Gβ
Gα
GTP

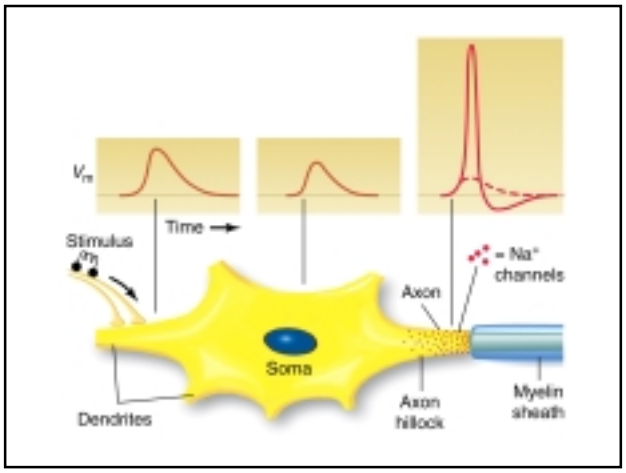

4
Gγ
Gβ
Gα
GTP
K+

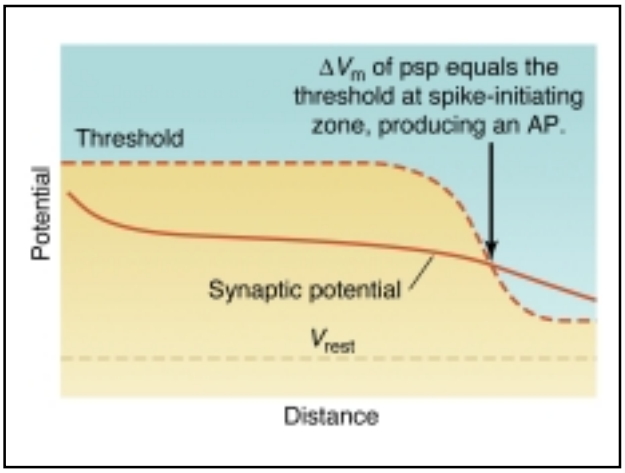

(a)
ACh
Muscarinic receptor
M channel
GnRH
Extracellular space
Cytoplasm
K+
GnRH receptor

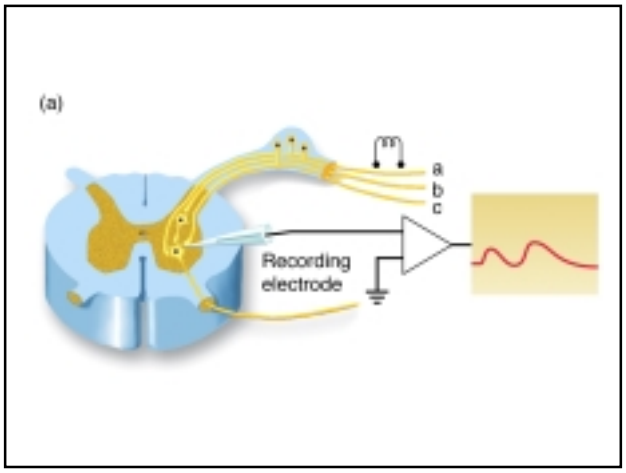

(b)
Control
GnRH present
After
50 mV
Current

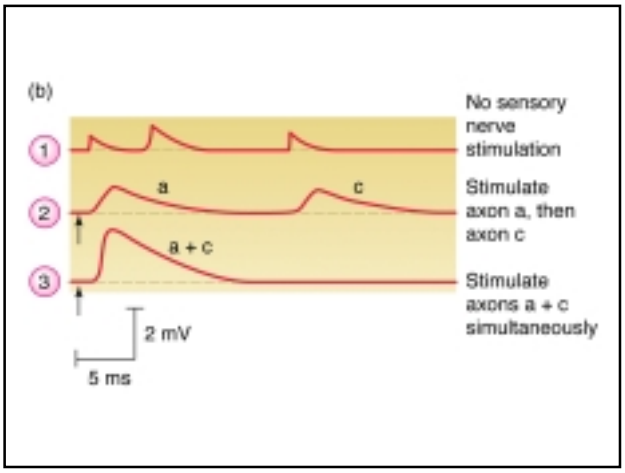

(c)
7th or 8th spinal nerve
3rd, 4th, or 5th spinal nerve
C cell
B cell
Sympathetic neurons in 9th and 10th chain ganglia
GnRH
ACh
GnRH receptor
ACh receptor

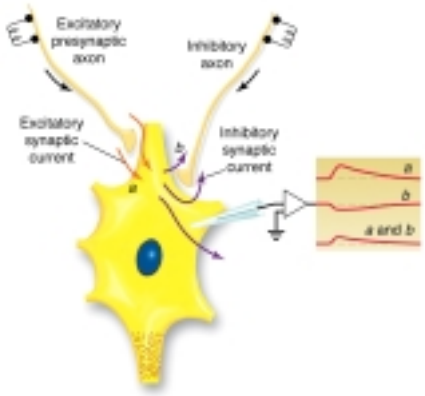

White matter
Skin receptor
Stimulus
Dorsal horn
Sensory neuron (soma in dorsal root ganglion)
Gray matter
Interneuron
α-Motor neuron
Ventral horn
Muscle fibers


V_m
Time
Stimulus
= Na^+ channels
Axon
Soma
Dendrites
Axon hillock
Myelin sheath

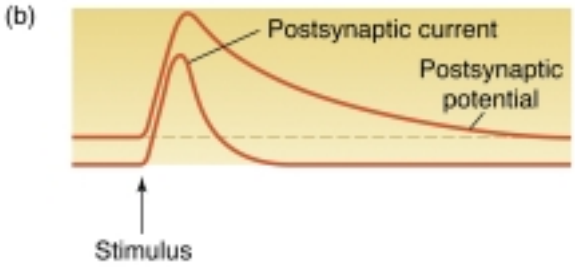

ΔV_m of psp equals the threshold at spike-initiating zone, producing an AP.
Threshold
Potential
Synaptic potential
V_{rest}
Distance

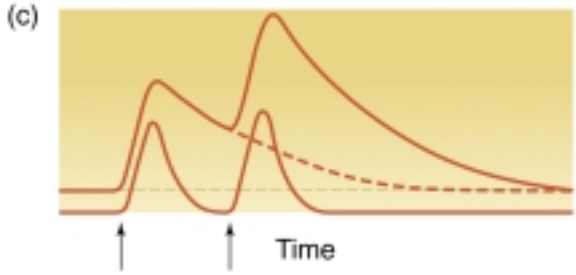

(a)
a
b
c
Recording electrode


(b)
1
2
3
a
c
a + c
No sensory nerve stimulation
Stimulate axon a, then axon c
Stimulate axons a + c simultaneously
2 mV
5 ms

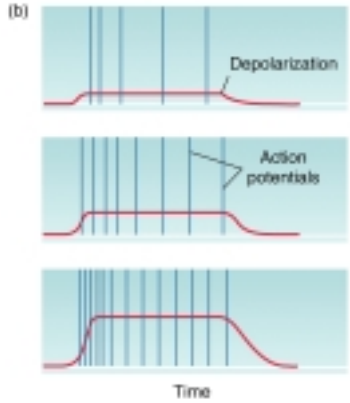

Excitatory presynaptic axon
Inhibitory axon
Excitatory synaptic current
Inhibitory synaptic current
a
b
a and b

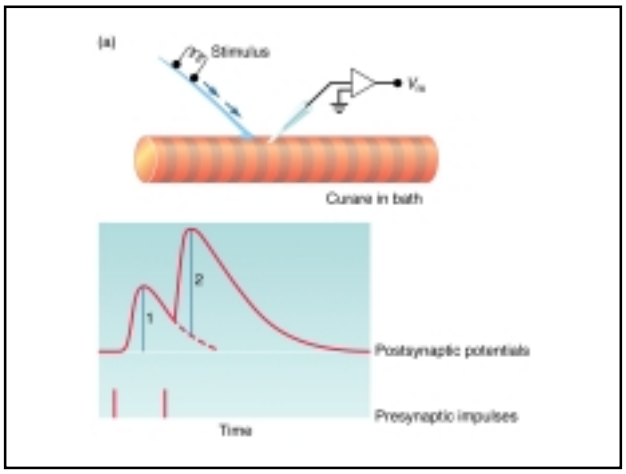
(a)
Stimulus

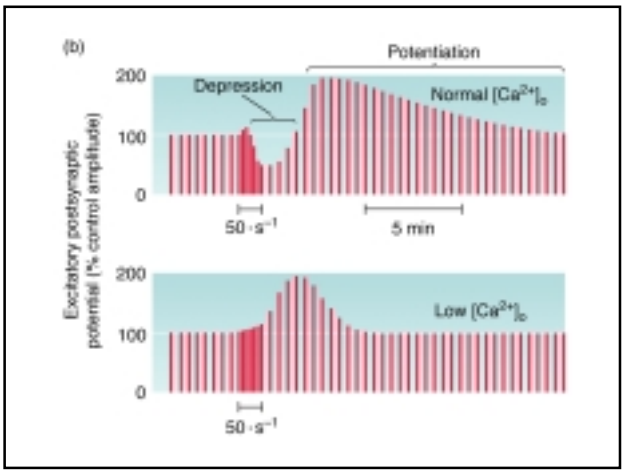

(b)
Postsynaptic current
Postsynaptic potential
Stimulus

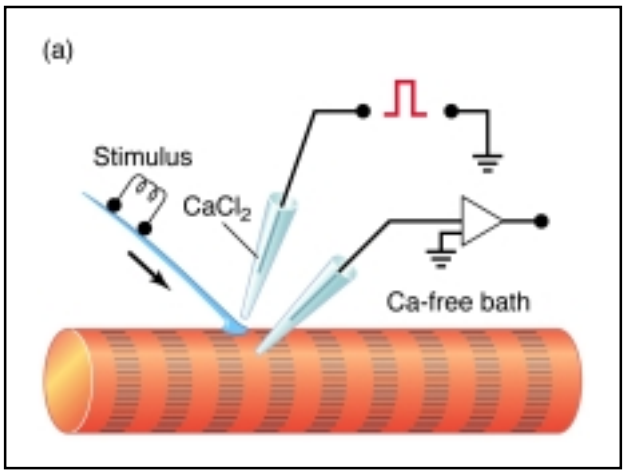

(c)
Time

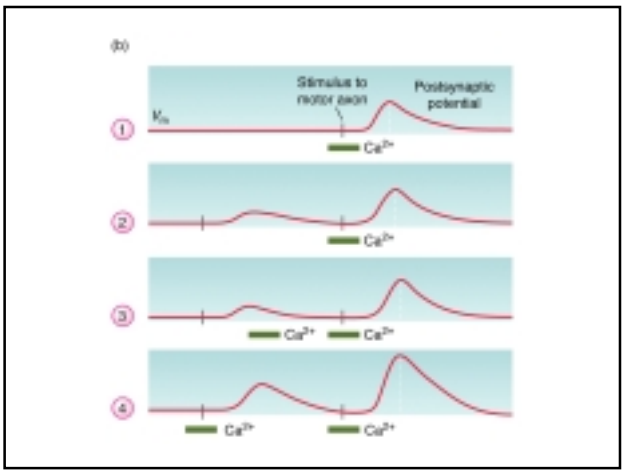
(a)

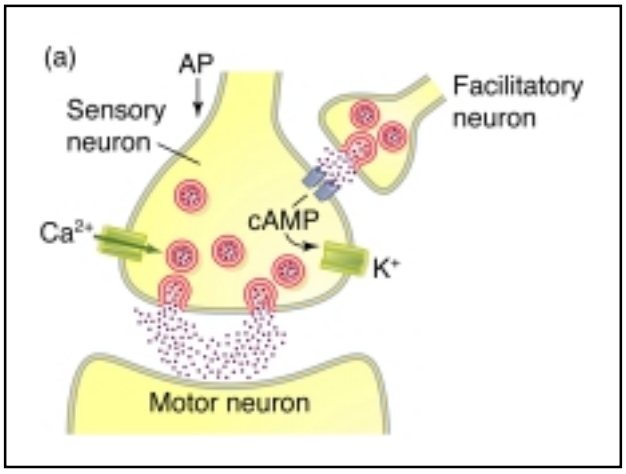

(b)
Depolarization
Action potentials
Time

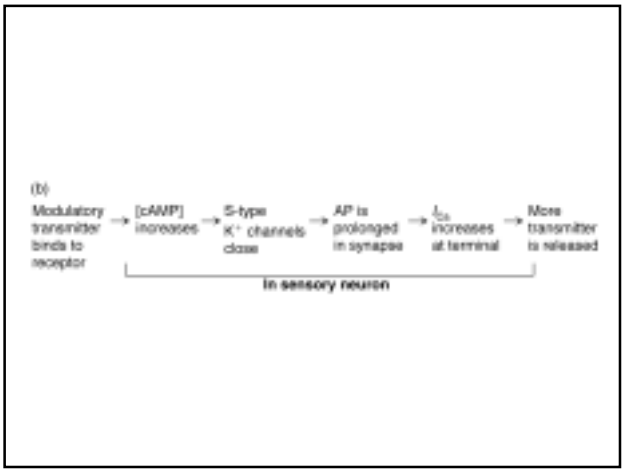

(a)
Stimulus
Curare in bath
1
2
Postsynaptic potentials
Presynaptic impulses
Time

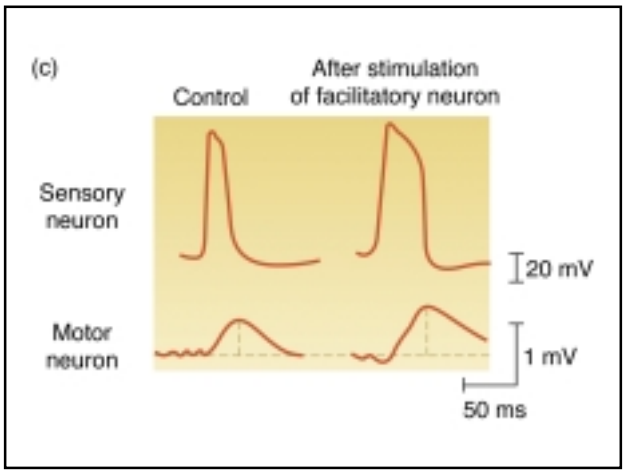

(b)
Potentiation
Depression
Normal [Ca2+]o
Low [Ca2+]o
Excitatory postsynaptic potential (% control amplitude)
200
100
0
50 · s−1
5 min

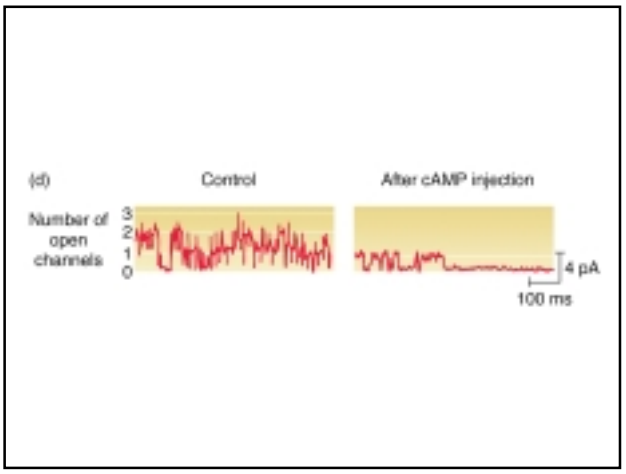

(a)
Stimulus
CaCl2
Ca-free bath

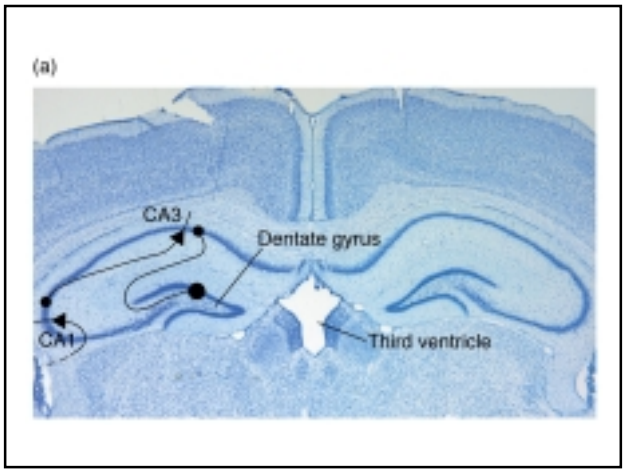

(b)
Stimulus to motor axon
Postsynaptic potential
Ca2+
1
2
3
4

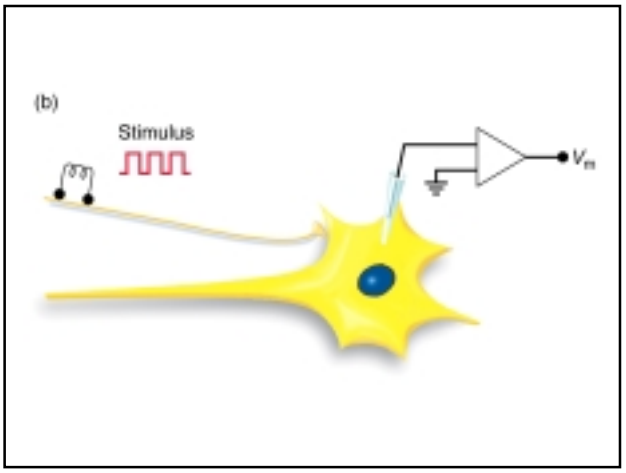

(a)
AP
Sensory neuron
Facilitatory neuron
Ca2+
cAMP
K+
Motor neuron

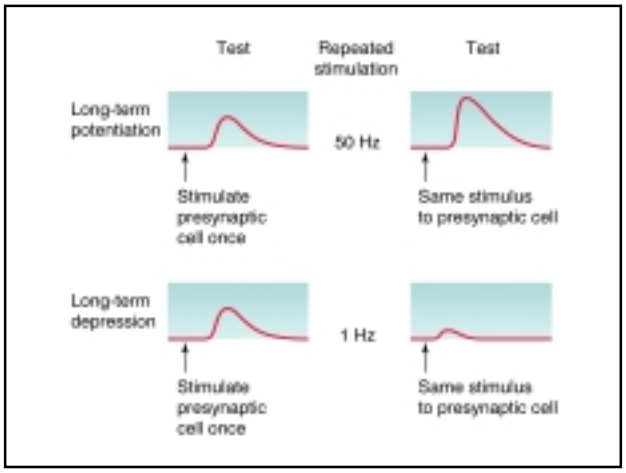

(b)
Modulatory transmitter binds to receptor
[cAMP] increases
S-type K+ channels close
AP is prolonged in synapse
ICa increases at terminal
More transmitter is released
In sensory neuron

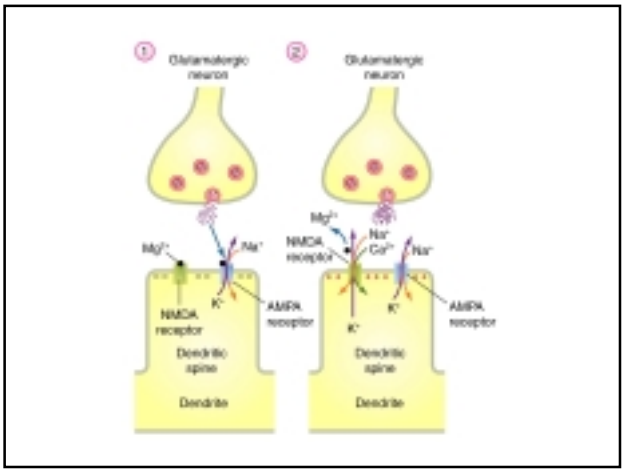

(c)
Control
After stimulation of facilitatory neuron
Sensory neuron
Motor neuron
20 mV
1 mV
50 ms

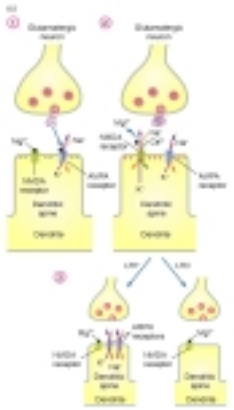

(d)
Control
After cAMP injection
Number of open channels
3
2
1
0
4 pA
100 ms

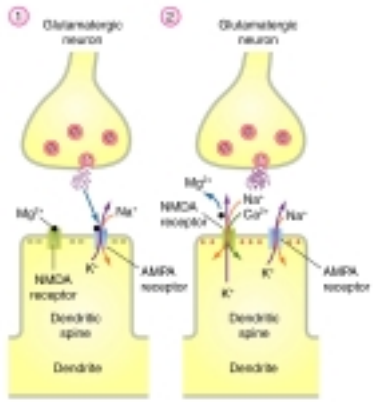

(a)
CA3
Dentate gyrus
CA1
Third ventricle

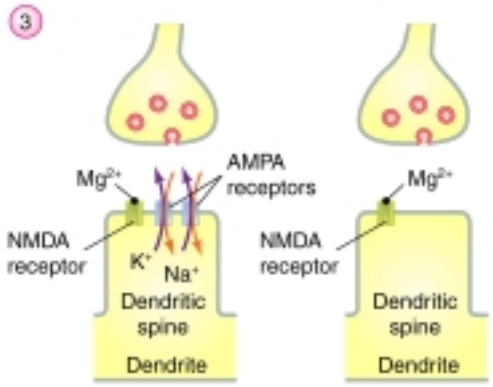

(b)
Stimulus
V_m

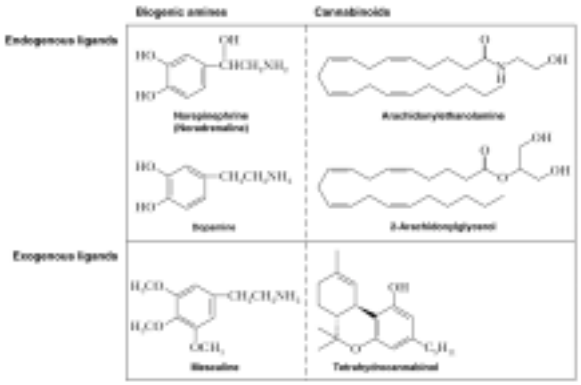

Test
Repeated stimulation
Test
Long-term potentiation
50 Hz
Stimulate presynaptic cell once
Same stimulus to presynaptic cell
Long-term depression
1 Hz
Stimulate presynaptic cell once
Same stimulus to presynaptic cell


Glutamatergic neuron
Glutamatergic neuron
NMDA receptor
AMPA receptor
Dendritic spine
Dendrite




1
Glutamatergic neuron
2
Glutamatergic neuron
Mg2+
Na+
NMDA receptor
K+
AMPA receptor
Dendritic spine
Dendrite
Mg2+
Na+
Ca2+
Na+
NMDA receptor
K+
AMPA receptor
Dendritic spine
Dendrite


3
Mg2+
AMPA receptors
NMDA receptor
K+
Na+
Dendritic spine
Dendrite
Mg2+
NMDA receptor
Dendritic spine
Dendrite


Biogenic amines
Cannabinoids
Endogenous ligands
Exogenous ligands