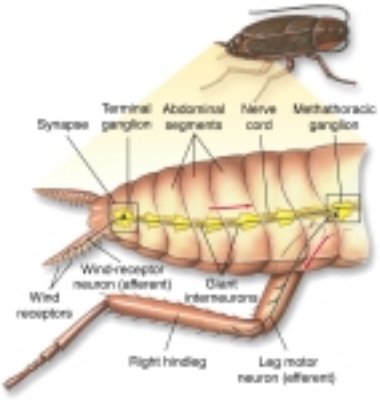
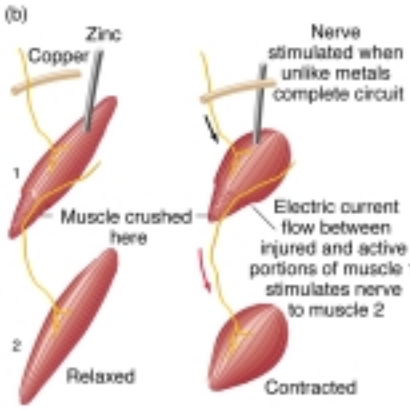
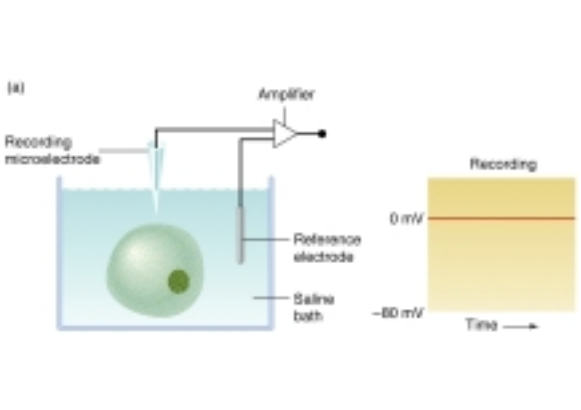
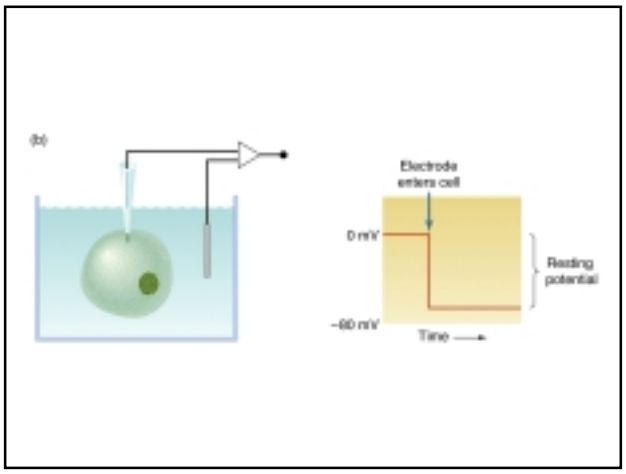
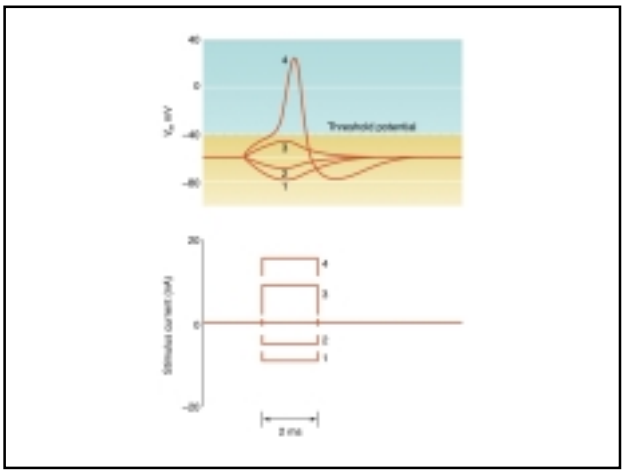
Chapter 5: Neuronal function



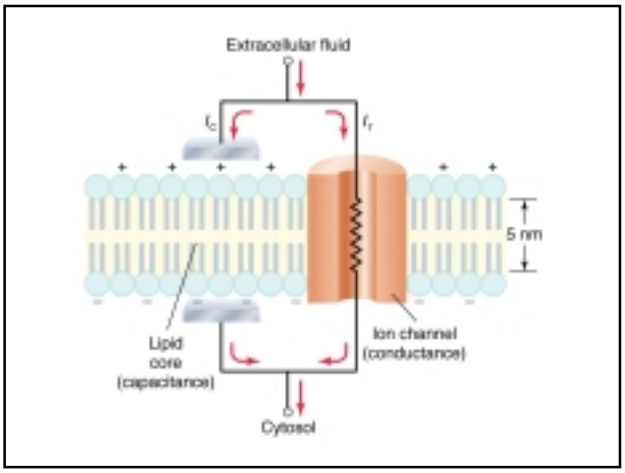


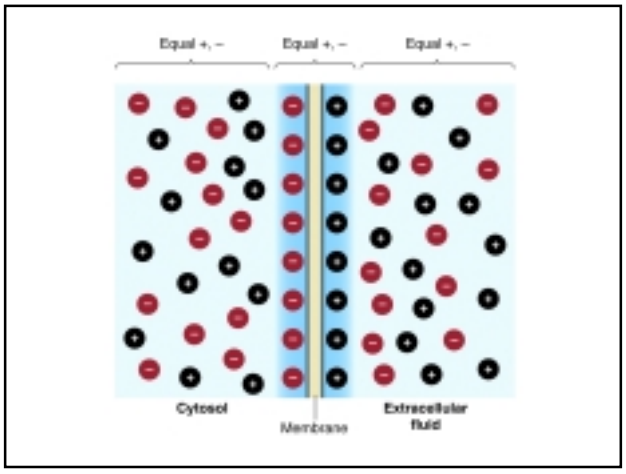


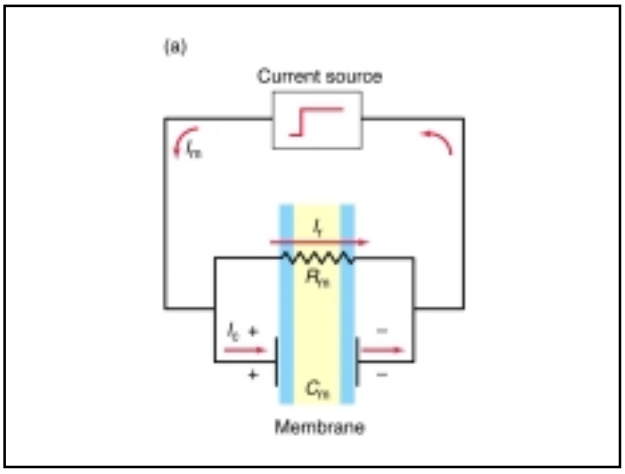


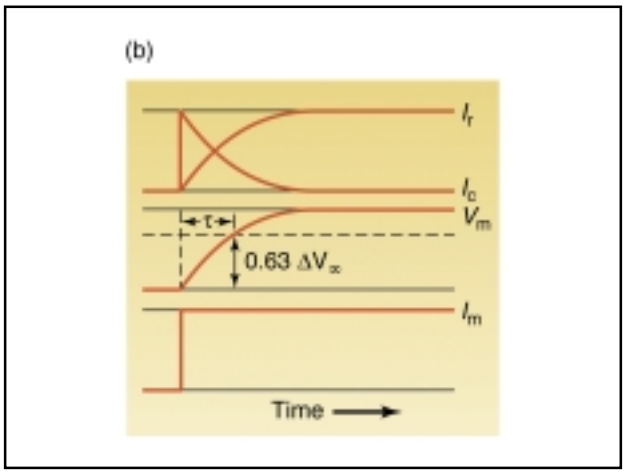


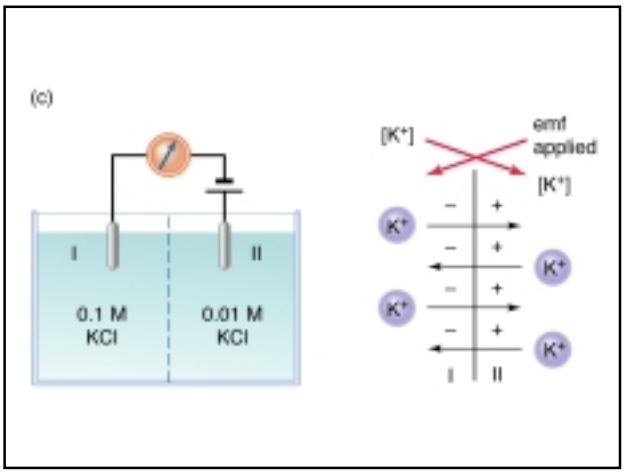
Channel	Current through channel	Characteristics	Selected Blockers	Function
Leak channel (open in resting state)	$I_{K\,(leak)}$	Produces relatively high P_K of resting cell	Partially blocked by tetraethylammonium (TEA)	Largely responsible for V_{rest}
Voltage-gated Na^+ channel	I_{Na}	Rapidly activated by depolarization; becomes inactivated several ms after activated	Tetrodotoxin (TTX)	Produces rising phase of AP
Voltage-gated Ca^{2+} channel	I_{Ca}	Activated by depolarization to less negative than Na^+ channel; inactivated as a function of cytoplasmic $[Ca^{2+}]$ or V_m	Verapamil, D600, Co^{2+}, Cd^{2+}, Mn^{2+}, Ni^{2+}, La^{3+}	Produces slow depolarization; allows Ca^{2+} to enter cell where it can act as second messenger
Voltage-gated K^+ channel ("delayed rectifier")	$I_{K(v)}$	Activated by depolarization to less negative than Na^+ channel; inactivated slowly and not completely if V_m remains depolarized	Intra- and extracellular TEA; amino pyridines	Carries current that rapidly repolarizes the membrane to resting or AP
Ca^{2+}–dependent K^+ channel	$I_{K(Ca)}$	Activated by depolarization (to plus-charged cytoplasmic $[Ca^{2+}]$); remains open as long as cytoplasmic $[Ca^{2+}]$ is higher than normal	Extracellular TEA	Carries current that repolarizes cell following APs based on either Na^+ or Ca^{2+} and that balances I_{Ca} that both triggers depolarization by I_{Ca}

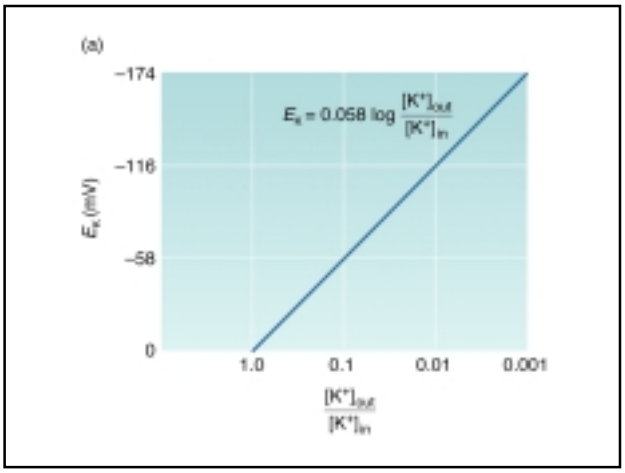


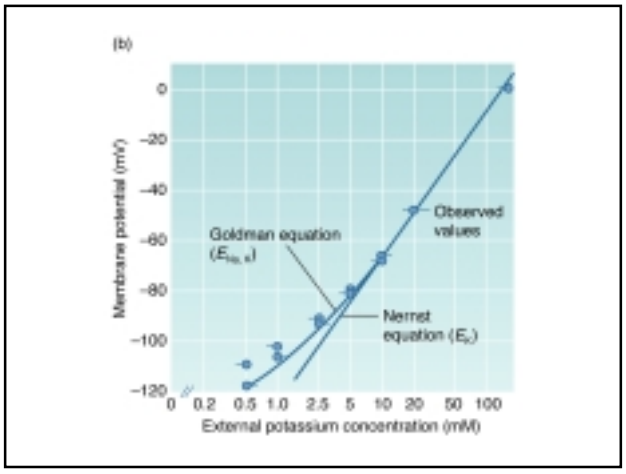


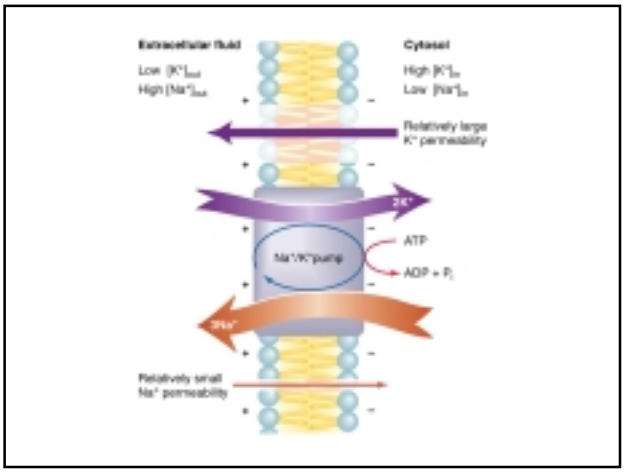


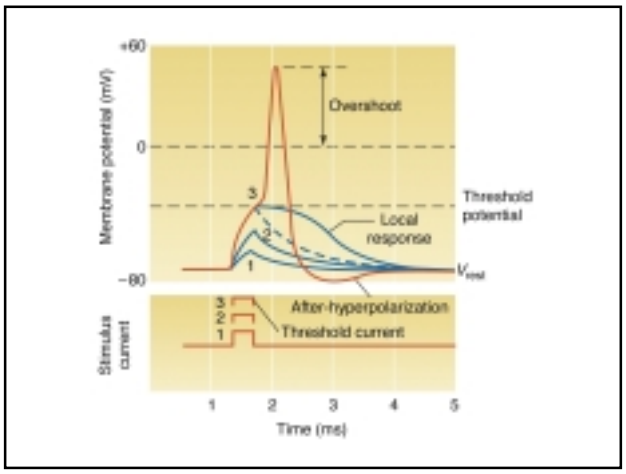

(b)
I_r
I_c
V_m
τ
0.63 ΔV∞
I_m
Time

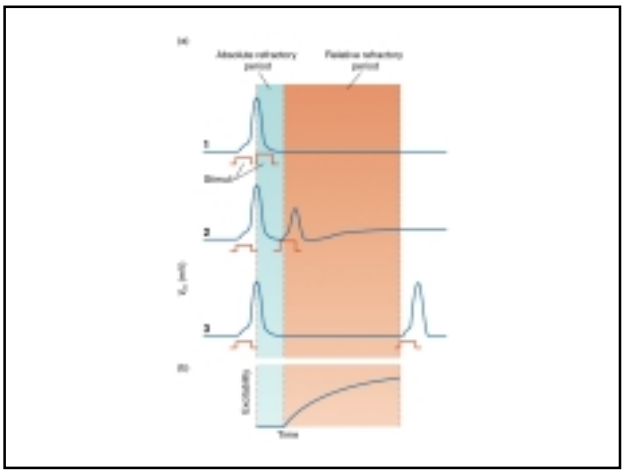

(c)
I
II
0.1 M KCl
0.01 M KCl
[K+]
emf applied
[K+]
K+
K+
K+
K+
I
II

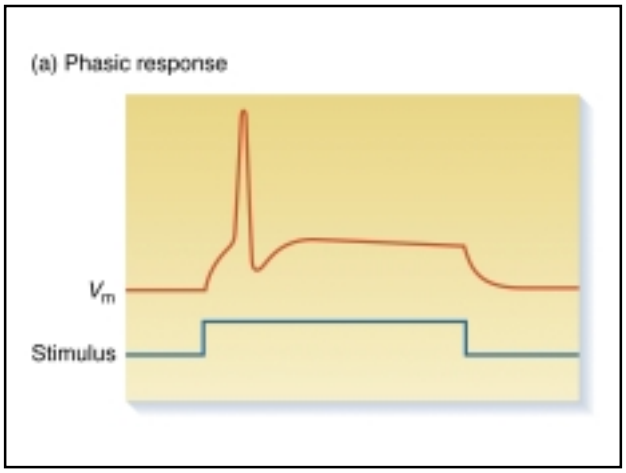

(a)
−174
−116
−58
0
E_K (mV)
$E_K = 0.058 \log \frac{[K^+]_{out}}{[K^+]_{in}}$
1.0
0.1
0.01
0.001
$\frac{[K^+]_{out}}{[K^+]_{in}}$

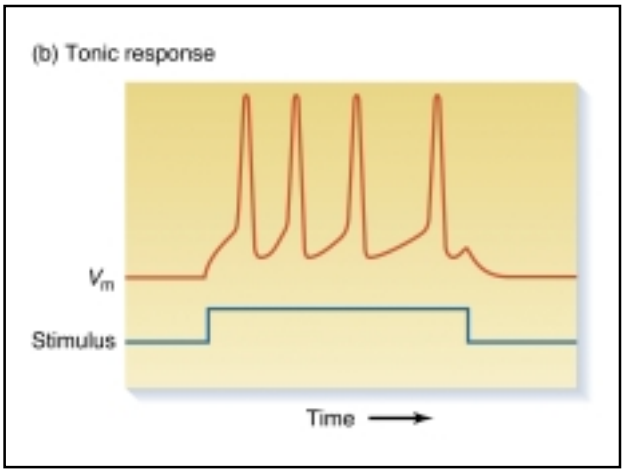

(b)
Membrane potential (mV)
0
−20
−40
−60
−80
−100
−120
Goldman equation
Observed values
Nernst equation (E_K)
0
0.2
0.5
1.0
2.5
5
10
20
50
100
External potassium concentration (mM)

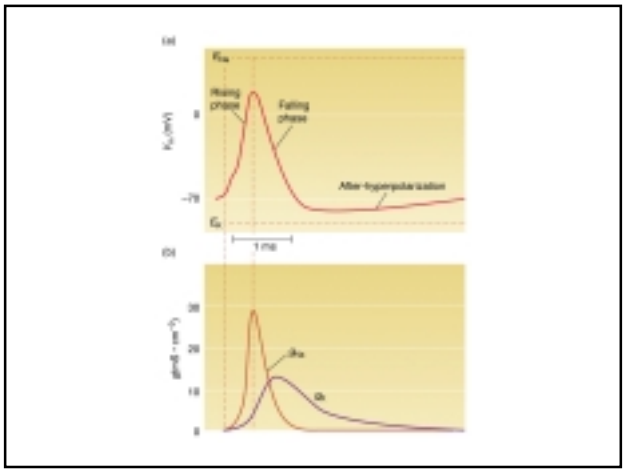

Extracellular fluid
Low $[K^+]_{out}$
High $[Na^+]_{out}$
Cytosol
High $[K^+]_{in}$
Low $[Na^+]_{in}$
Relatively large K^+ permeability
2K+
ATP
ADP + P_i
3Na+
Relatively small Na^+ permeability

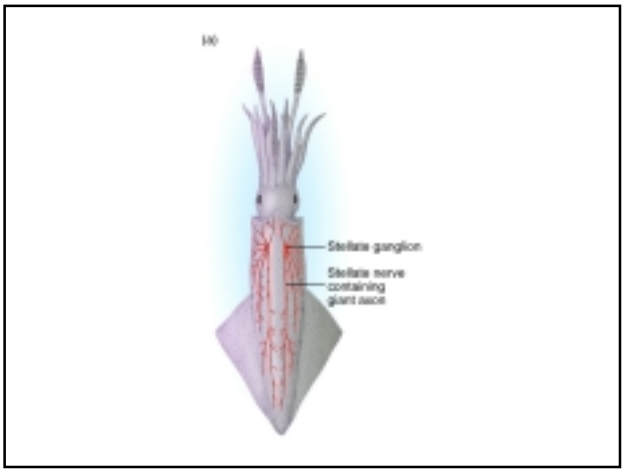

+60
0
−80
Membrane potential (mV)
Overshoot
Threshold potential
Local response
After-hyperpolarization
Threshold current
Stimulus current
1
2
3
1
2
3
4
5
Time (ms)

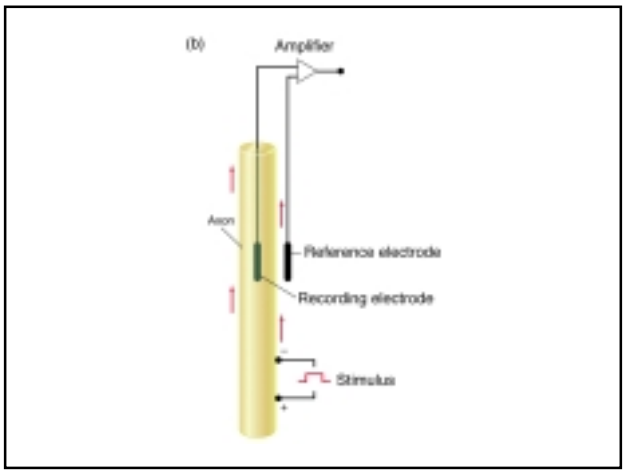

Absolute refractory period
Relative refractory period
Stimuli
Excitability
Time

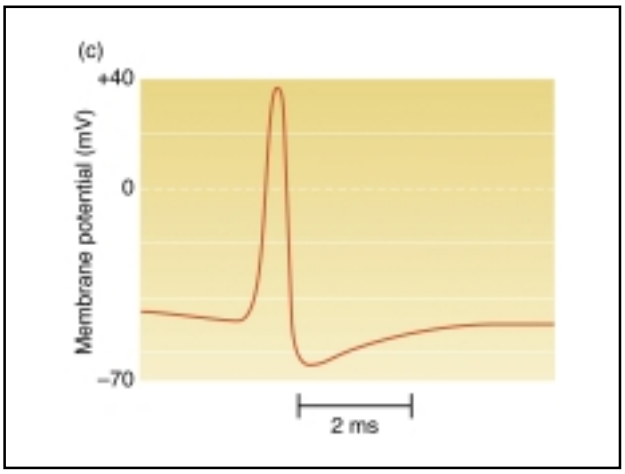

(a) Phasic response
V_m
Stimulus

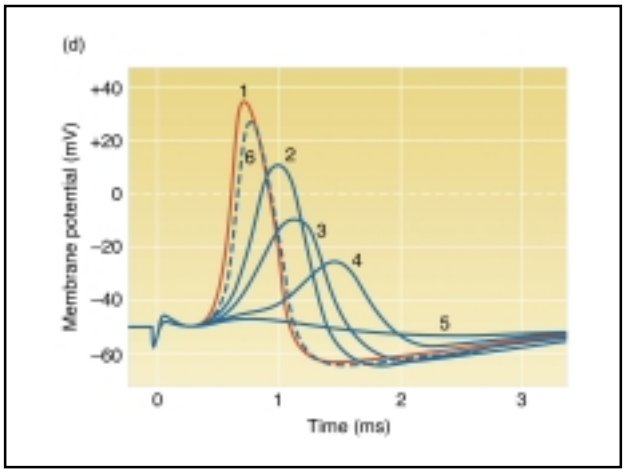

(b) Tonic response
V_m
Stimulus
Time

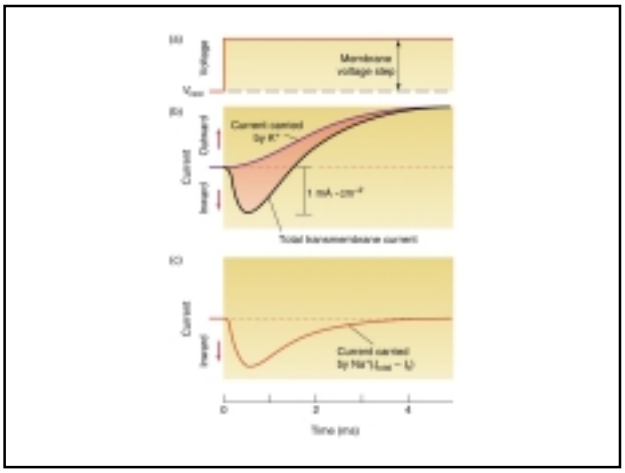

Rising phase
Falling phase
After-hyperpolarization
1 ms

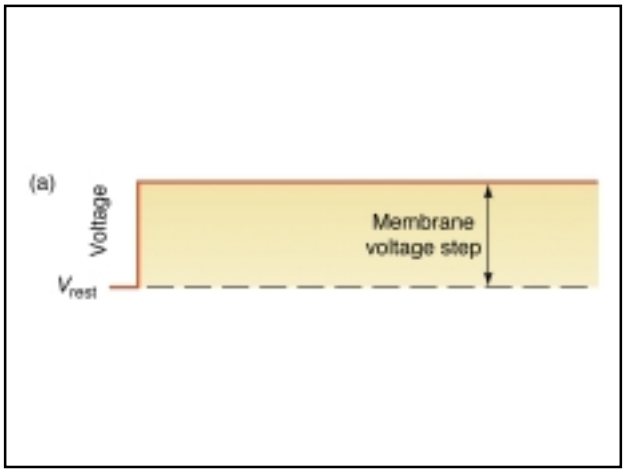

Stellate ganglion
Stellate nerve containing giant axon

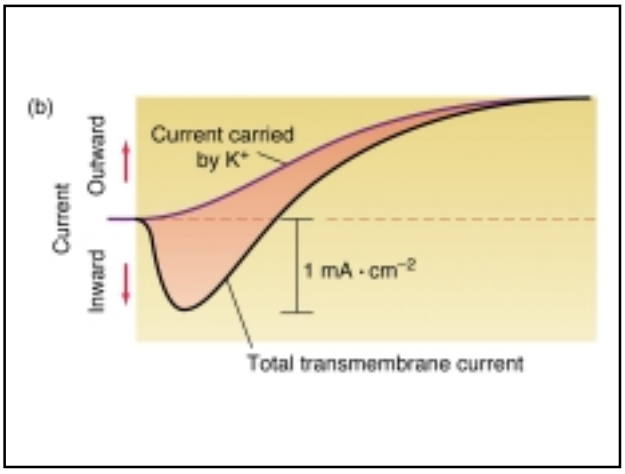

(b)
Amplifier
Axon
Reference electrode
Recording electrode
Stimulus

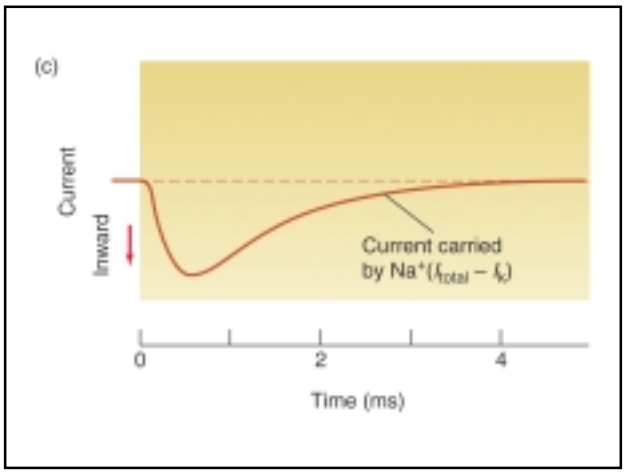

(c)
+40
0
−70
Membrane potential (mV)
2 ms

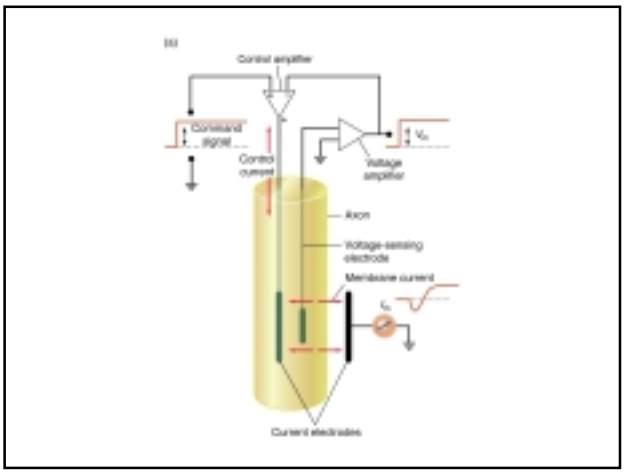

(d)
+40
+20
0
−20
−40
−60
Membrane potential (mV)
1
2
3
4
5
6
0
1
2
3
Time (ms)

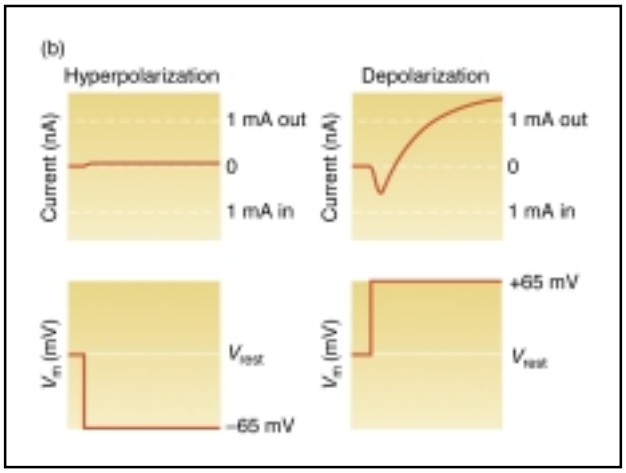

Membrane voltage step
Current carried by K+
1 mA · cm−2
Total transmembrane current
Current carried by Na+ (or Ca2+)
Time (ms)

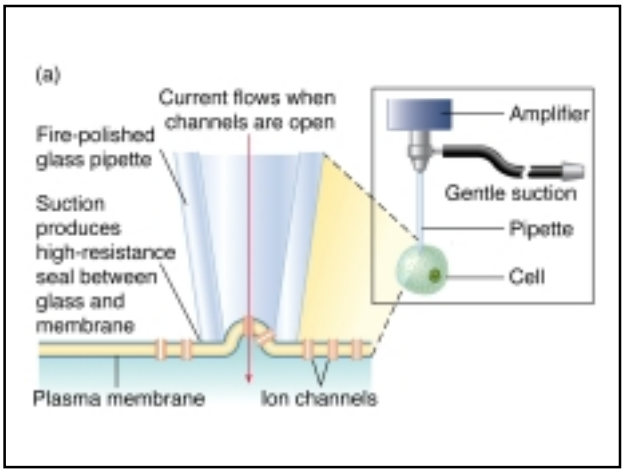

(a)
Voltage
Membrane voltage step
Vrest

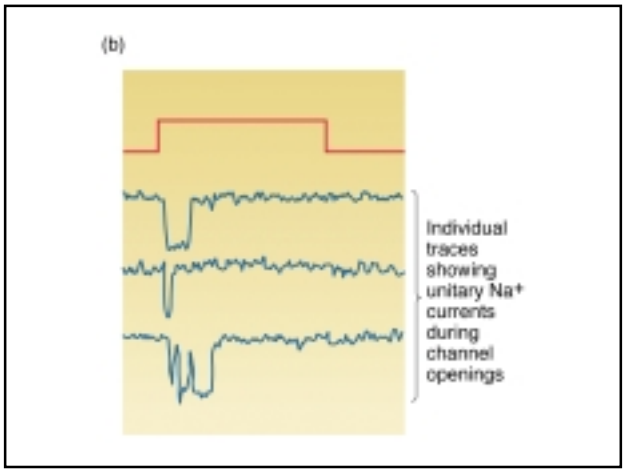

(b)
Current
Outward
Inward
Current carried by K+
1 mA · cm−2
Total transmembrane current

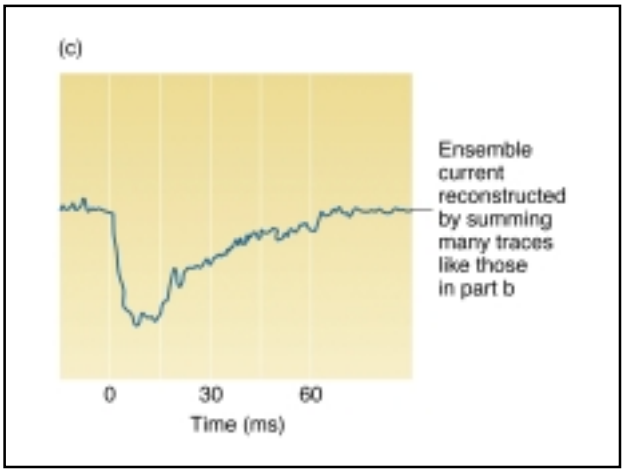

(c)
Current
Inward
Current carried by Na+ ($I_{total} - I_K$)
0
2
4
Time (ms)

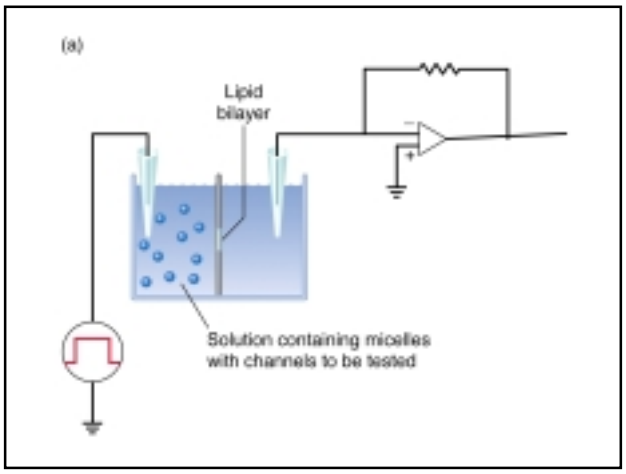

Control amplifier
Command signal
Control current
Voltage amplifier
Axon
Voltage-sensing electrode
Membrane current
Current electrodes

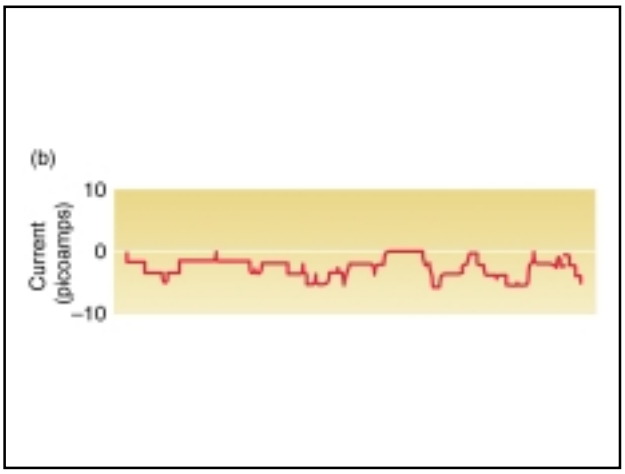

(b)
Hyperpolarization
Depolarization
Current (nA)
1 mA out
0
1 mA in
V_m (mV)
V_{test}
−65 mV
+65 mV

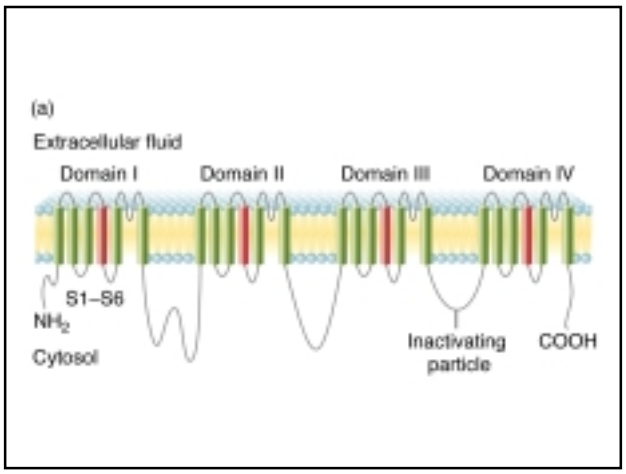

(a)
Current flows when channels are open
Fire-polished glass pipette
Suction produces high-resistance seal between glass and membrane
Amplifier
Gentle suction
Pipette
Cell
Plasma membrane
Ion channels


(b)
Individual traces showing unitary Na+ currents during channel openings


(c)
Ensemble current reconstructed by summing many traces like those in part b
0
30
60
Time (ms)


(a)
Lipid bilayer
Solution containing micelles with channels to be tested


(b)
Current (picoamps)
10
0
–10


(a)
Extracellular fluid
Domain I
Domain II
Domain III
Domain IV
S1–S6
NH2
Cytosol
Inactivating particle
COOH