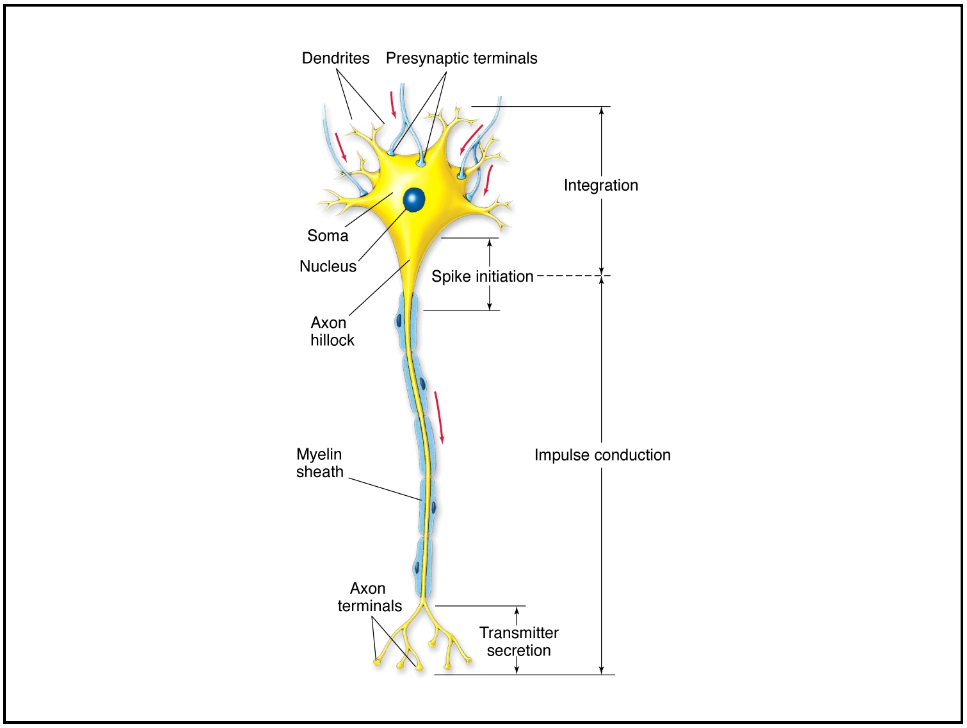
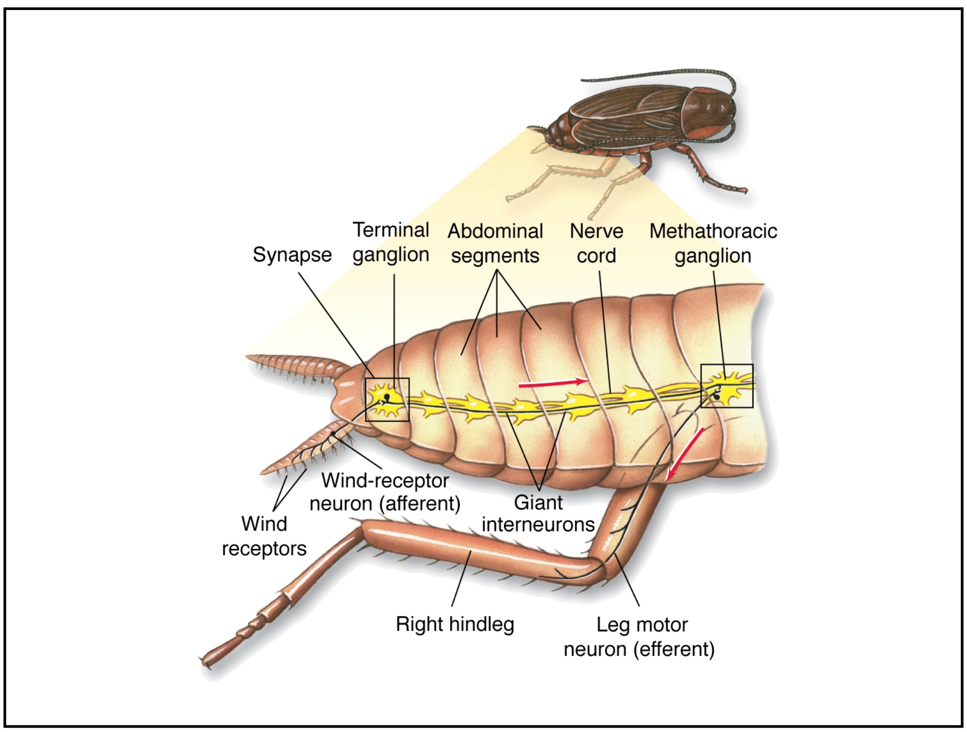
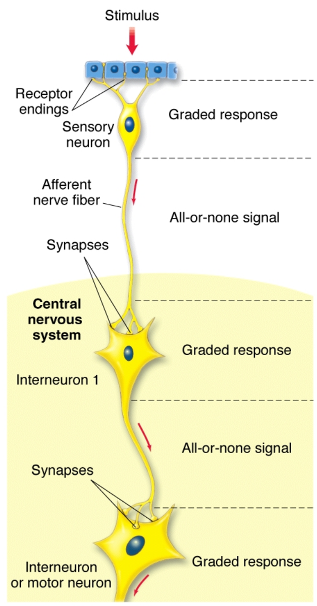

Dendrites
Presynaptic terminals
Integration
Soma
Nucleus
Spike initiation
Axon hillock
Myelin sheath
Impulse conduction
Axon terminals
Transmitter secretion


Synapse
Terminal ganglion
Abdominal segments
Nerve cord
Methathoracic ganglion
Wind-receptor neuron (afferent)
Giant interneurons
Wind receptors
Right hindleg
Leg motor neuron (efferent)



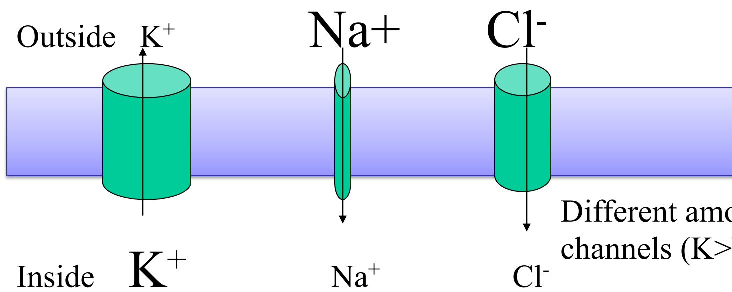
Neuron membranes at rest are permeable (leaky) to K^{+}, Na^{+} and Cl^{-}

but to different degrees:

Giant squid axon $P_{k}^{+} : P_{Na}^{+} : P_{Cl}^{-}$

1 : 0.04 : 0.45

Different size channels

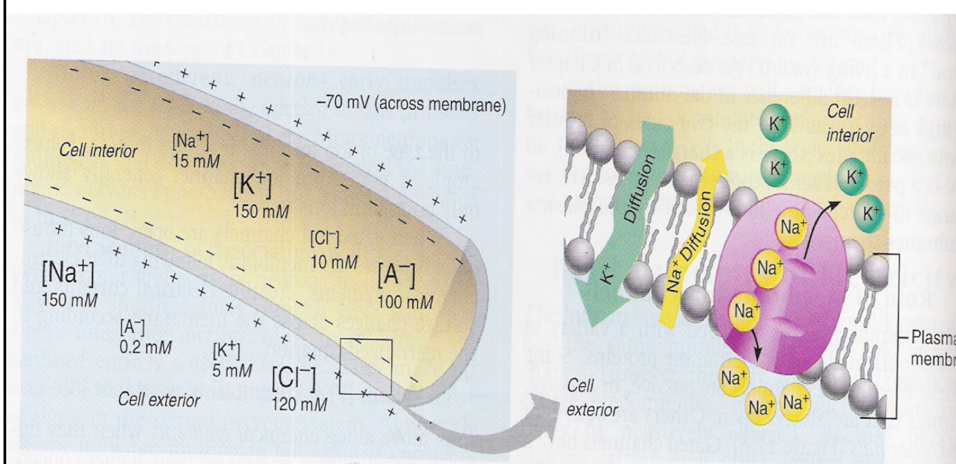


Different amount of channels (K>Na)

Ion concentration (mM) gradients across the plasma membrane.
giant squid axon

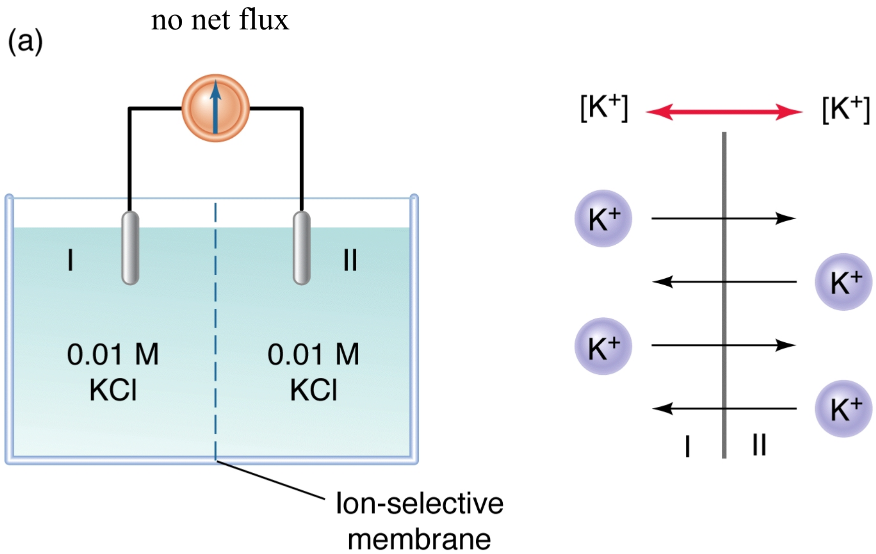
Ion	[Cytoplasm]	[Extracellular Fluid]
K^+	400	20
Na^+	50	440
Cl^-	52	560
Organic$^-$	385	0
Vertebrates		
K^+	150	5
Na^+	15	150
Cl^-	10	120
Organic$^-$	100	0.2

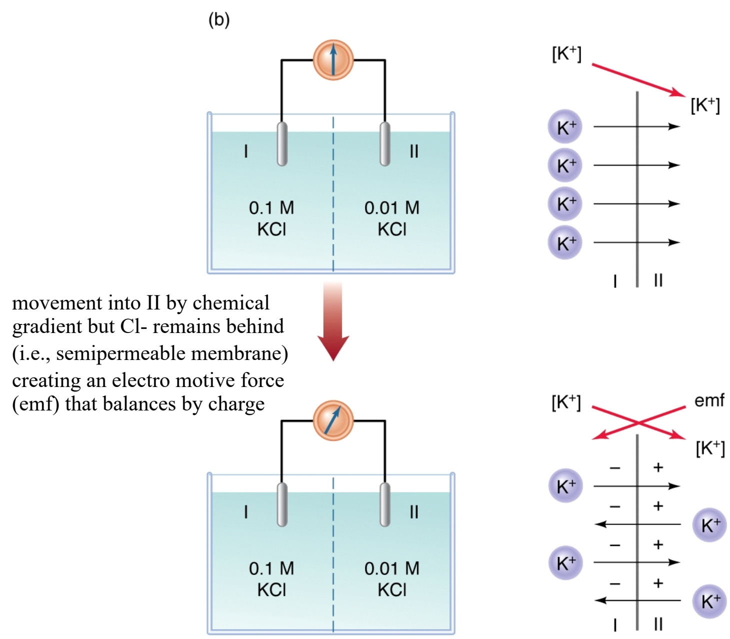
- The small influx of Na^+ is balanced by the small efflux of K^+ (active transport)



Membrane potentials (V_m) = a voltage difference between the intracellular and extracellular fluids.

- V_m is always negative inside relative to outside.
- V_m ranges from -40 to -200 mV, depending on the type of cell.
- Range of resting V_ms for mammalian neurons is -40 to -75 mV;
- Any electrical signaling involves deviating from the resting value.





Nernst Equation: Theoretical V_m membrane permeable only to K^+

$E = RT/zF \ln [ion]_{o(outside)}/[ion]_{I(inside)}$

E = membrane potential (Volts)

R = gas constant (8.3143 joules/deg-mole)

T = absolute temperature (273° + °C); usually 20°C for giant squid axon

z = valence, including charge and number

F = Faraday's constant (96,490 coulombs/mole)

simplifying the Equation

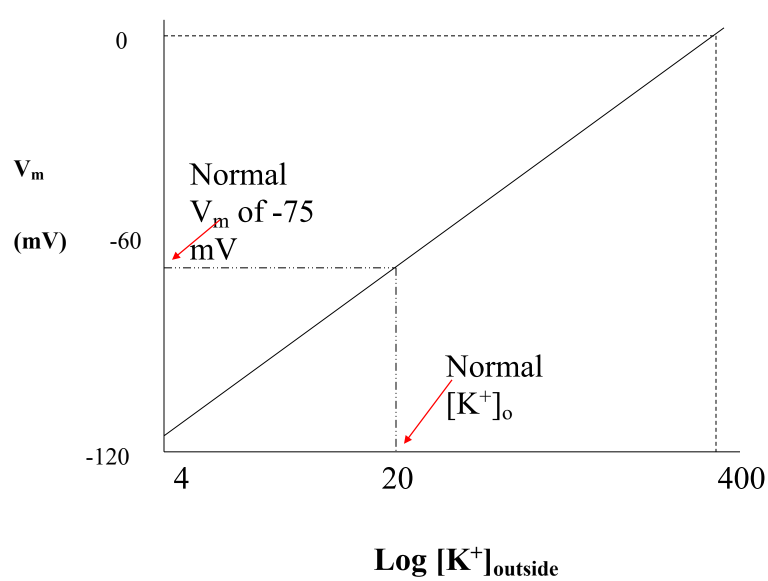
Example at 20^oC and a valence of +1 (K^+ and Na^+)

RT/zF = (8.3143 x293)/(1 x 96,490) =0.025V (25mV)

E (mV) = 25 ln $[ion]_o/[ion]_I$

converting to $\log_{10}$: E (mV) = 25 x 2.3 log $[ion]_o/[ion]_I$

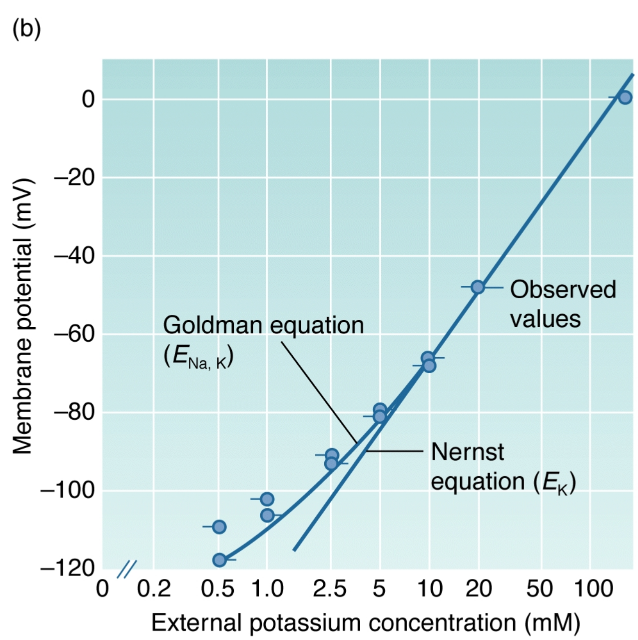
E (mV) = 58 log $[ion]_o/[ion]_I$

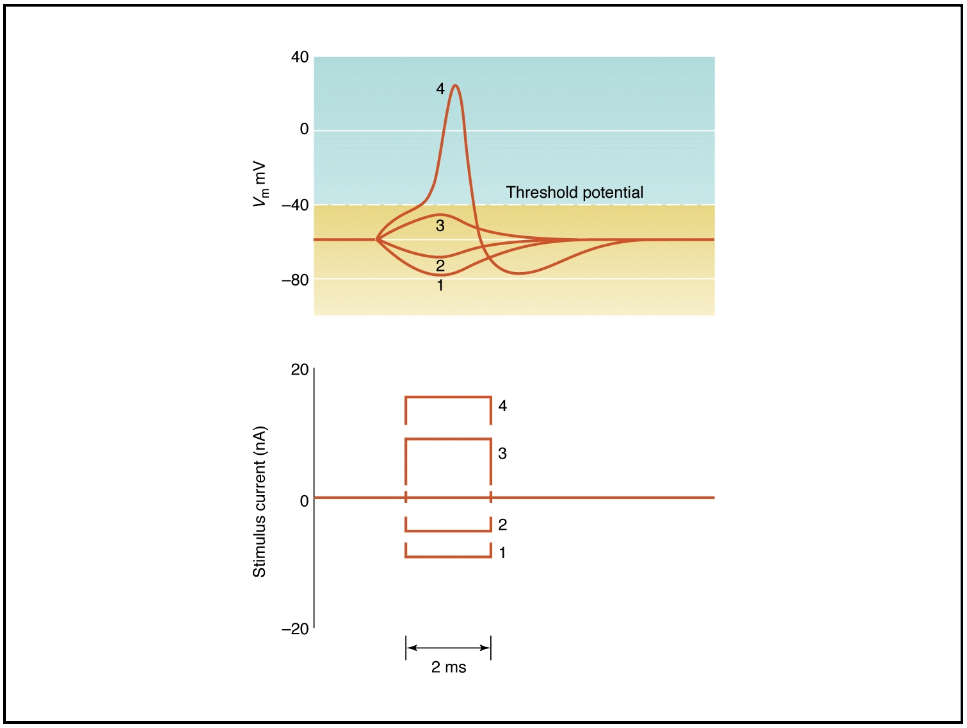


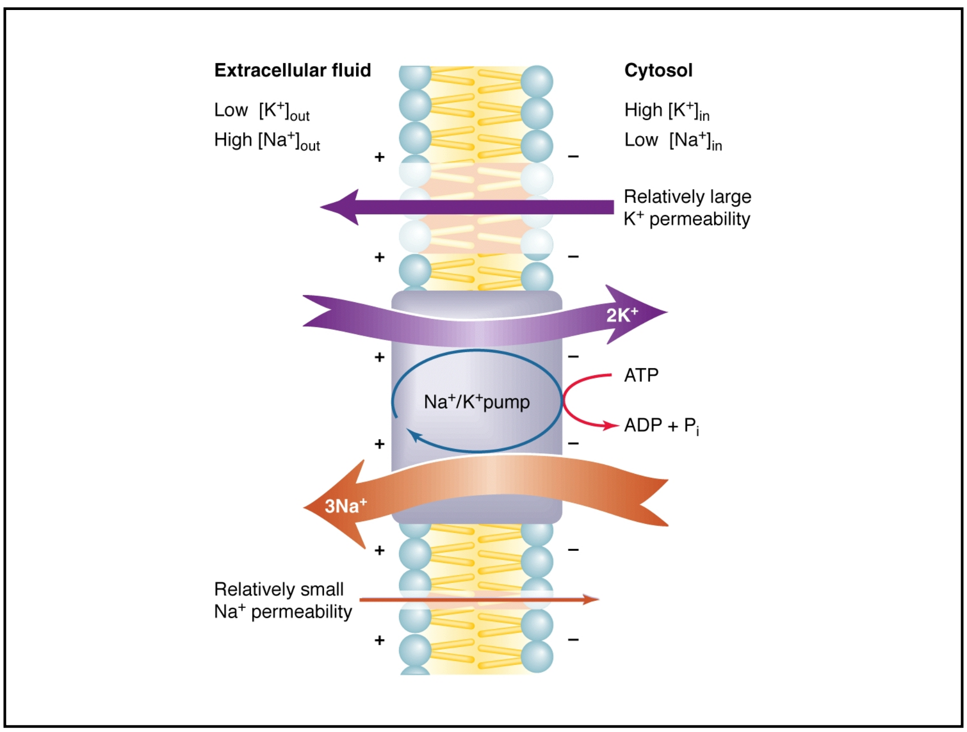
Goldman-Equation can be used to Predict V_m when the Membrane is Permeable to Multiple Ions

$$V_m = \frac{RT}{F} \times \ln \frac{P_{K^+}[K^+]_o + P_{Na^+}[Na^+]_o + P_{Cl^-}[Cl^-]_i}{P_{K^+}[K^+]_i + P_{Na^+}[Na^+]_i + P_{Cl^-}[Cl^-]_o}$$

V_m *theoretical* = - 60 mV ~ the *empirically measured value* in a resting neuron




40
4
0
V_m mV
Threshold potential
−40
3
2
−80
1
20
4
3
Stimulus current (nA)
0
2
1
−20
2 ms


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

Animal	Fiber or cell	Resting potential (mV)	Action potential peak (mV)	Spike duration (ms)
Squid (*Loligo*)	Giant axon	60	120	0.75
Earthworm (*Lumbricus*)	Median giant fiber	70	100	1.0
Crayfish (*Cambarus*)	Median giant fiber	90	145	2
Cockroach (*Periplaneta*)	Giant fiber	70	80–104	0.4
Shore crab (*Carcinus*)	30-μm leg axon	71–94	116–153	1.0
Frog (*Rana*)	Sciatic nerve axon	60–80	100–130	1.0
Sea slug (*Aplysia*)	Visceral ganglion	40–60	80–120	10
Land snail (*Onchidium*)	Visceral ganglion	60–70	80–100	9
Crayfish (*Cambarus*)	Stretch receptor cell	70–80	80–90	2.5
Puffer fish (*Sphaeroides*)	Supramedullary cell	50–80	80–110	3
Toad (*Bufo*)	Dorsal root ganglion	50–80	80–125	2.8
Toad (*Bufo*)	Spinal motor neuron	40–60	40–84	2
Rabbit (*Oryctolagus*)	Sympathetic cell	65–82	75–103	4–7
Cat (*Felis*)	Spinal motor neuron	55–80	80–110	1–1.5

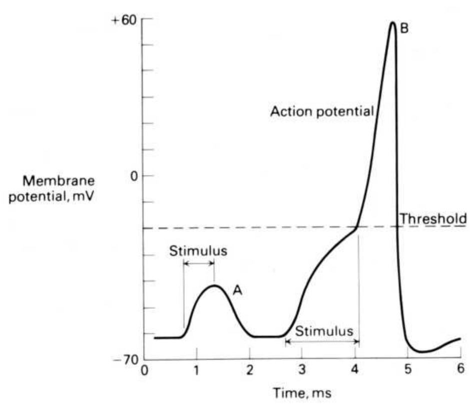
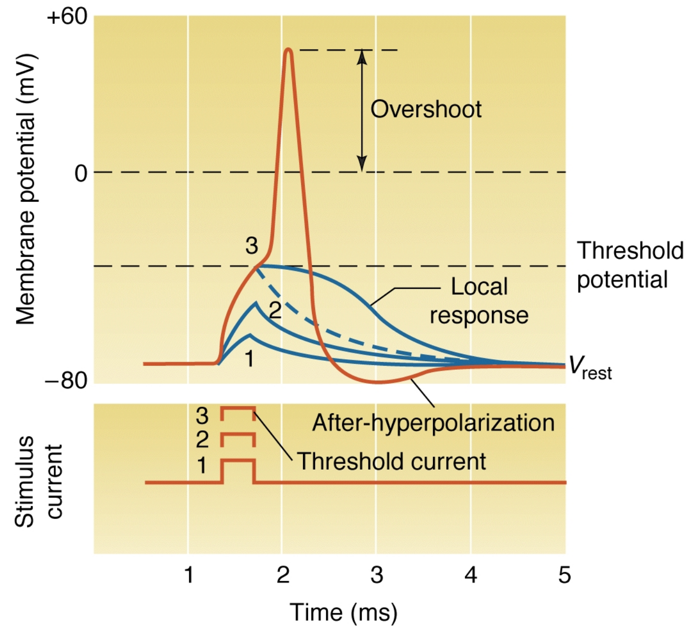
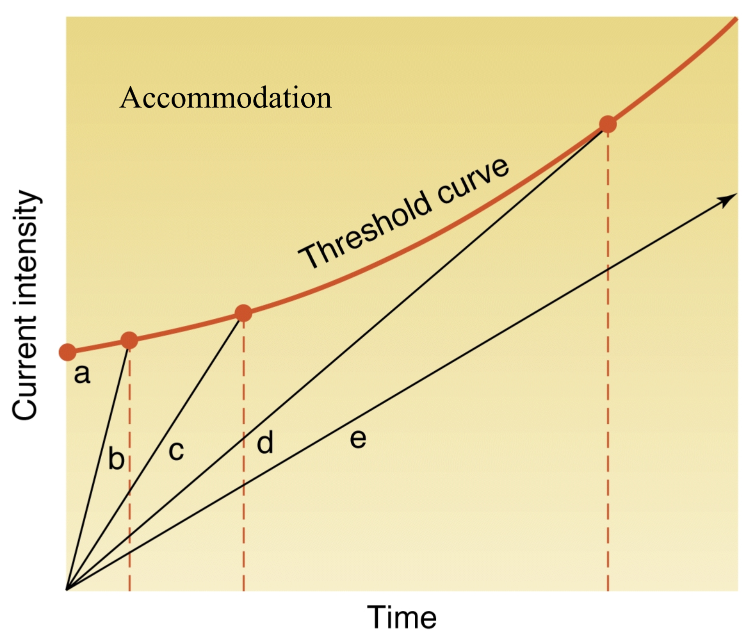


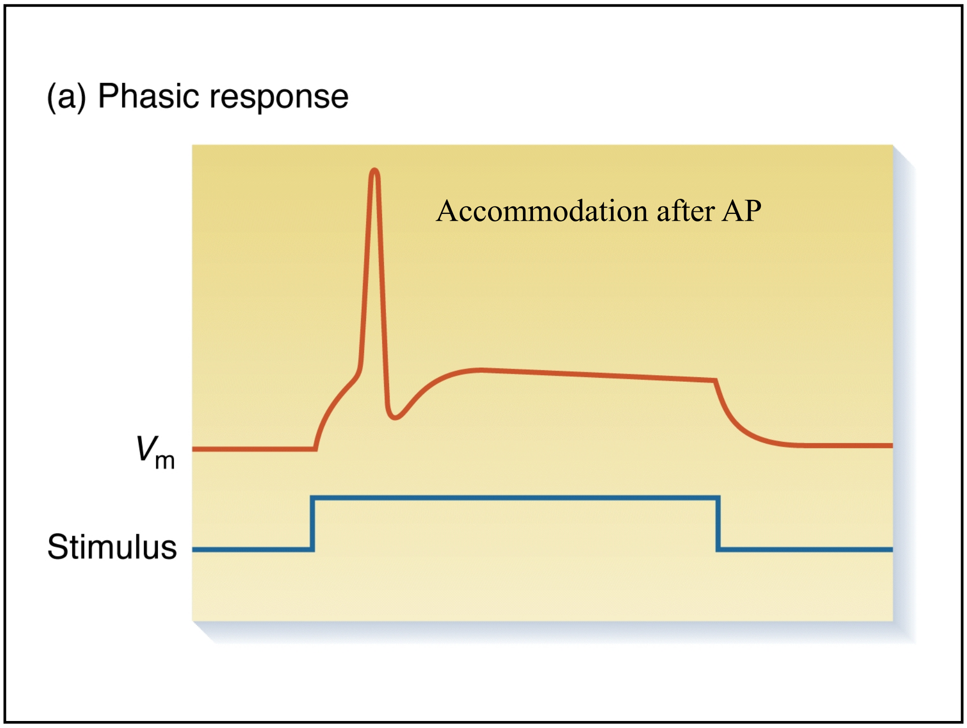
Figure 16.5
When the membrane potential of an excitable cell is depolarized below the threshold, the membrane potential returns to resting values when the stimulus is removed (A). However, if threshold depolarization occurs the membrane potential will undergo action-potential formation (B).

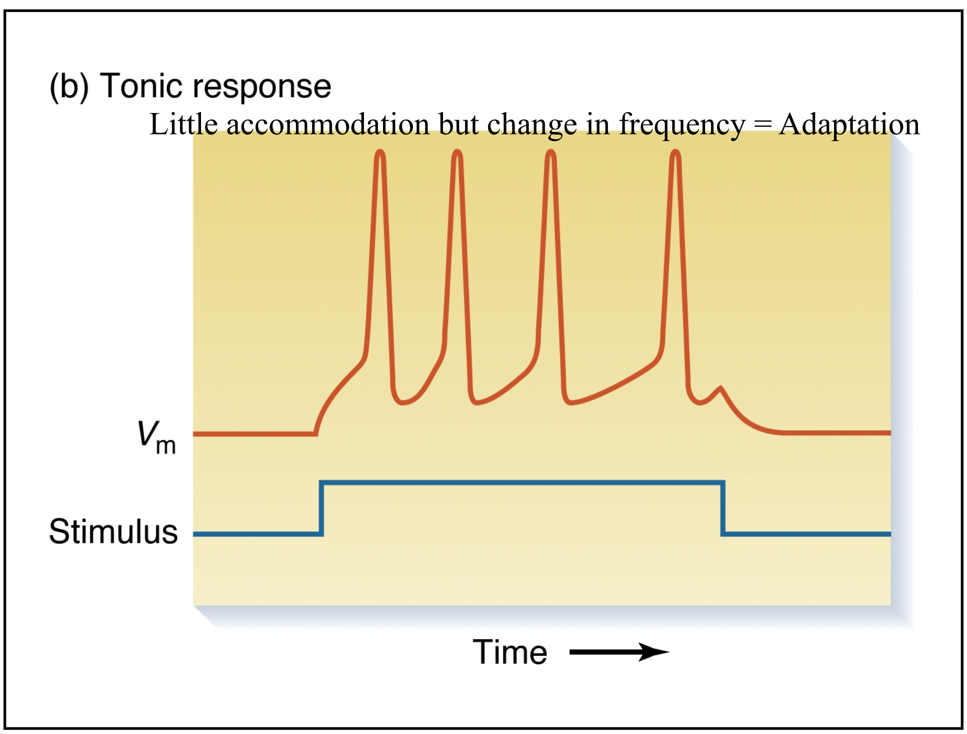


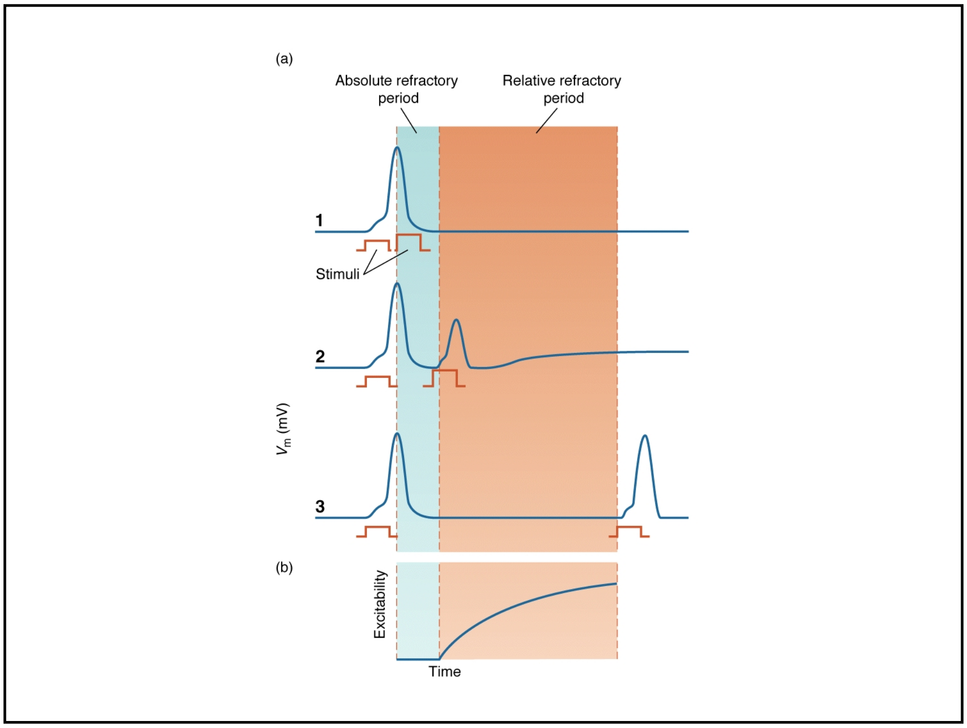
+60
0
−80
Membrane potential (mV)
Overshoot
Threshold potential
Local response
V_{rest}
3
2
1
After-hyperpolarization
Threshold current
Stimulus current
1
2
3
4
5
Time (ms)



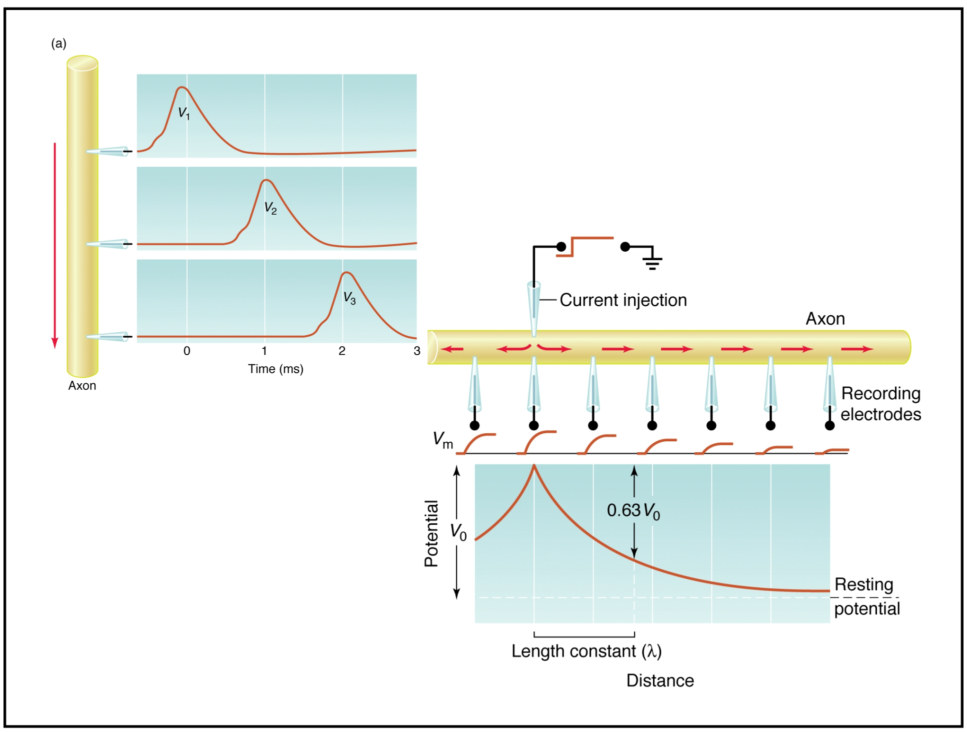
Accommodation
Threshold curve
Current intensity
a
b
c
d
e
Time


(a) Phasic response
Accommodation after AP
Vm
Stimulus


(b) Tonic response
Little accommodation but change in frequency = Adaptation
Vm
Stimulus
Time

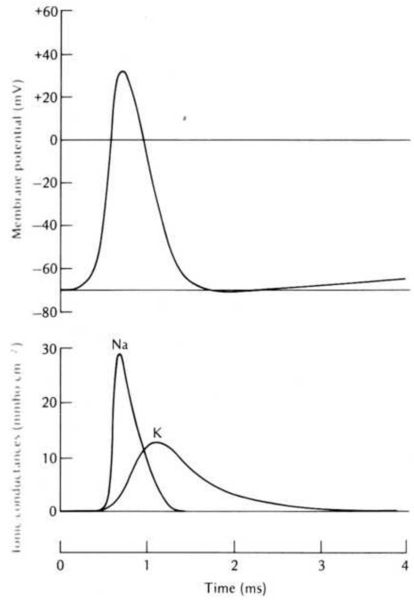


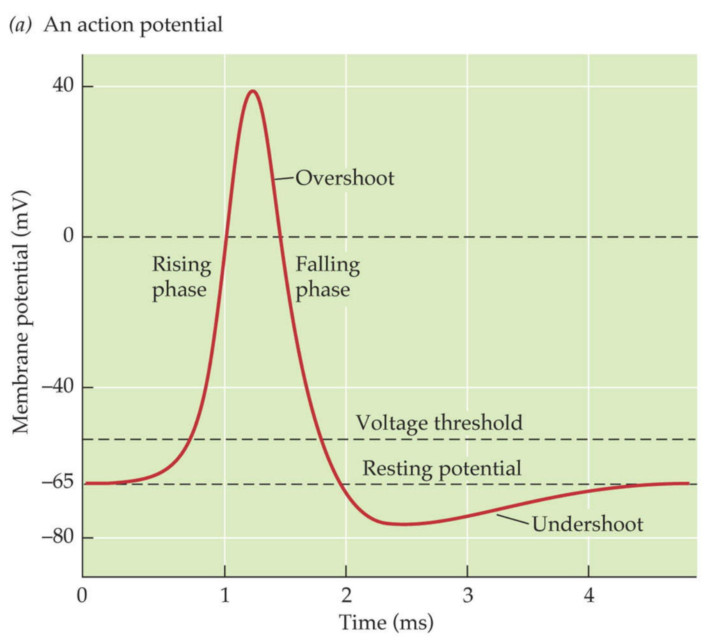
(a)
Absolute refractory period
Relative refractory period
1
Stimuli
2
V_m (mV)
3
(b)
Excitability
Time



(a)
V_1
V_2
V_3
0
1
2
3
Time (ms)
Axon
Current injection
Axon
Recording electrodes
V_m
Potential
V_0
0.63 V_0
Resting potential
Length constant (λ)
Distance

Two simple ion gates: First Na^{+}, then K^{+}





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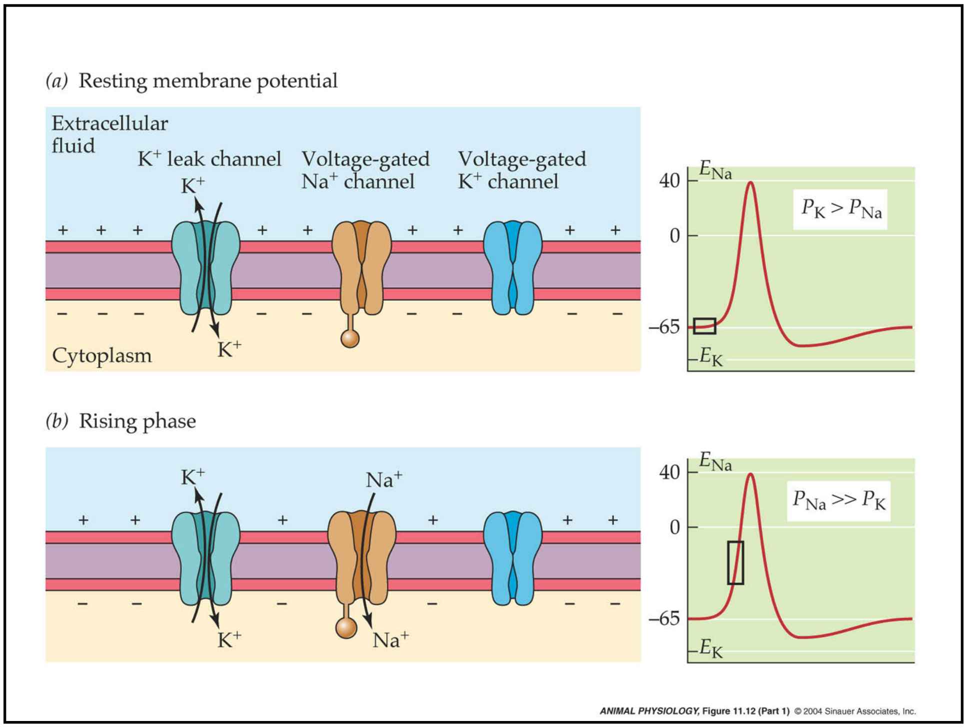
(a) Resting membrane potential
Extracellular fluid
K+ leak channel
Voltage-gated Na+ channel
Voltage-gated K+ channel
K+
K+
Cytoplasm
40
0
–65
E_{Na}
E_K
$P_K > P_{Na}$
(b) Rising phase
K+
Na+
K+
Na+
40
0
–65
E_{Na}
E_K
$P_{Na} >> P_K$
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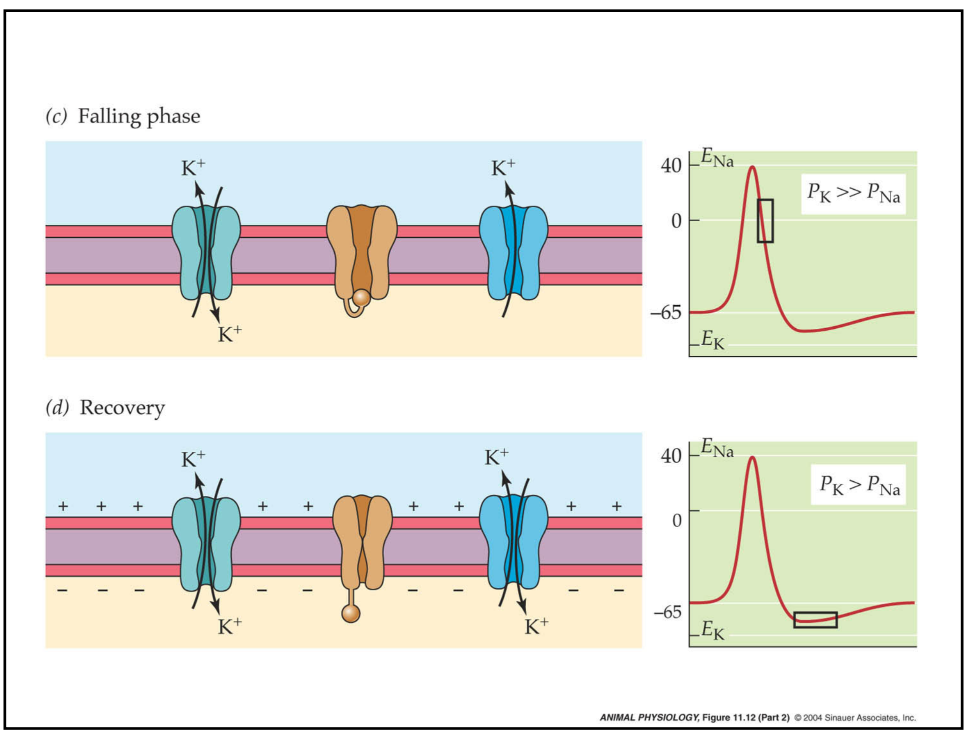
(c) Falling phase
K+
K+
K+
40
0
–65
E_{Na}
E_K
$P_K >> P_{Na}$
(d) Recovery
K+
K+
K+
K+
40
0
–65
E_{Na}
E_K
$P_K > P_{Na}$
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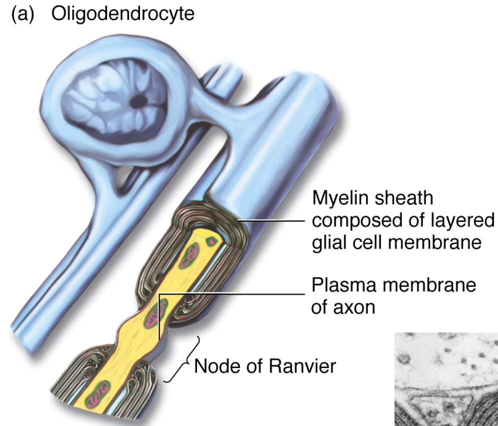
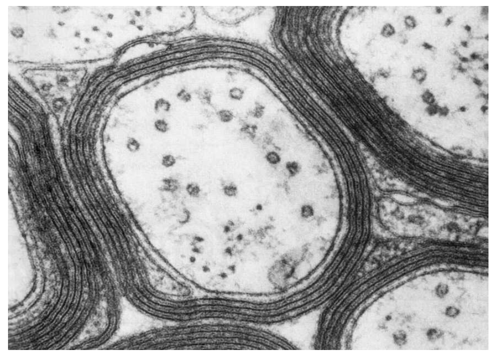
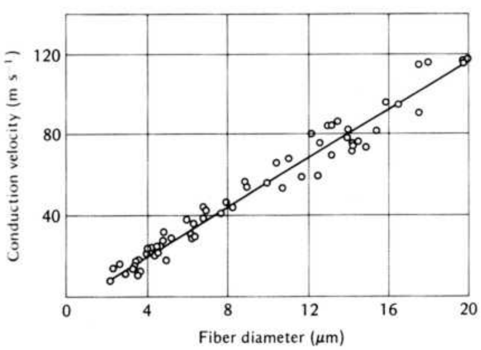






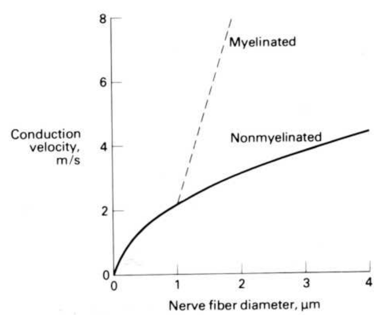
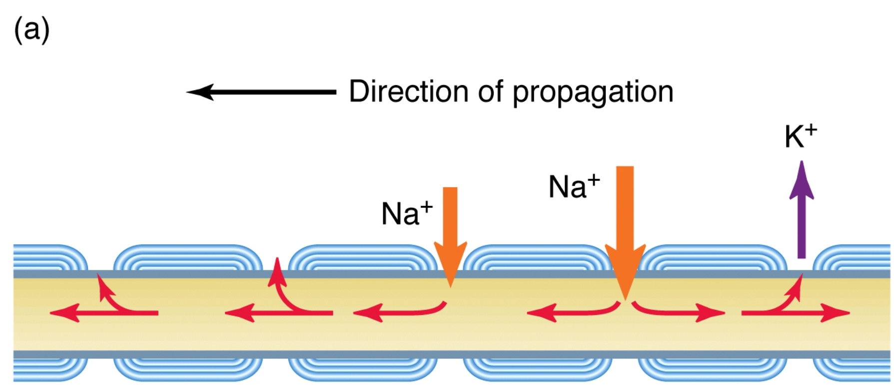
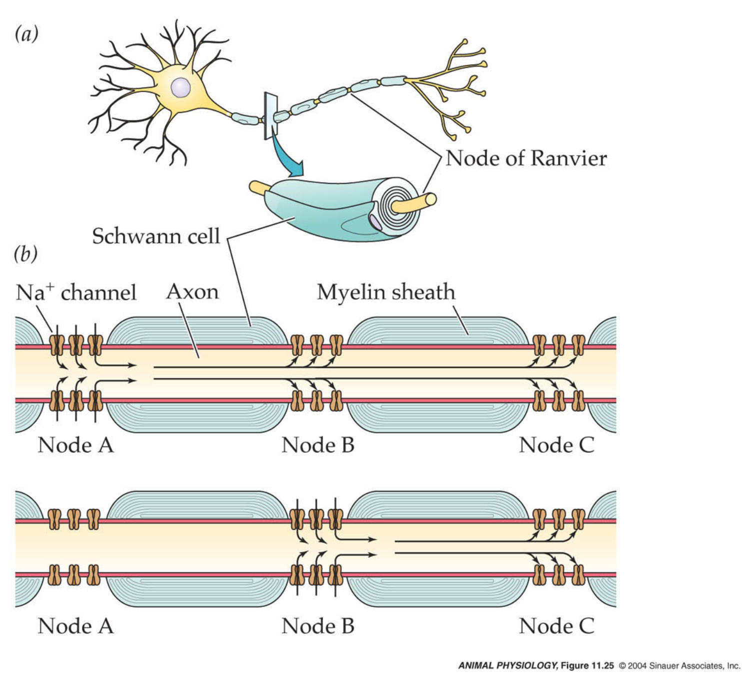


Figure 16.9
The velocity of conduction of an action potential depends on the square root of nerve-fiber diameter for nonmyelinated nerves but increases linearly with fiber diameter for myelinated nerves (from Rushton, 1951).


(a)
Direction of propagation
K+
Na+
Na+


(a)
Node of Ranvier
Schwann cell
(b)
Na+ channel
Axon
Myelin sheath
Node A
Node B
Node C
Node A
Node B
Node C
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