Física do Corpo Humano

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Energia Elétrica no Corpo Humano

B07

Cargas Elétricas

Table 12.2. The molar conductance at infinite dilution $\Lambda_{0,i}$ for different ions. (Using data from [596])

ion	$\Lambda_{0,i}$ (1/ohm-m-M)
H^+	34.9
OH^-	19.8
Na^+	5.0
Cl^-	7.6

Table 12.3. Ionic concentrations in blood and cell cytoplasm of unbound ions. (Using data from [597])

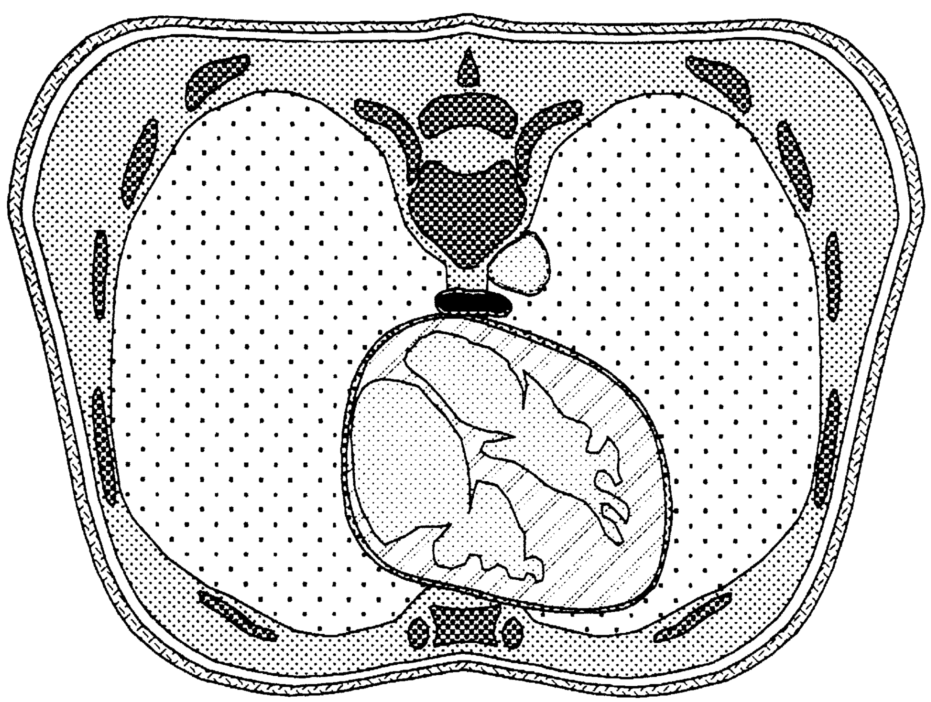
ion	blood concentration	cytoplasm concentration	ratio
Na^+	145 mM	12 mM	12:1
K^+	4 mM	140 mM	1:35
H^+	40 nM	100 nM	1:2.5
Mg^{2+}	1.5 mM	0.8 mM	1.9:1
Ca^{2+}	1.8 mM	100 nM	18:1
Cl^-	115 mM	4 mM	29:1
HCO_3^-	25 mM	10 mM	2.5:1

Cargas Elétricas

Table 12.4. Low frequency resistivity of some body tissues, in ohm-m (Ω-m). (Using data from [567, 573, 586])

tissue	resistivity
cerebrospinal fluid	0.650
blood plasma	0.7
whole blood	1.6 (Hct = 45%)
skeletal muscle	
– longitudinal	1.25–3.45
– transverse	6.75–18.0
liver	7
lung	
– inspired	17.0
– expired	8.0
neural tissue (as in brain)	
– gray matter	2.8
– white matter	6.8
fat	20
bone	>40
skin	
– wet	10^5
– dry	10^7

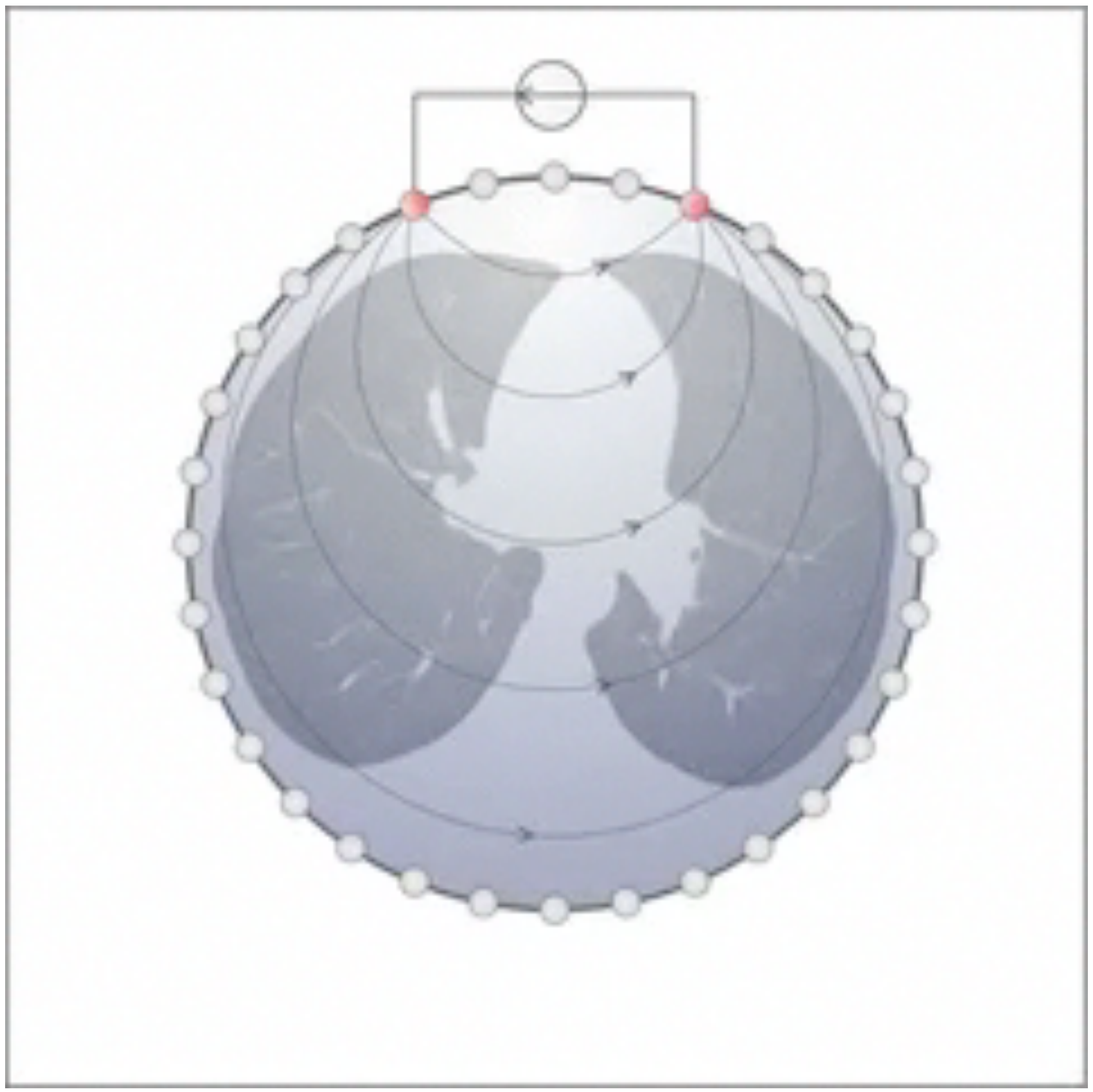
Cargas Elétricas

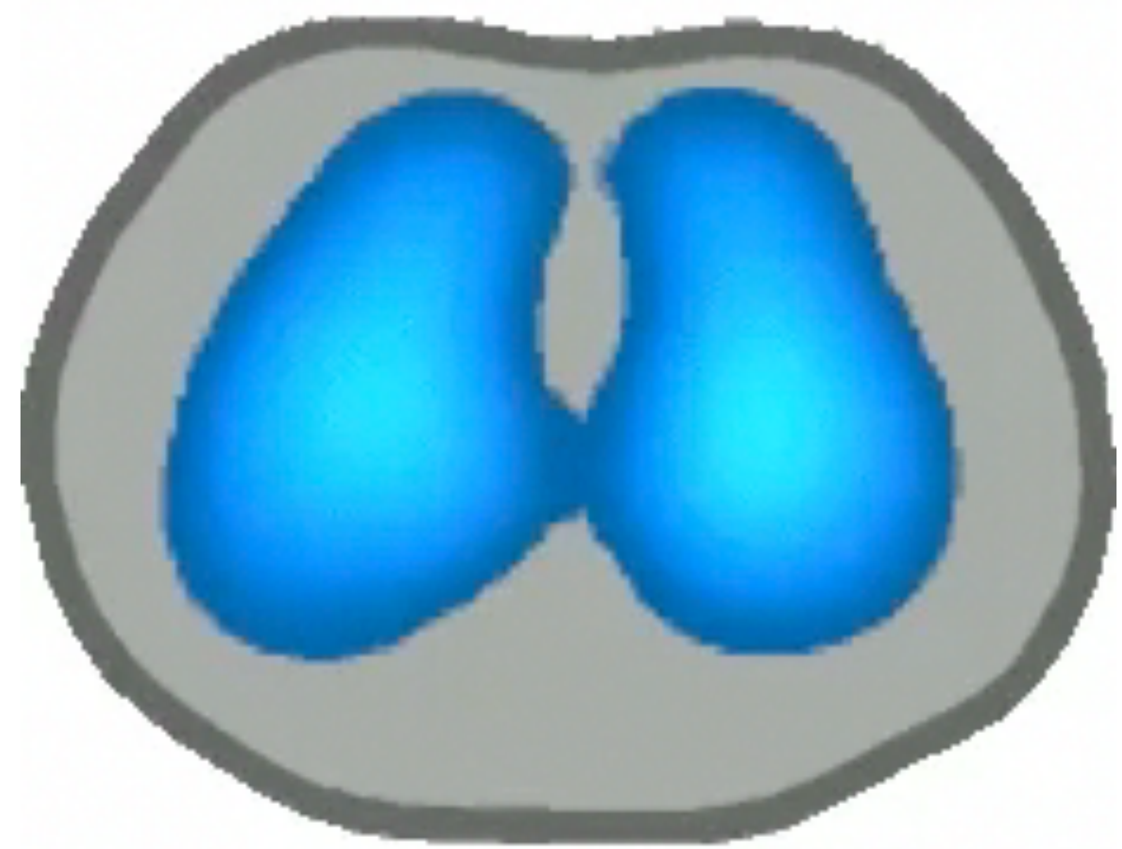


	Tissue	Resistivity [Ω m]	
	Blood	1.6	
	Heart muscle	2.5	(parallel to fibers)
		5.6	(normal to fibers)
	Skeletal muscle	1.9	(parallel to fibers)
		13.2	(normal to fibers)
	Lungs	20	
	Fat	25	
	Bone	177	

Fig. 12.6. Cross-section of the thorax, with the electrical resistivity of six types of tissues. (From [586]. Used with permission)

Impedância





Neurônios

Neurônios são células especializadas, eletricamente excitáveis, que processam e transmitem informação via sinais elétricos e químicos

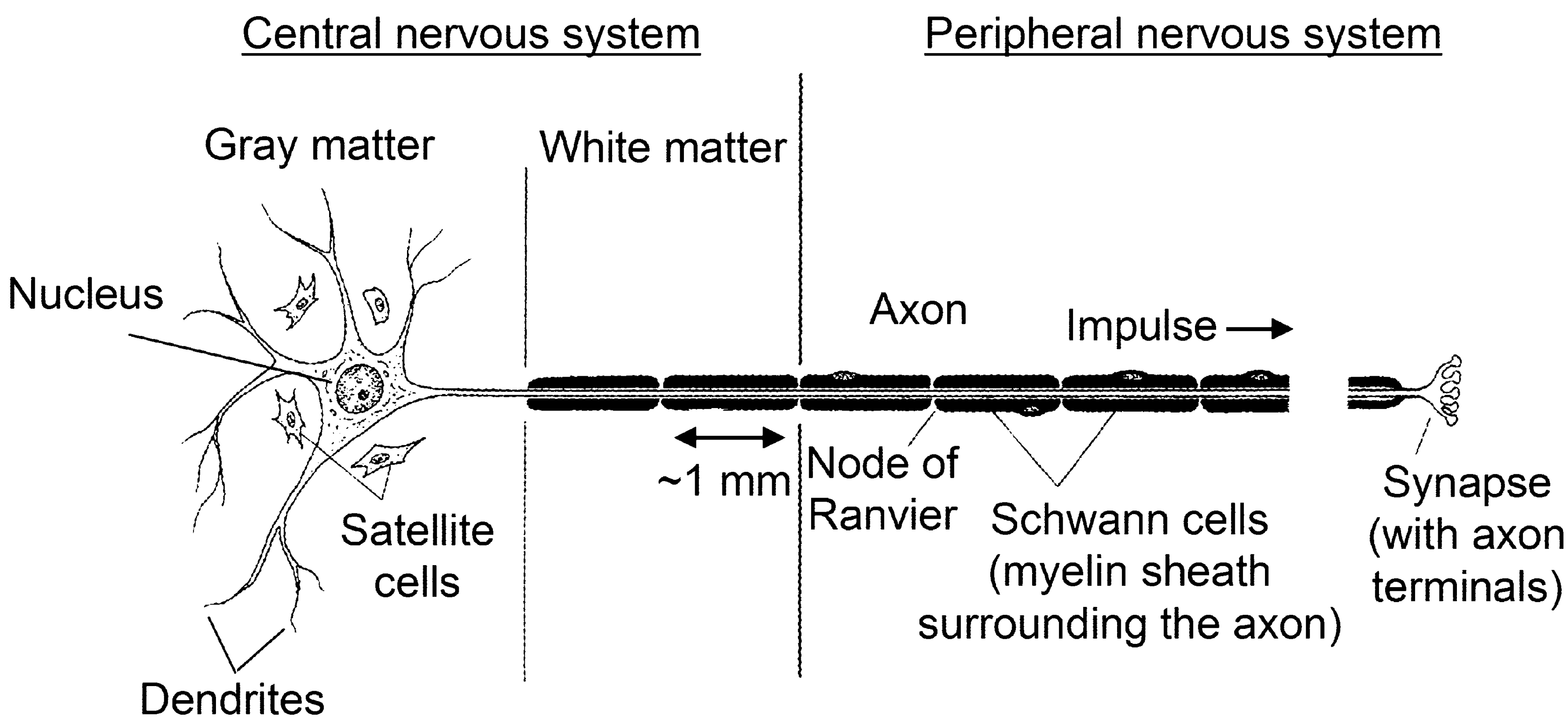


Fig. 12.7. Structure of a neuron. (From [592])

Neurônios

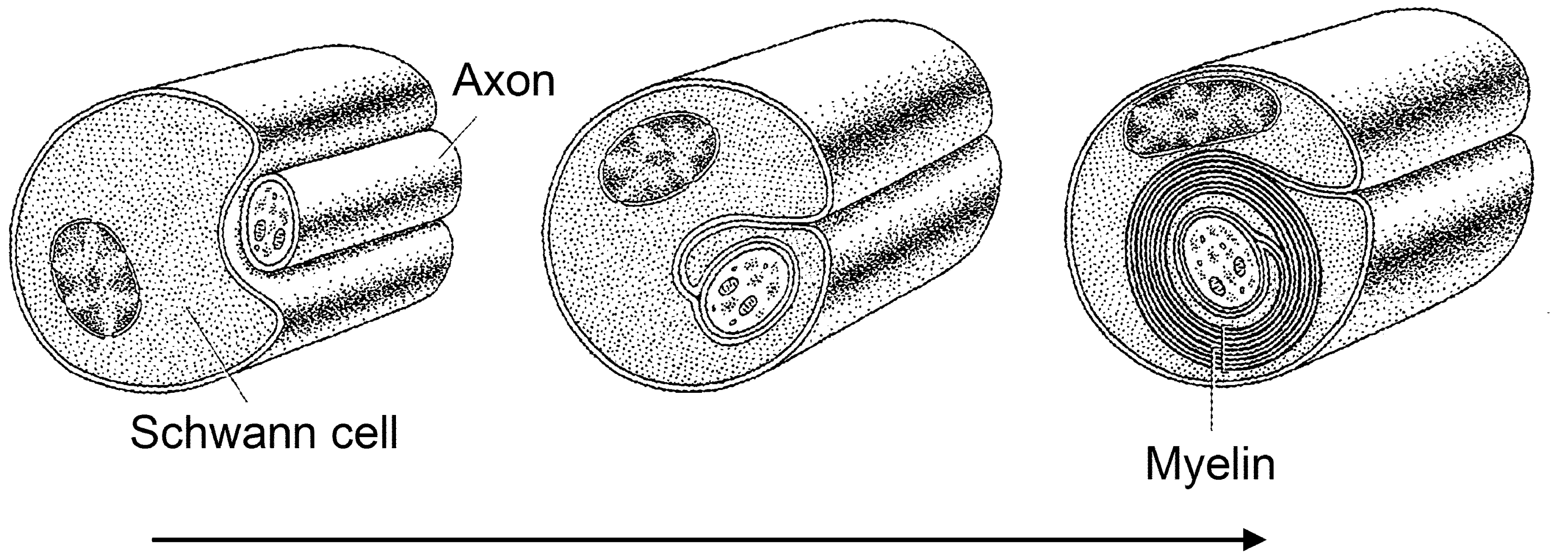


Fig. 12.8. The successive wrapping of Schwann cells about the axon of a neuron to form the myelin sheath of a myelinated nerve. (From [592])

- Axônios sem myelin não tem proteção em torno deles
- Essas proteções são formadas por células de Schwann que enrolam os axônios
- Aproximadamente 2/3 das fibras de axônios no corpo não possuem Myelin

$$R[\mu m] = 0.05 - 0.6\mu m\,,\ \ v = 1.8\sqrt{R[\mu m]}m/s$$

Neurônios

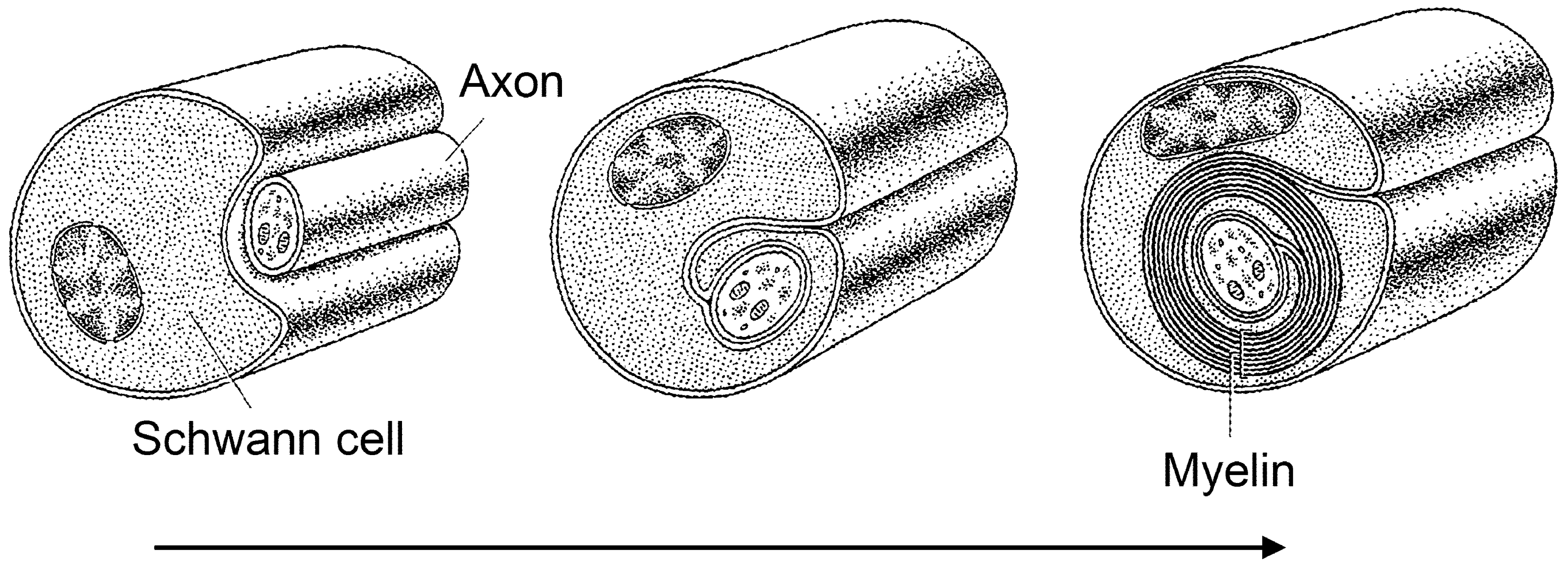


Fig. 12.8. The successive wrapping of Schwann cells about the axon of a neuron to form the myelin sheath of a myelinated nerve. (From [592])

- Axônios com Myelin são mais grossos devido essa proteção, de raio b

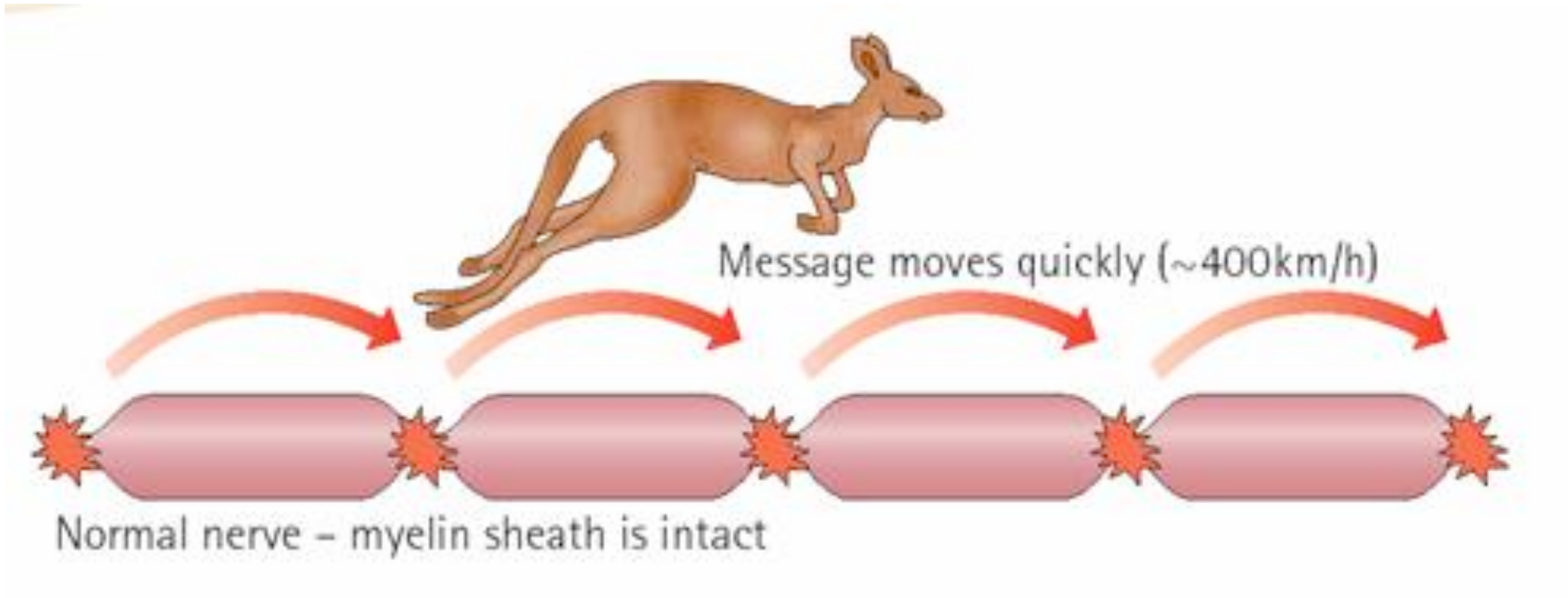
$$R[\mu m] = 0.5 - 10\mu m\,,\;\; v = 12(R+b)[\mu m] \approx 17(R[\mu m])m/s$$

$$R[\mu m] = 0.05 - 0.6\mu m\,,\;\; v = 1.8\sqrt{R[\mu m]}m/s$$ **Sem Myelin**

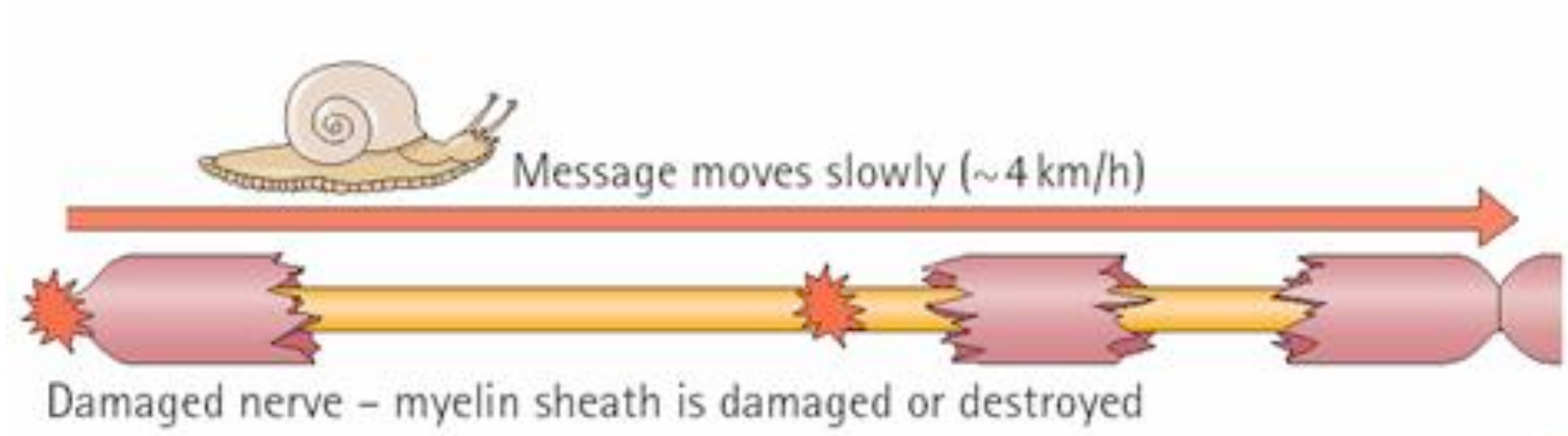
Neurônios

- Myelin é um dielétrico (isolante)
- Começa a ser produzido na decima quarta semana fetal
- O processo de Myelinação é intenso na infância e continua até a adolescência
- Myelin é típico nos animais vertebrados
- Myelin é branco e a gordura ajuda a isolar eletricamente os axônios dos átomos e moléculas carregadas.
- Myelin faz parte do desenvolvimento infantil, conduzindo uma evolução rápida das crianças
- A função principal é aumentar a velocidade de propagação dos impulsos nervosos.
- Myelin funcina como um duto onde fibras periféricas de axônio pode se regenerar.

Neurônios



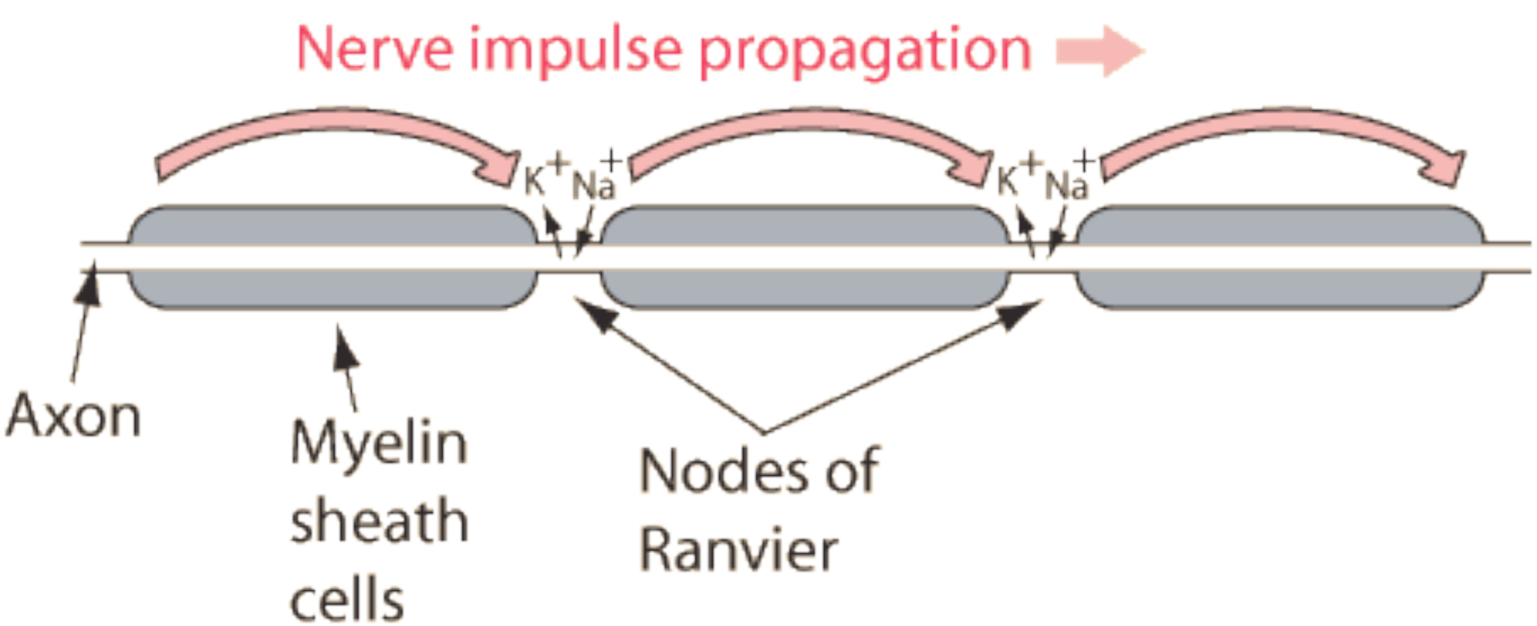
Onda propaga em saltos

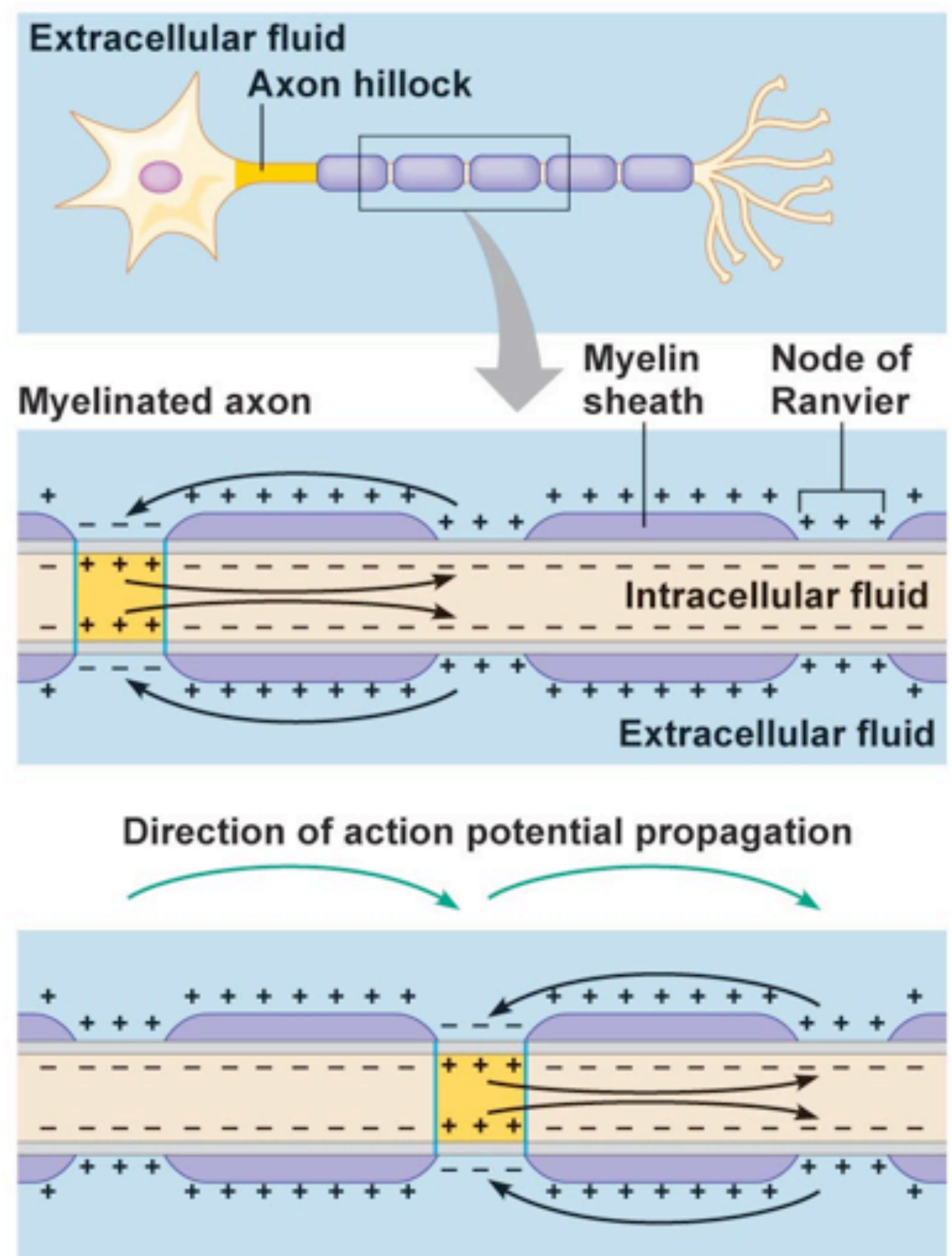


Onda continua

Neurônios

Saltatory conduction:





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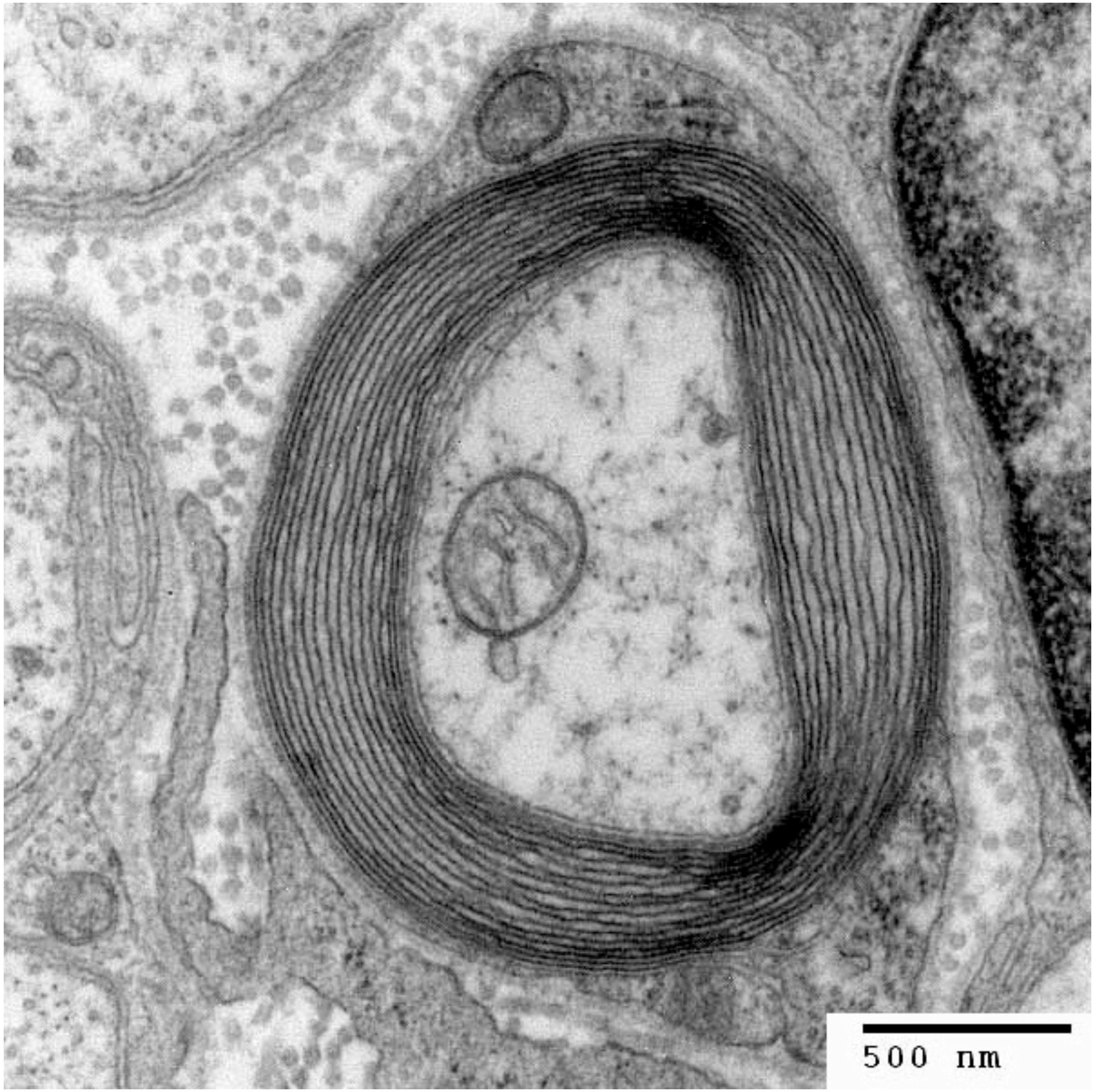
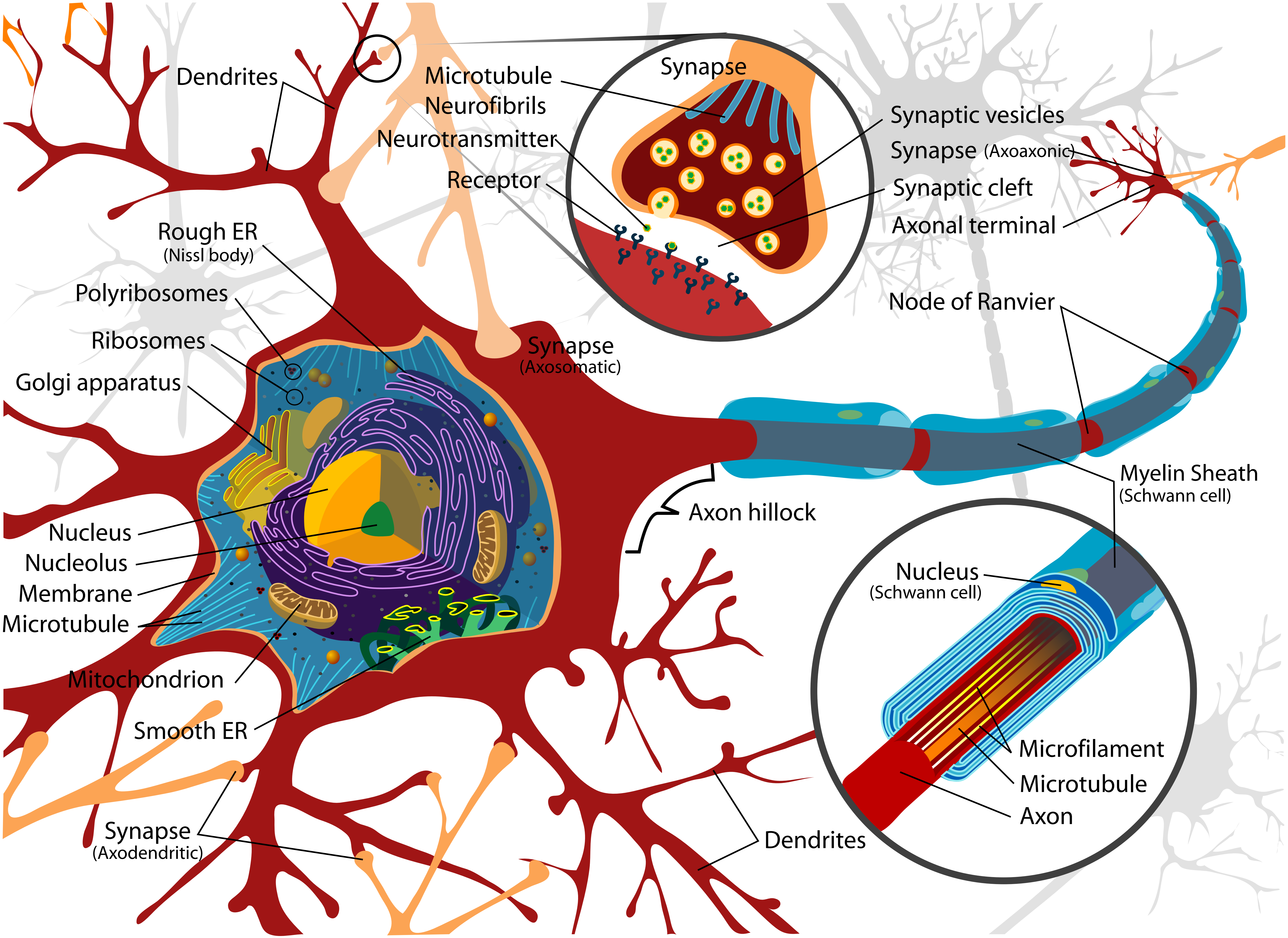
Além de aumentar a velocidade do impulso nervoso, a bainha de mielina ajuda a reduzir o gasto de energia na zona de despolarização e, consequentemente, a quantidade de íons de sódio / potássio, que necessitam de ser bombeados para trazer a concentração de volta ao normal, é diminuída.

Neurônios



Transmission electron micrograph of a myelinated axon, generated at the Electron Microscopy Facility at Trinity College, Hartford, CT



Dendrites
Microtubule
Neurofibrils
Neurotransmitter
Receptor
Synapse
Synaptic vesicles
Synapse (Axoaxonic)
Synaptic cleft
Axonal terminal
Rough ER
(Nissl body)
Polyribosomes
Ribosomes
Golgi apparatus
Synapse
(Axosomatic)
Node of Ranvier
Myelin Sheath
(Schwann cell)
Axon hillock
Nucleus
Nucleolus
Membrane
Microtubule
Mitochondrion
Smooth ER
Nucleus
(Schwann cell)
Microfilament
Microtubule
Axon
Synapse
(Axodendritic)
Dendrites

Neurônios

• Neurônios aferentes (ou sensoriais): sinais nos axonios seguem das zonas sensitivas para a espinha dorsal. Eles são afetados pelas condições externas - 10 milhões deles.

• Neurônios eferentes (ou motores): sinais nos axônios seguem do cérebro para as zonas motoras - 0.5 milhões.

• 100 bilhões de neunônios no cérebro com 100 trilhoes de sinápses.

There are approximately $1 - 2 \times 10^6$ optical nerves from the $1 - 2 \times 10^8$ rods and cones in our eyes, 20,000 nerves from the 30,000 hair cells in our ears, 2,000 nerves from the 10^7 smell cells in our noses, 2,000 nerves from the 10^8 taste sensing cells in our tongues, 10,000 nerves from the 500,000 touch-sensitive cells throughout our body, and many (but an uncertain number of) nerves from the 3×10^6 pain cells throughout our body.

Neurônios

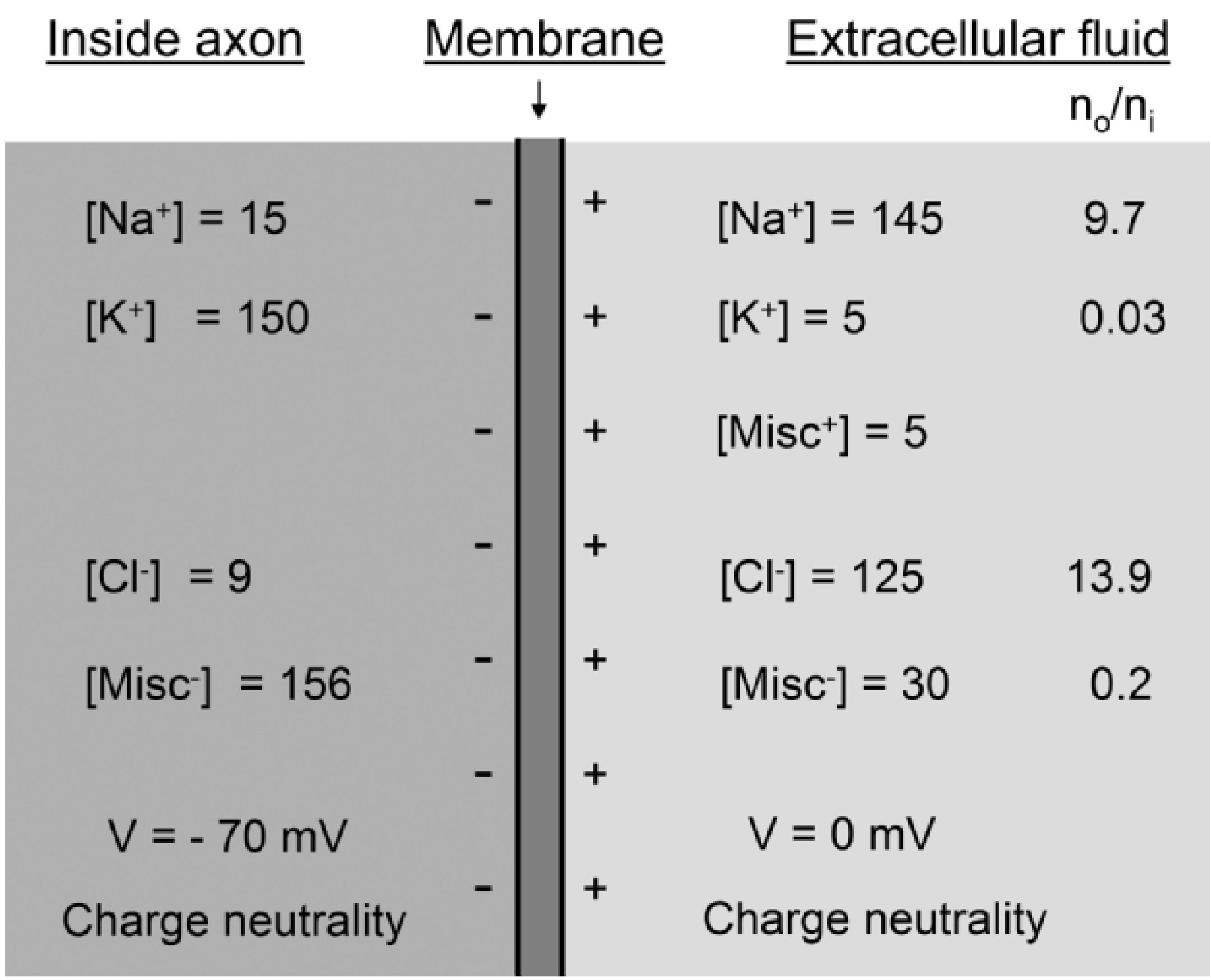


Fig. 12.9. Ion concentrations (in mmol/L) in a typical mammalian axon nerve cell (n_i) and in the extracellular fluid surrounding it (n_o), and their ratios (n_i/n_o). (Based on [581])

Neurônios

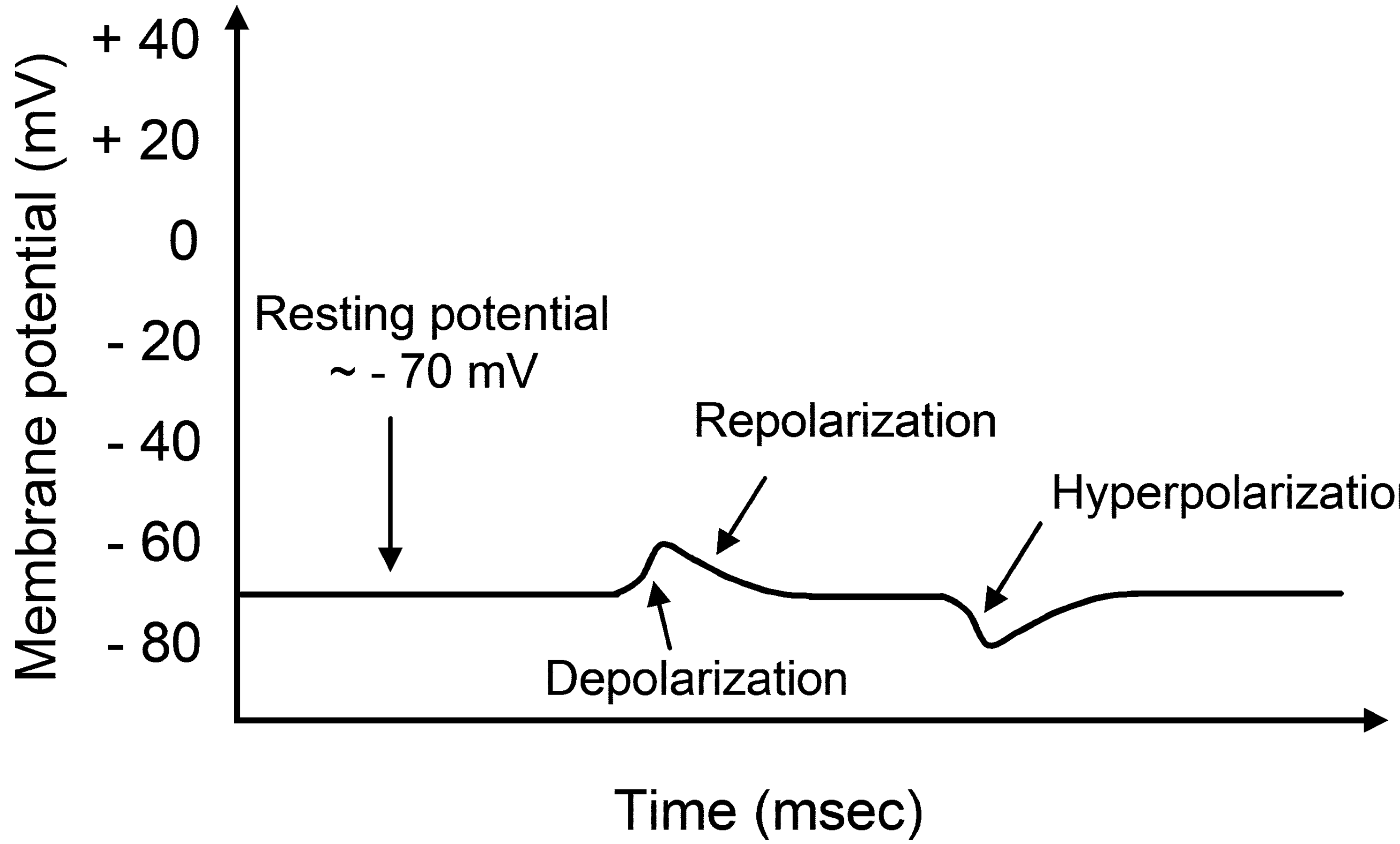


Fig. 12.10. The membrane resting potential of $-70\,\text{mV}$ (inside the membrane relative to the always fixed $0\,\text{mV}$ outside) – the polarized state, along with potential disturbances showing depolarization (voltage increases from the resting potential value), repolarization (returns to the resting potential), and hyperpolarization (decreases from the resting potential)

Neurônios

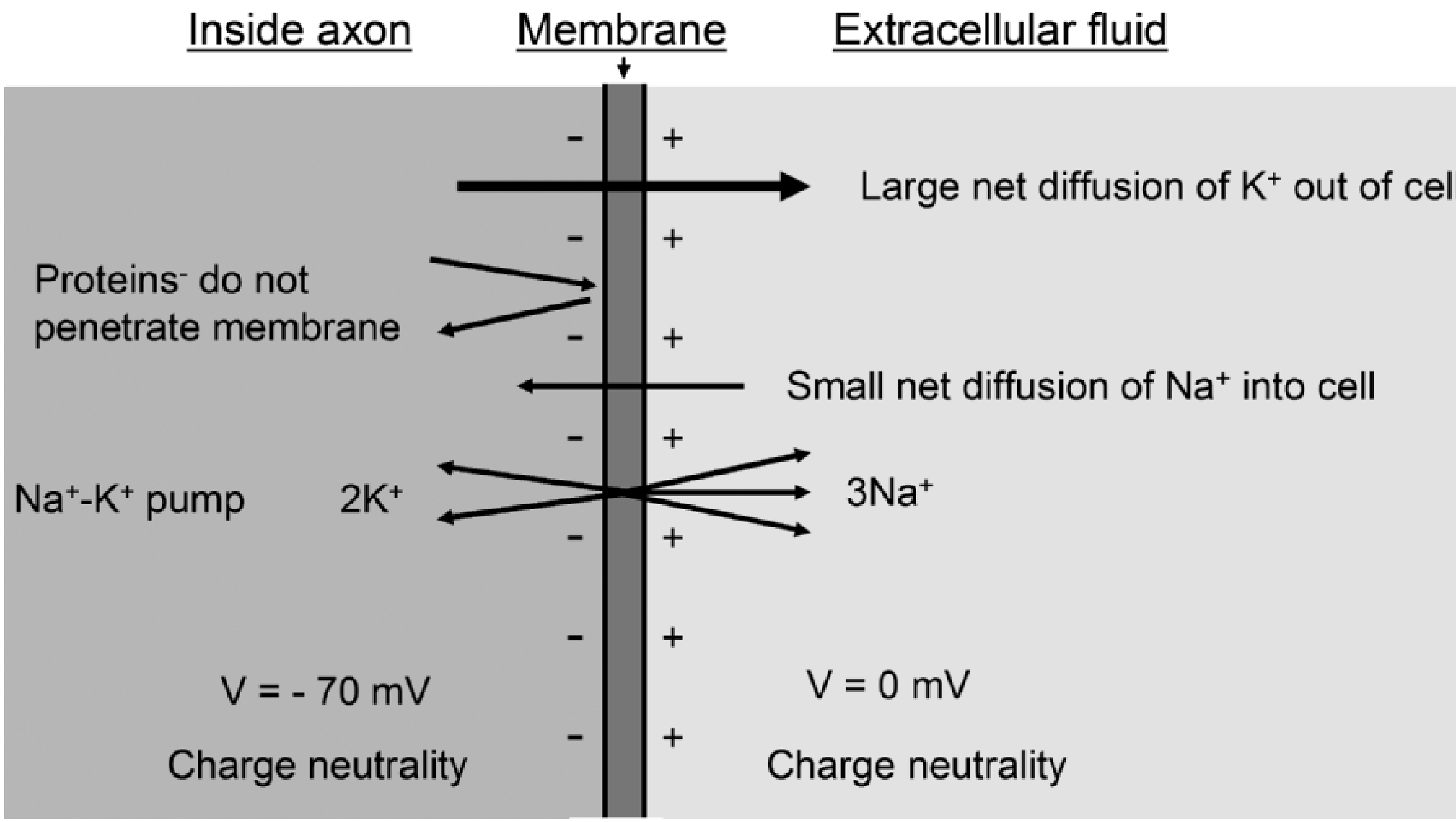


Fig. 12.11. Mechanisms for ion flow across a polarized cell membrane that determine the resting membrane potential

Neurônios

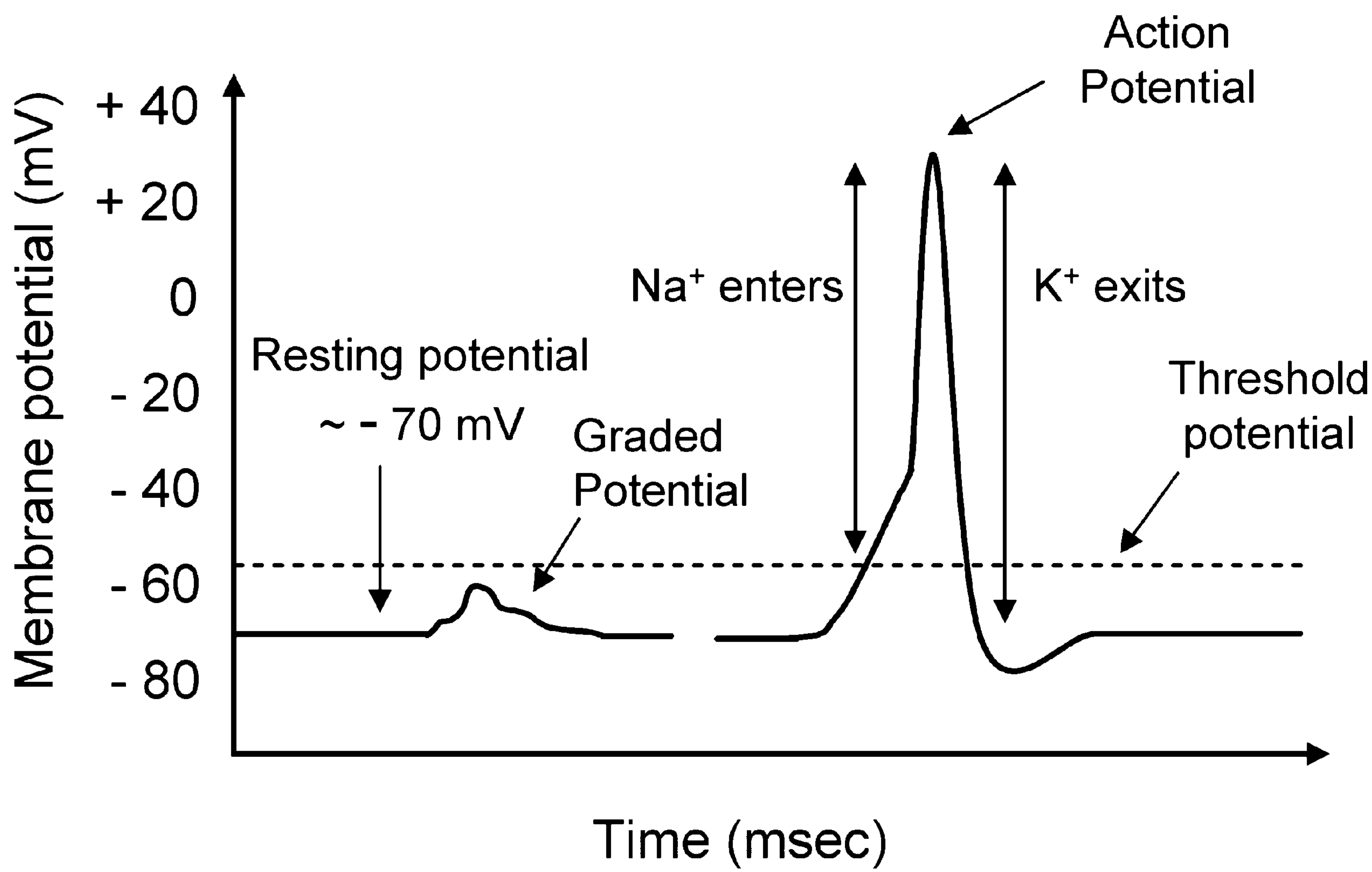
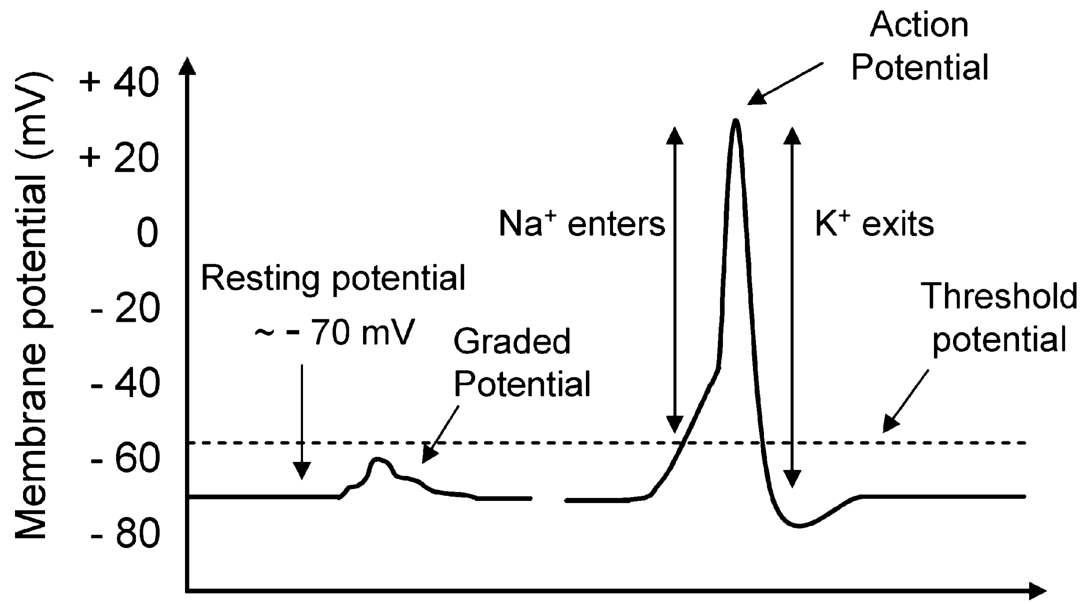


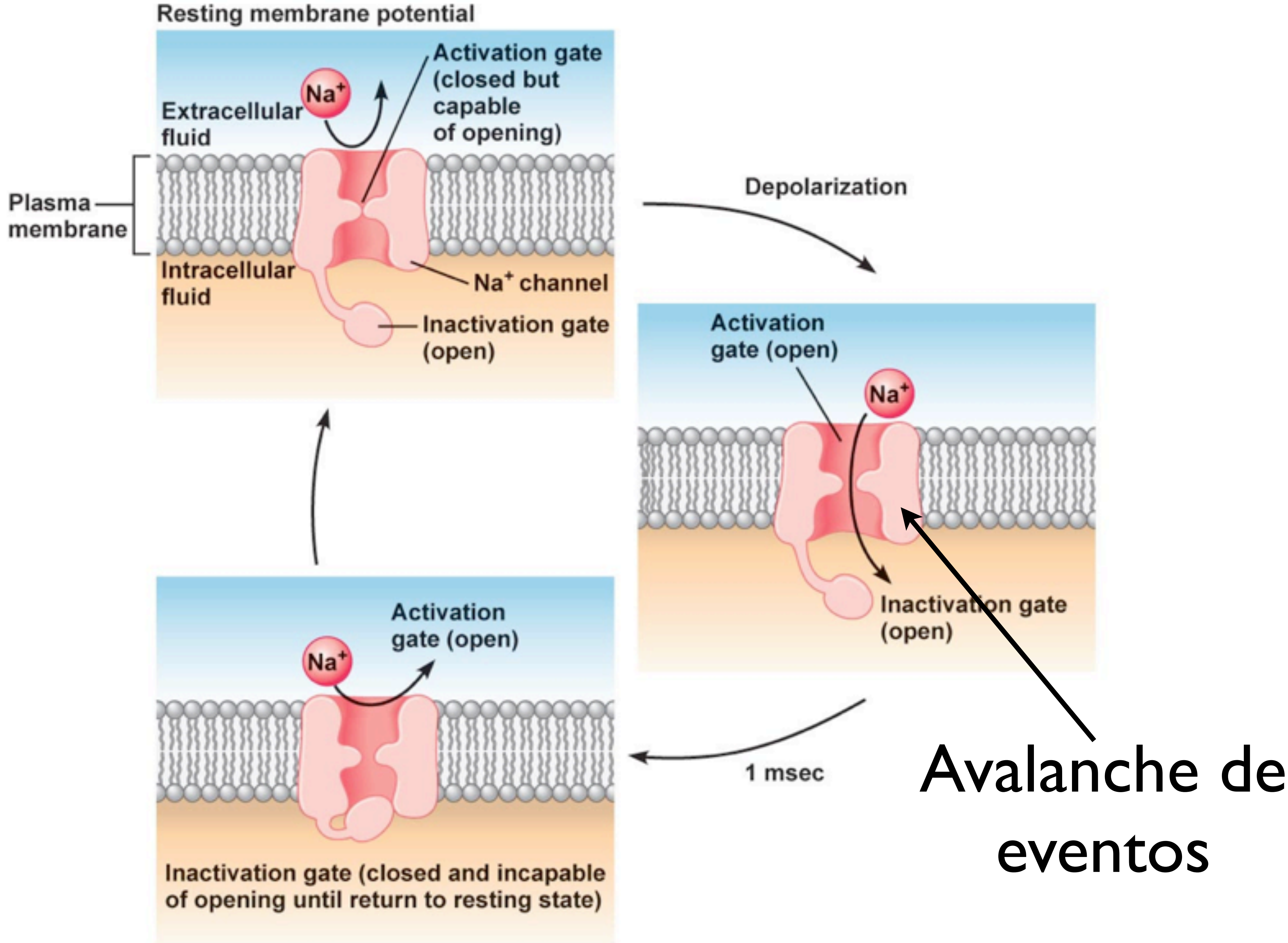
Fig. 12.14. The (subthreshold) graded potentials and (above threshold) action potentials

Neurônios

- Potencial *graded*: são pequenas perturbações no potencial da membrana devido a adesão de neurotransmissores, estímulo sensorial - depolarização ou hiperpolarização.
- Potencial de ação: grande depolarização de aproximadamente 15 a 20 mV, levando a membrana acima de um limiar aproximadamente -55mV.
- Nesse limiar, a membrana abre permitindo a entrada de Na+ durante 1 a 5 ms
- Com o potencial alto, estimula a saida de K+ da célula



Neurônios



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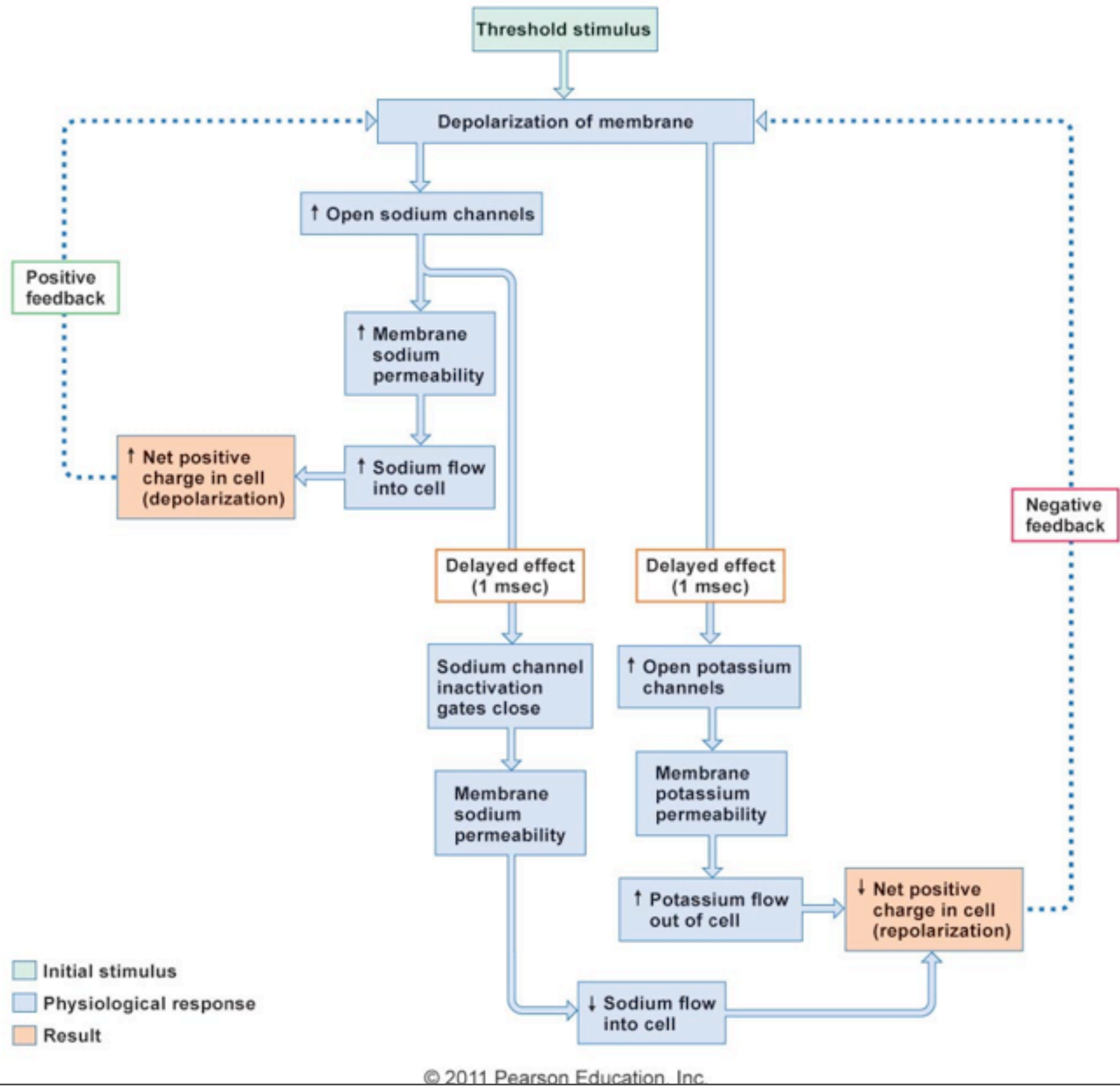
Neurônios


Threshold stimulus
Depolarization of membrane
↑ Open sodium channels
Positive feedback
↑ Membrane sodium permeability
↑ Net positive charge in cell (depolarization)
↑ Sodium flow into cell
Negative feedback
Delayed effect (1 msec)
Delayed effect (1 msec)
Sodium channel inactivation gates close
↑ Open potassium channels
Membrane sodium permeability
Membrane potassium permeability
↑ Potassium flow out of cell
↓ Net positive charge in cell (repolarization)
↓ Sodium flow into cell
Initial stimulus
Physiological response
Result
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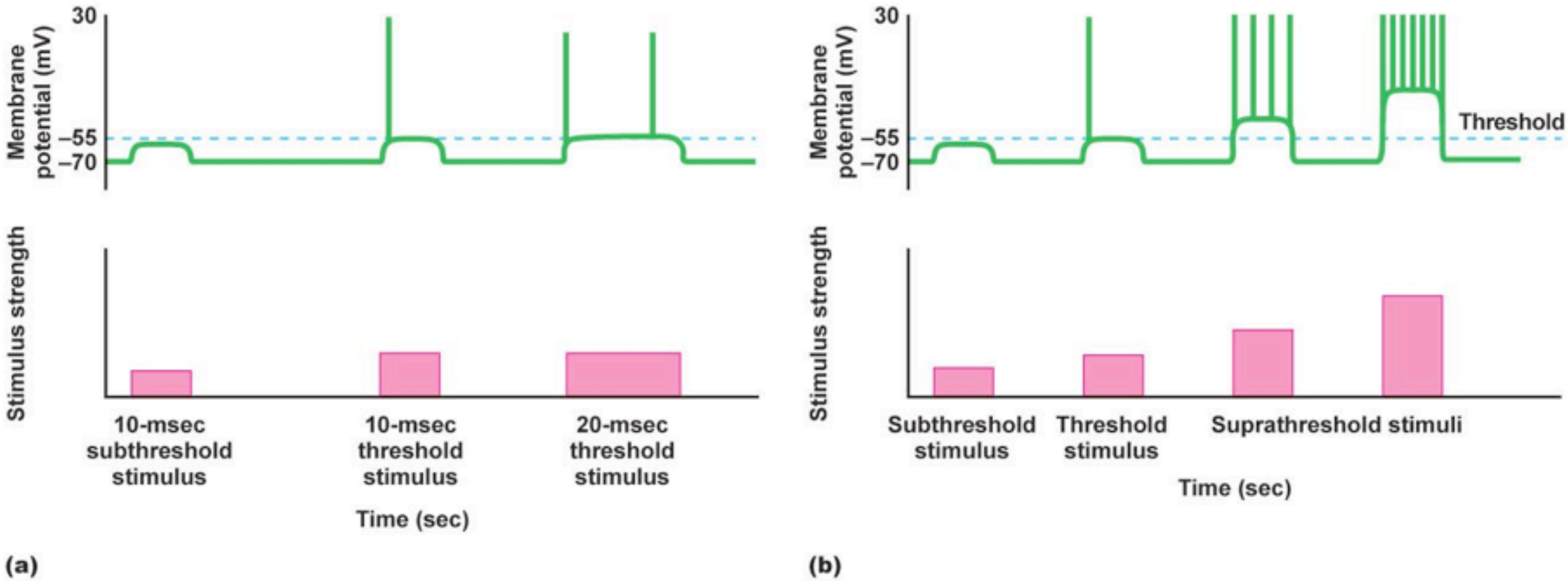
Neurônios



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Os períodos refratários relativos tornam possível codificar a informação através da conversão da intensidade de um estímulo para a frequência dos potenciais de ação. Um *suprathreshold* de *gradded potential* pode produzir um número maior de potenciais de ação dentro de um determinado período de tempo que estímulos menores.

Neurônios

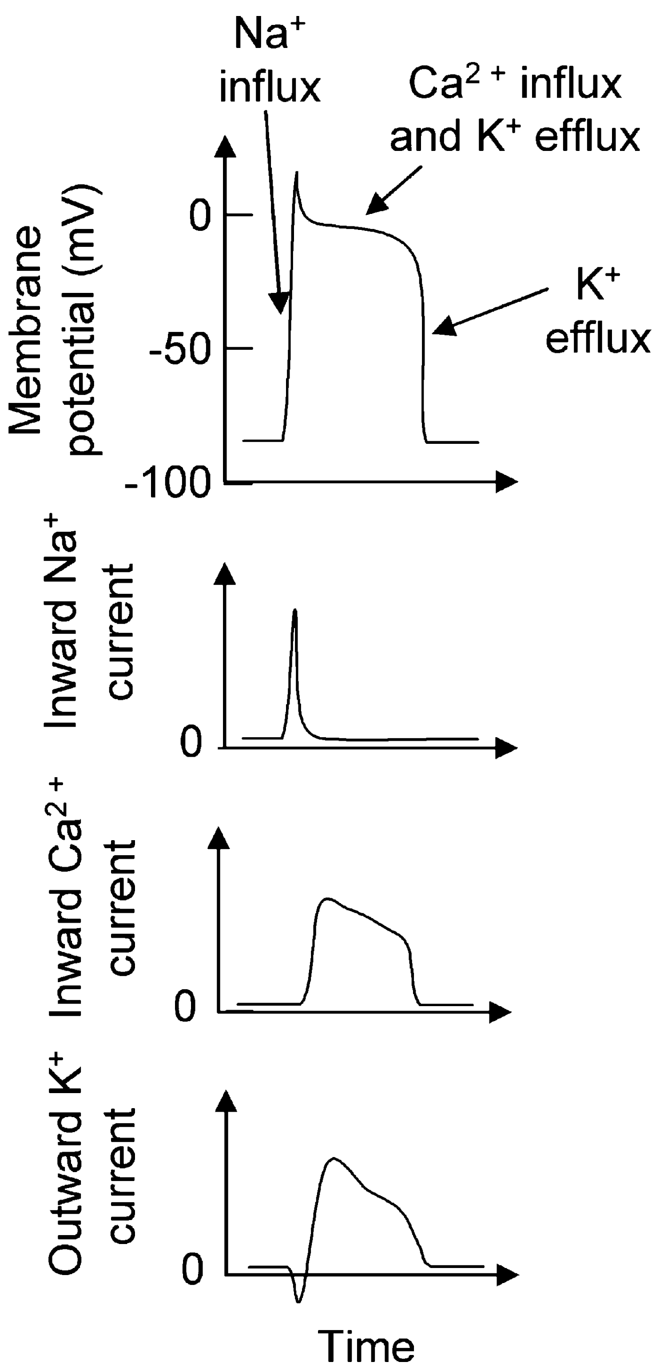

Fig. 12.15. The depolarization and repolarization of cardiac muscle, along with the flows of Na^+, Ca^{2+}, and K^+ ions. The inward flux of Na^+ and Ca^{2+} increases the potential and the outward flux of K^+ decreases it. (Based on [585])

Neurônios

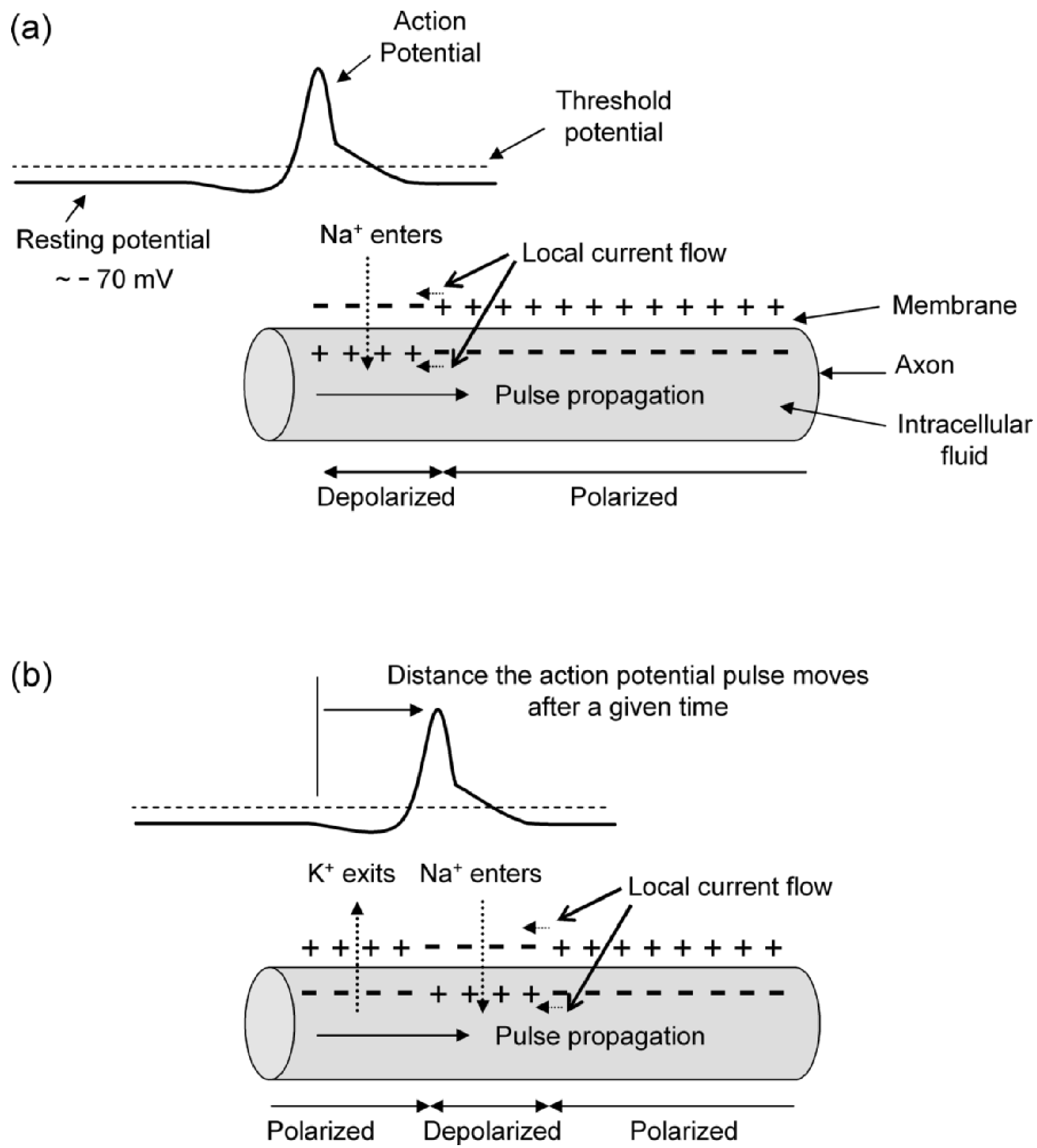

Fig. 12.16. The flow of ions across the membrane during action potential propagation (**a**) at a given time and (**b**) at a later time

Neurônios

Table 12.5. Typical parameters for unmyelinated and myelinated nerves. (From [570, 571, 581])

		unmyelinated	myelinated
axon inner radius (m)	a	5×10^{-6}	5×10^{-6}
membrane/myelin thickness (m)	b	6×10^{-9}	2×10^{-6}
axoplasm resistivity (ohm-m)	ρ_{i}	1.1	1.1
membrane dielectric constant (s/ohm-m)	$\kappa\epsilon_0$	6.20×10^{-11}	6.20×10^{-11}
membrane/myelin resistivity (ohm-m)	ρ_{m}	10^7	10^7
resistance per unit length of fluid[a] (ohm/m)	r	6.37×10^9	6.37×10^9
conductivity/length axon membrane (mho/m)	g_{m}	1.25×10^4	3×10^{-7}
capacitance/length axon (F/m)	c_{m}	3×10^{-7}	8×10^{-10}

[a]Fluid both inside and outside the axon.

Monday, May 6, 13

Neurônios

Resistência dentro do axonio sem myelin por unidade de comprimento:

$$r_\mathrm{i} = \frac{\rho_\mathrm{i}}{\pi a^2} = \frac{0.5 \text{ ohm-m}}{\pi(5 \times 10^{-6} \text{ m})^2} = 6.4 \times 10^9 \text{ ohm/m} = 6.4 \times 10^3 \text{ ohm/}\mu\text{m}.$$

Para a membrana:

$$r_\mathrm{m} = \frac{\rho_\mathrm{m}}{2\pi ab} = \frac{1.6 \times 10^7 \text{ ohm-m}}{2\pi(5 \times 10^{-6} \text{ m})(6 \times 10^{-9} \text{ m})}$$
$$= 8 \times 10^{19} \text{ ohm/m} = 8 \times 10^{13} \text{ ohm/}\mu\text{m},$$

Capacitância na membrana do axonio sem myelin por unidade de area:

$$\begin{aligned} c_\text{parallel plates} &= C_\text{parallel plates}/La = \kappa\epsilon_0/b \\ &= (6.20 \times 10^{-11} \text{s/ohm-m})/6 \times 10^{-9} \text{ m} \\ &= 0.01 \text{ F/m}^2. \end{aligned}$$

Neurônios

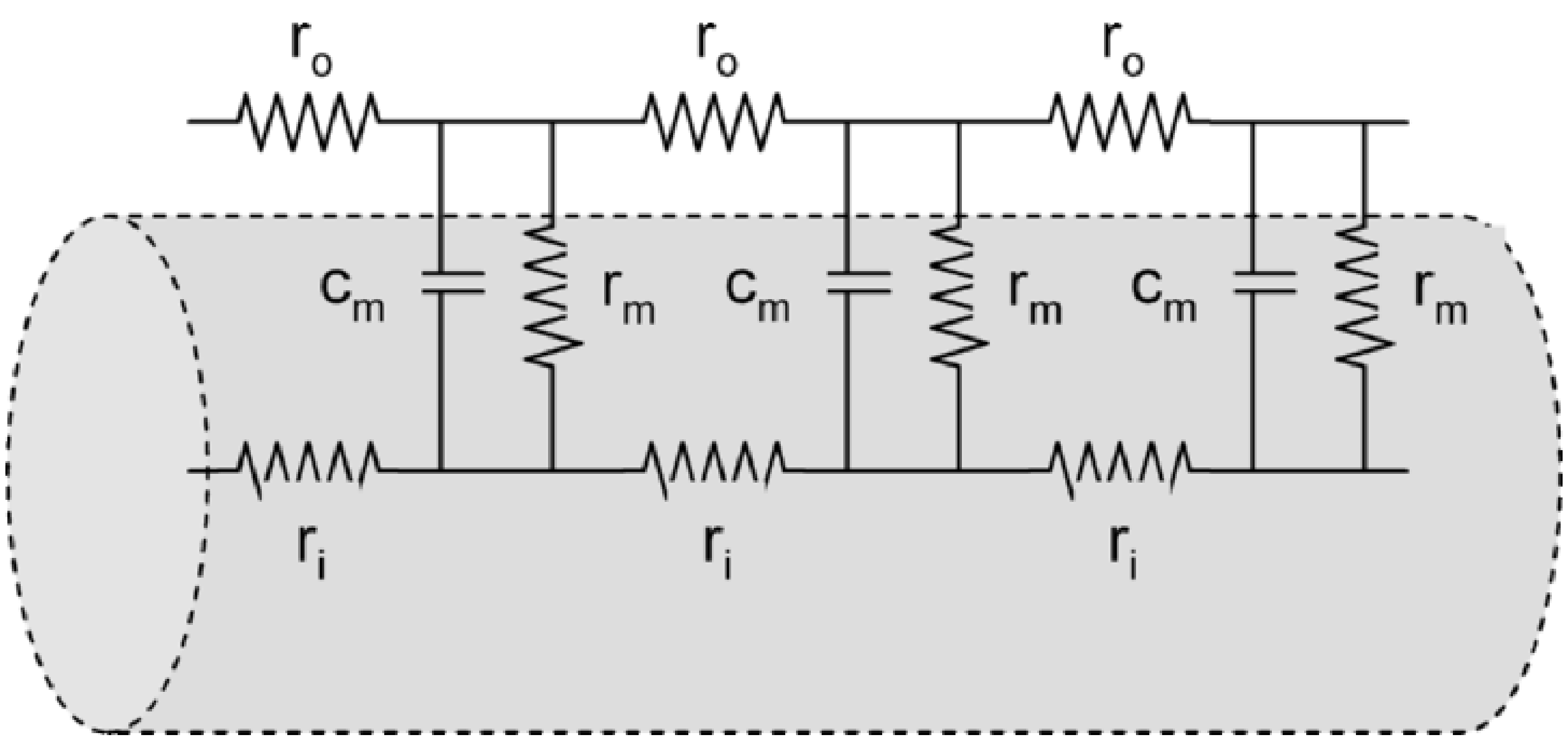

Fig. 12.17. Distributed circuit model of an axon, with resistance inside the axon r_i, membrane resistance r_m and capacitance c_m, and resistance outside the axon r_o, each per unit length

Neurônios

Table 12.5. Typical parameters for unmyelinated and myelinated nerves. (From [570, 571, 581])

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capacitance/length axon (F/m)	c_{m}	3×10^{-7}	8×10^{-10}

[a] Fluid both inside and outside the axon.

Neurônios

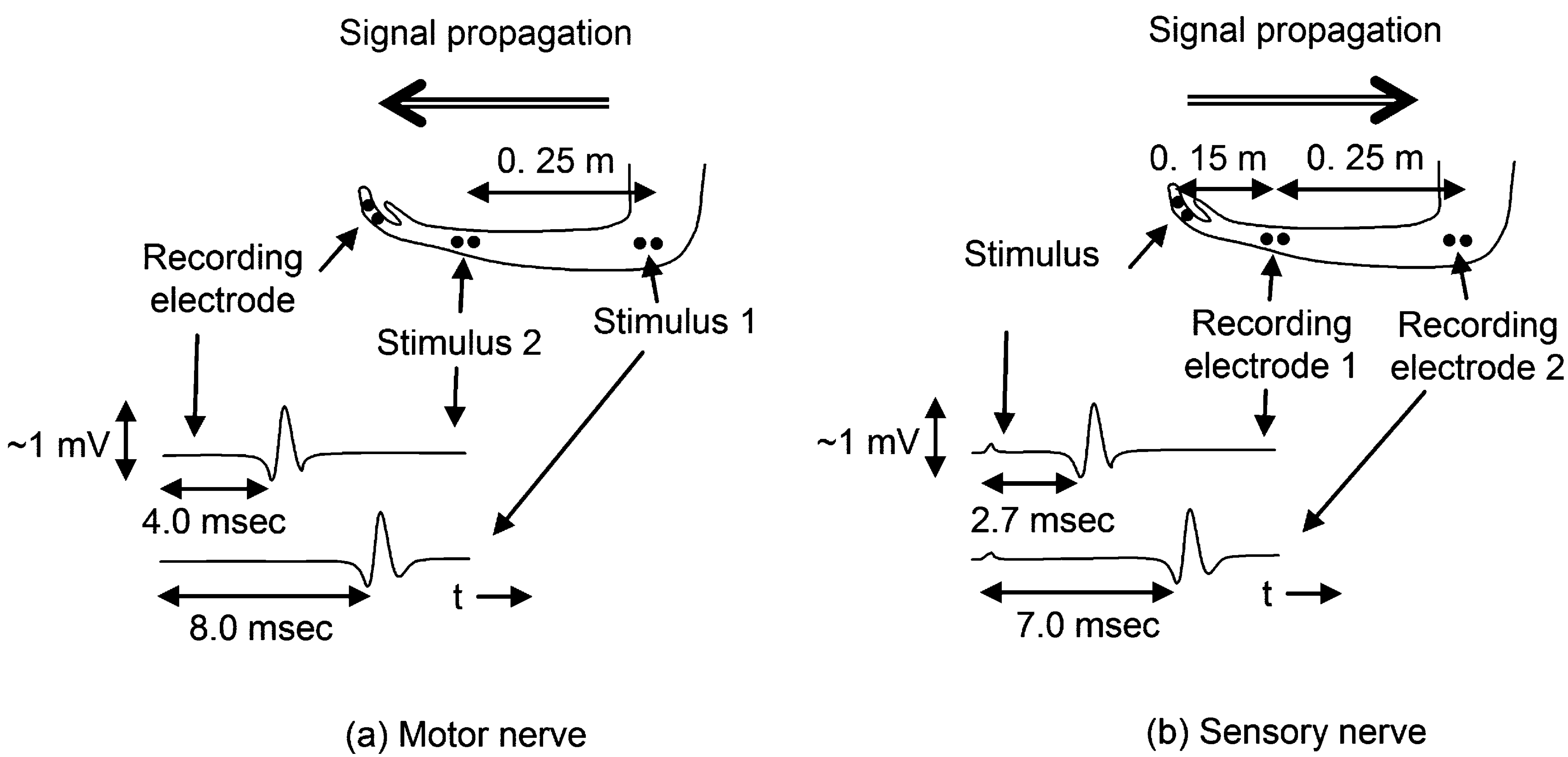

Fig. 12.22. Measuring the conduction speed along the lower arm and hand of (**a**) a motor nerve and (**b**) a sensory nerve, along with associated EMG signals. The conduction speed of the motor nerve in (a) is 62.5 m/s, and the conduction speed of the sensory nerve in (b) is 58.1 m/s (see Problem 12.18). (Based on [568])

Neurônios

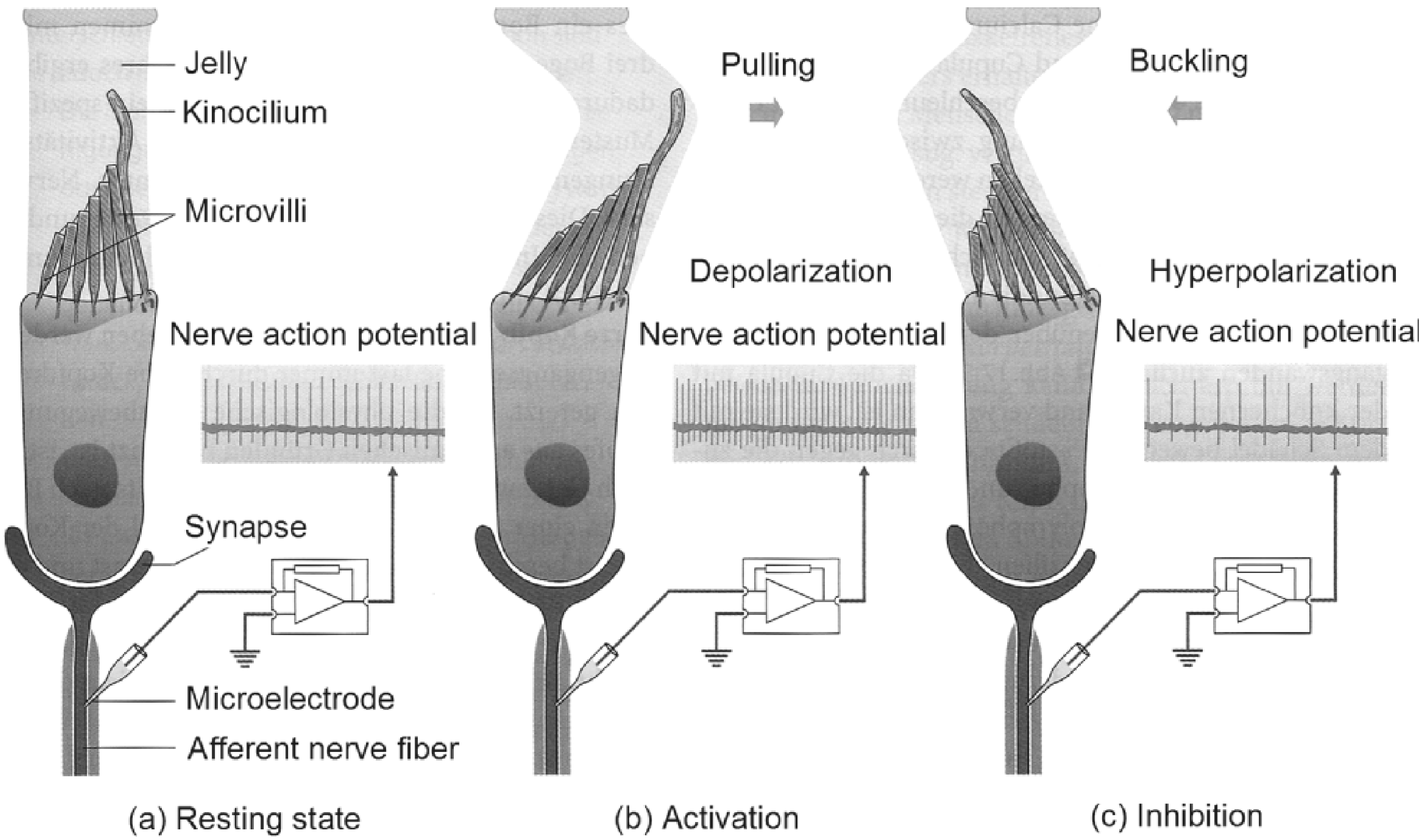

Fig. 12.25. In one mechanism for hair cell response, the hair bundle moves toward the kinocilium (hair with the bead) opening channels that are permeable to Na^+ (which is depolarization), as shown in (**b**). Resting activity is seen in (**a**) and hyperpolarization in (**c**). (From [593])

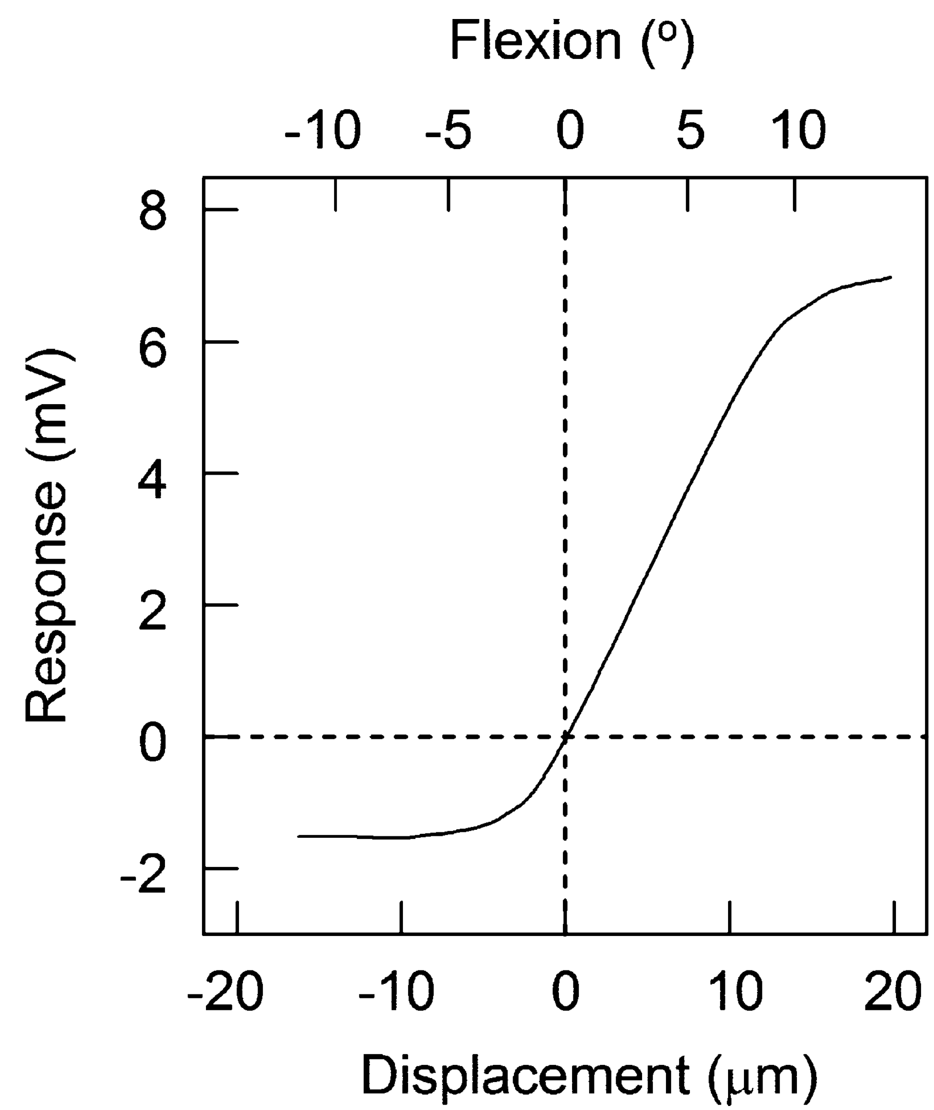

Fig. 12.26. Membrane potential vs. hair displacement (in position and angle). Positive displacements are toward the kinocilium. (Based on [574, 583])

Neurônios

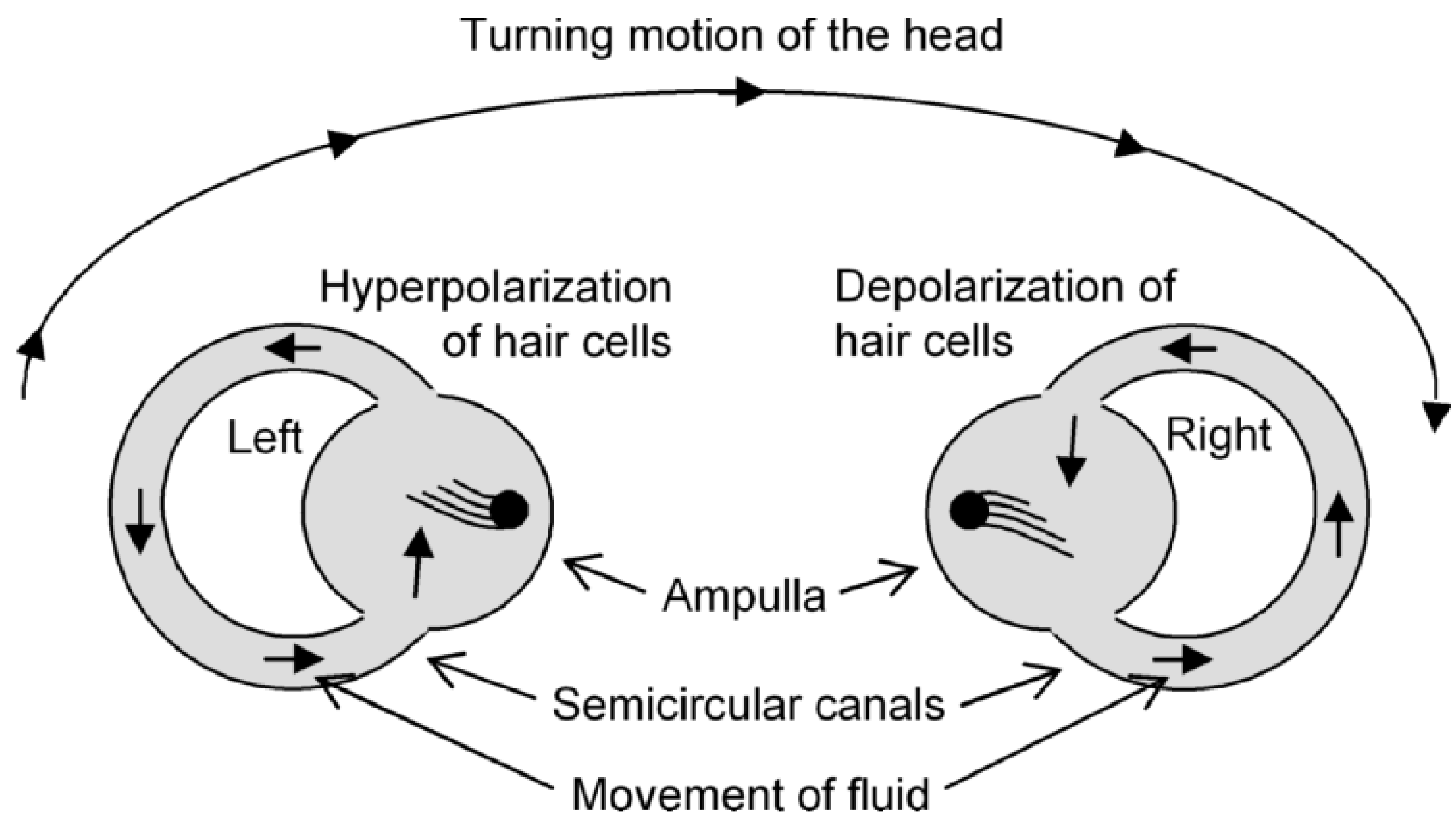

Fig. 12.27. The sense of balance is seen by examining the pair of horizontal semicircular canals, by looking at the head from above. When you turn your head clockwise there is counterclockwise motion of the cochlear fluid that depolarizes the hair cells in the semicircular canal in the right ear and hyperpolarizes them in the left ear. (Based on [574])