



**UNIVERSIDADE FEDERAL
DE SANTA CATARINA**



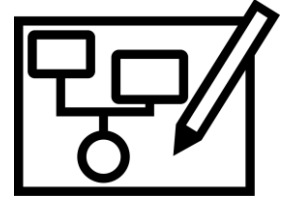
PÓS-GRADUAÇÃO
ENGENHARIA ELÉTRICA
FLORIANÓPOLIS | SANTA CATARINA



Eletricidade básica, medidas elétricas e instrumentos aplicados aos estudos de eletrofisiologia

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Profa. Daniela O. H. Suzuki, Dr. Eng.

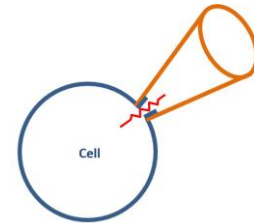
- Definições: carga elétrica, tensão elétrica, corrente elétrica, componentes elétricos;



- Características elétricas da membrana;



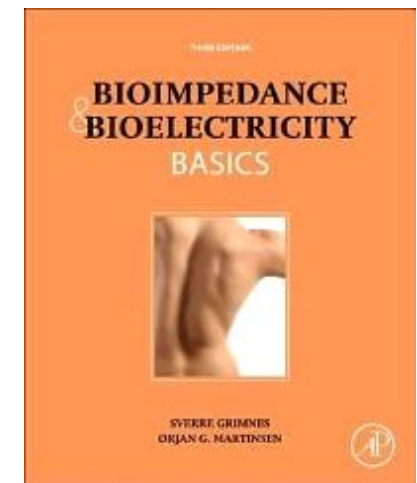
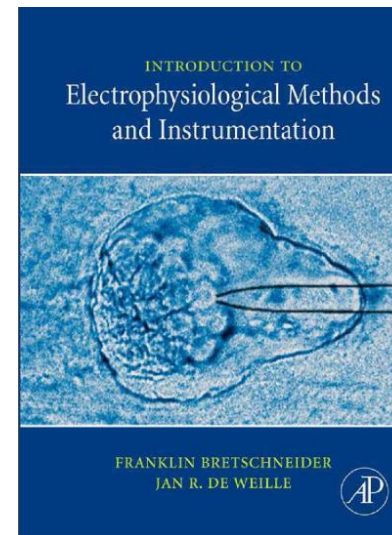
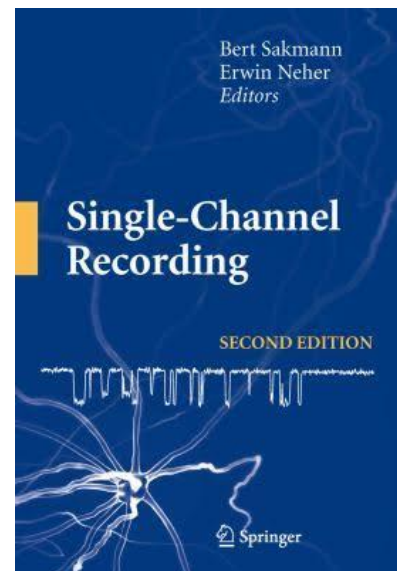
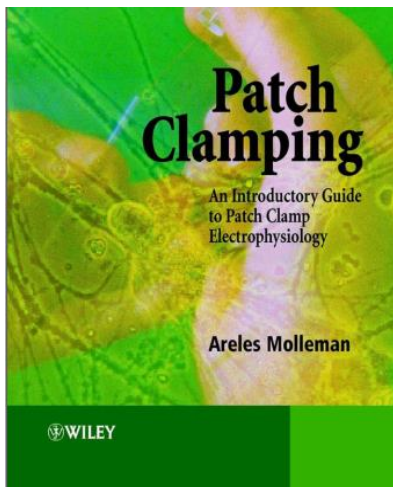
- Instrumentação e equipamentos para patch clamp;



- Outras informações em eletricidade.

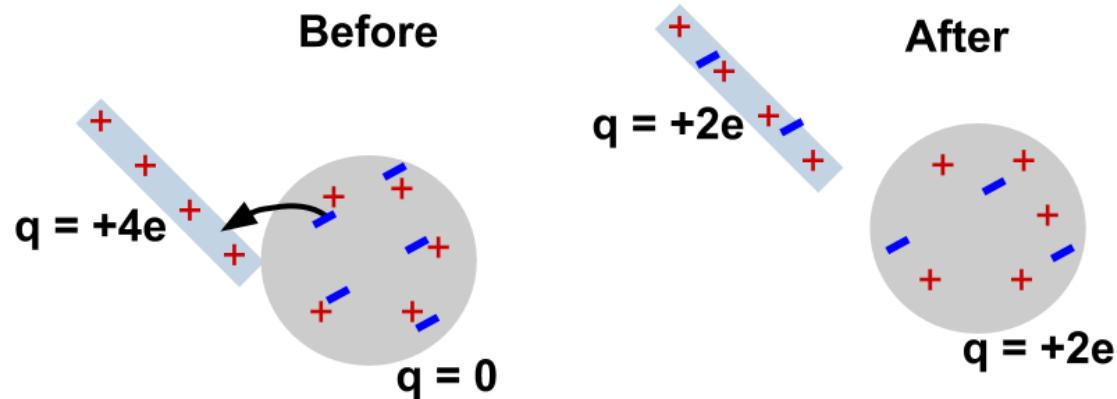
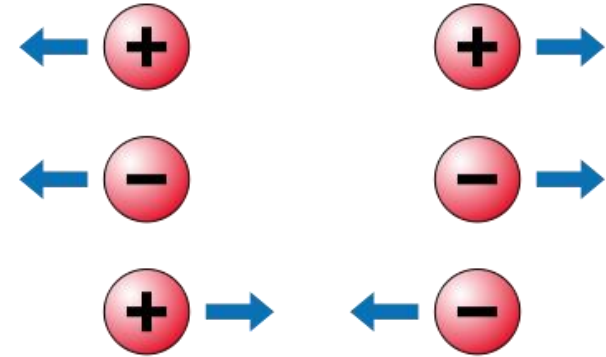


Bioeletricidade // Eletrofisiologia

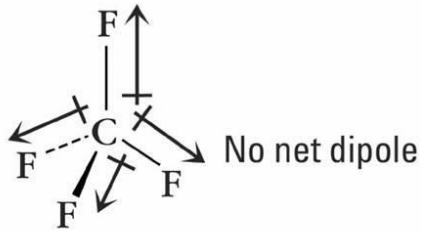


Carga Elétrica

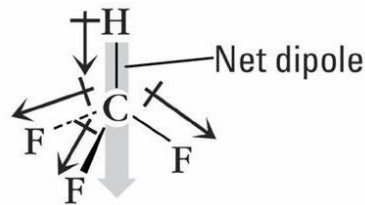
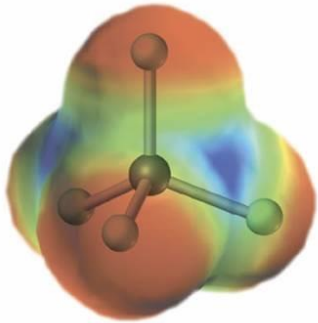
- Coulomb (C, SI);
- $1 \text{ C} = 6.24 \times 10^{18}$ electrons;
- Forças elétricas;
- Conservação da carga.



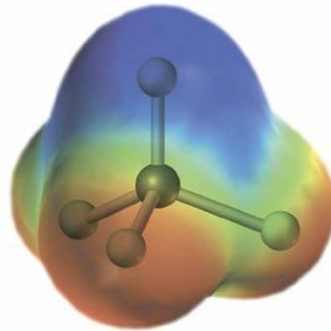
- Polaridade de moléculas



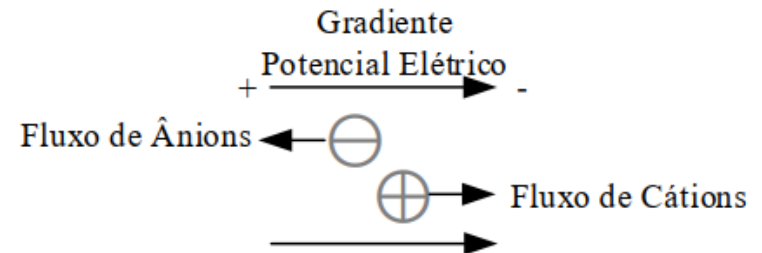
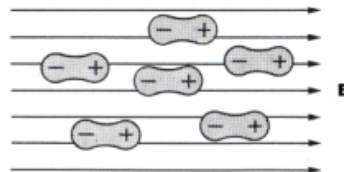
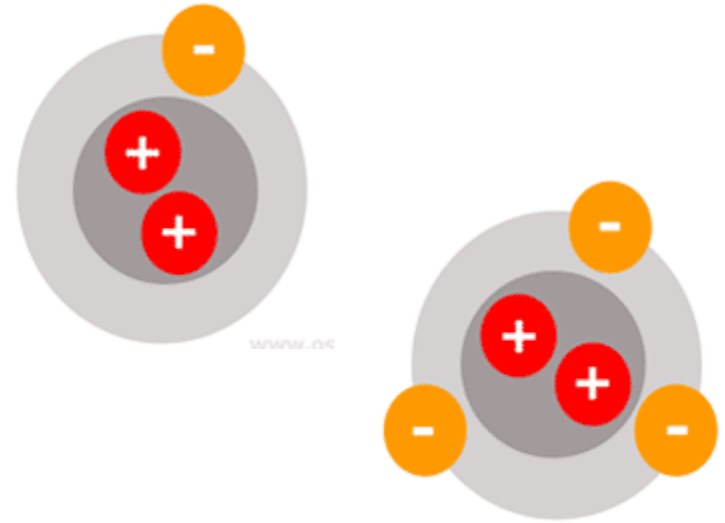
CF₄ is nonpolar



CHF₃ is polar

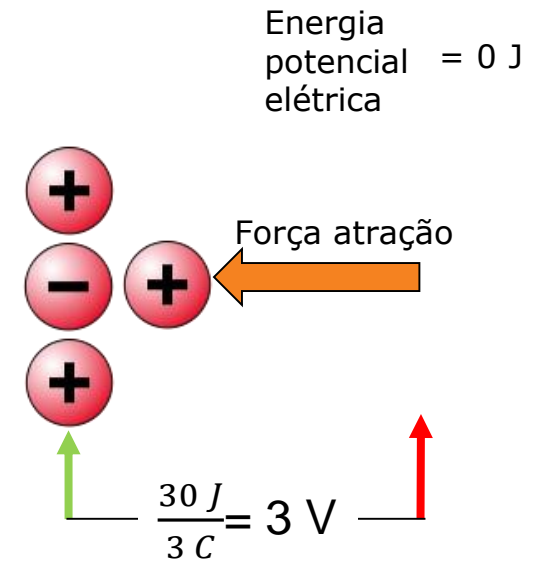
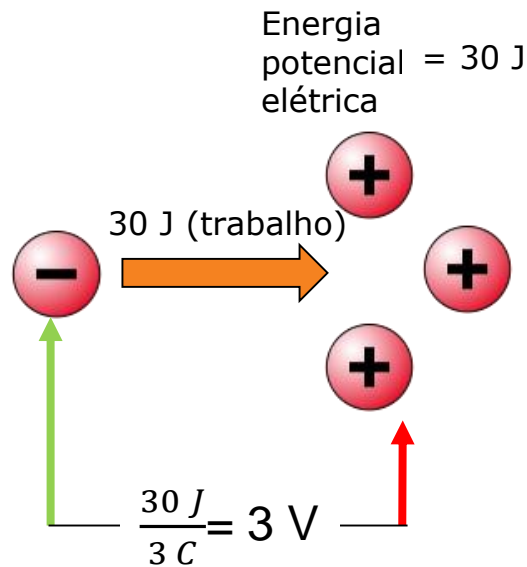
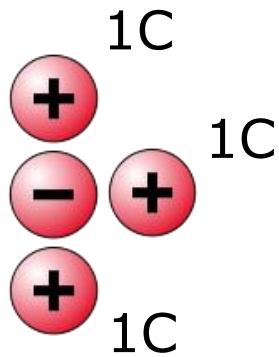


- Tipos de íons (Cátion e ânion) (Formam a corrente de condução)

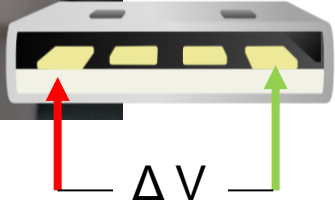
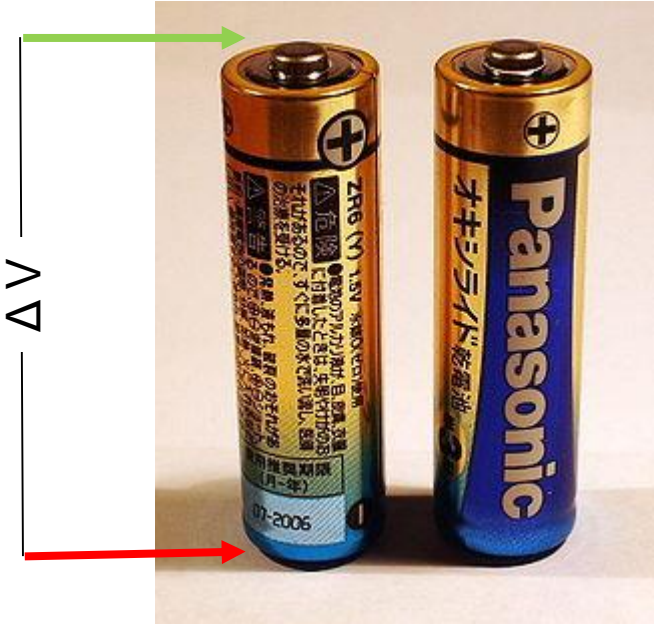
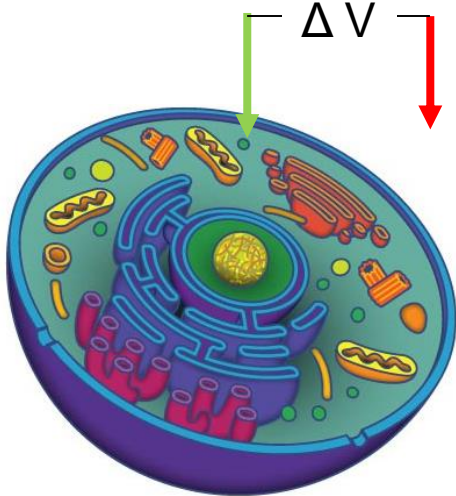
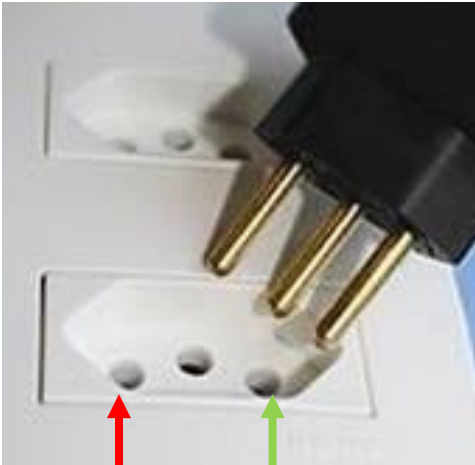


Potencial Elétrico (Tensão Elétrica)

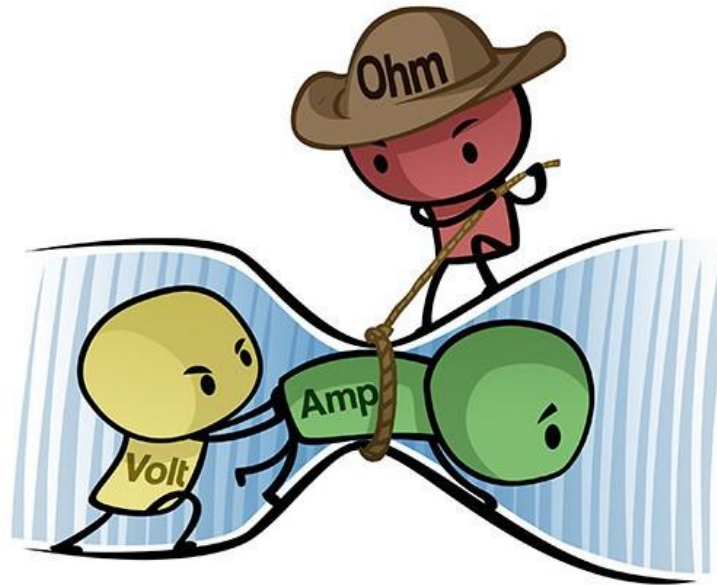
- Volts (V, SI);
- 1 V = 1 Joule/Coulomb (J/C).



Potencial Eléctrico (Tensão Eléctrica)



- Ampères (A, SI);
- $1 \text{ A} = 1 \text{ C/s}$;
- Tensão = Resistência \times Corrente ($V = R \times I$).



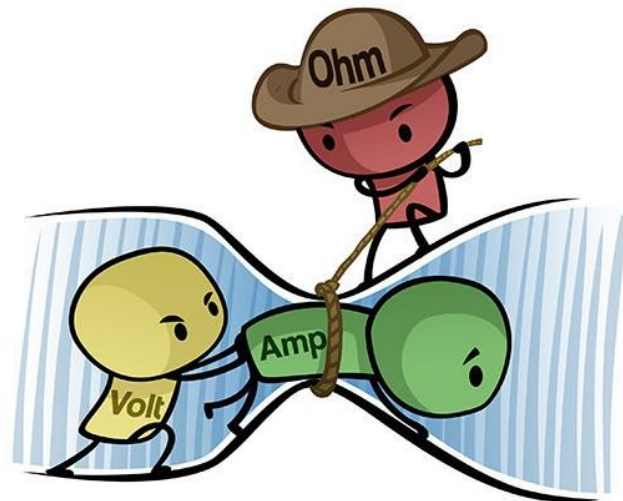
Resistência Elétrica



- Ohm (Ω , SI);
- $V = R \times I$;
- Qual permite maior corrente (maior aquecimento)?
Sendo que $\uparrow I \sim \uparrow P$



$$G = \frac{1}{R}$$

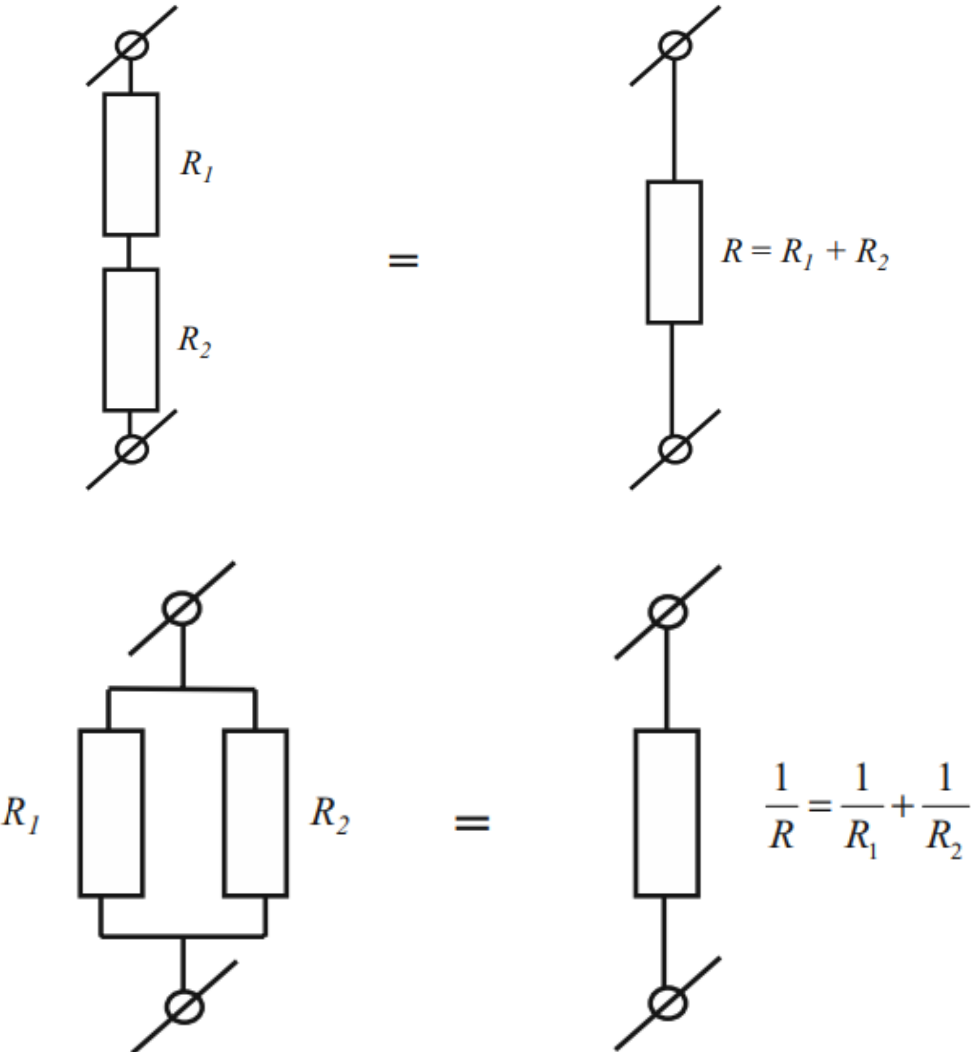


$\sim 5 \Omega$
44 A

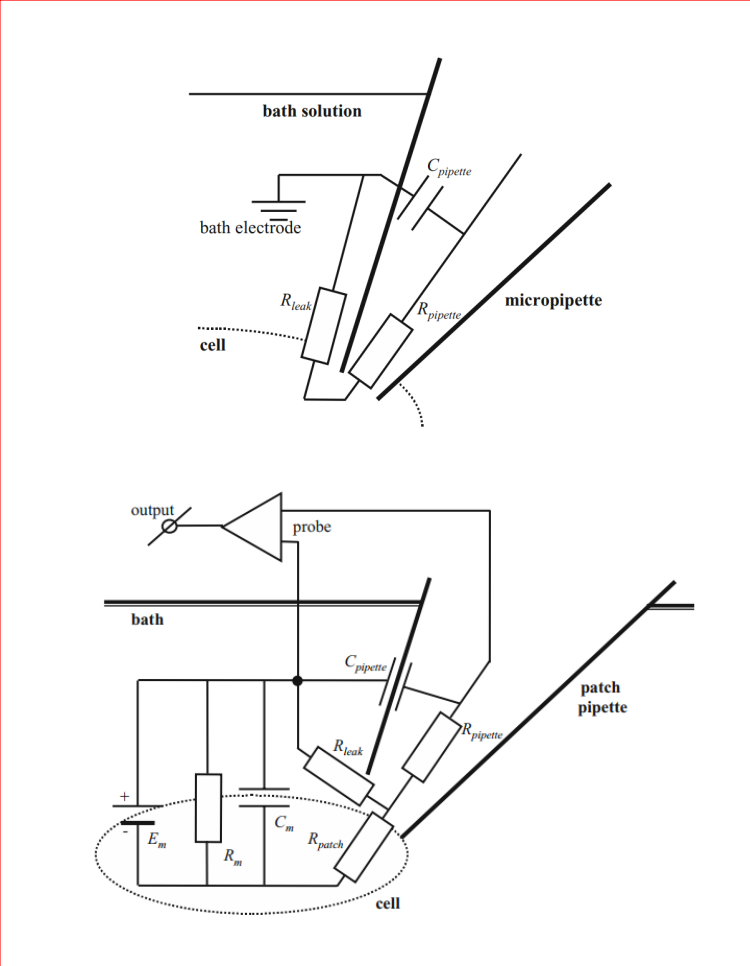


$\sim 9 \Omega$
24 A

Resistência Elétrica



• Por que isso é importante?



- H₂O pura não conduz (dielétrico);
- Porém, meios biológicos são eletrólitos.

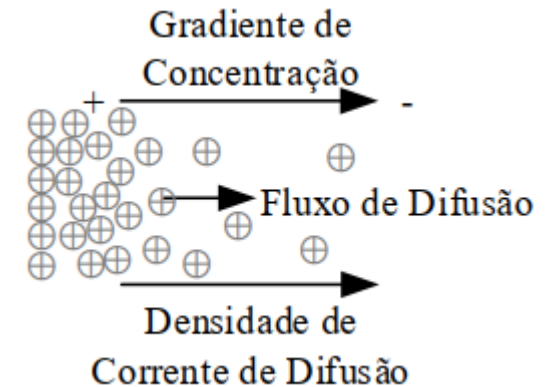
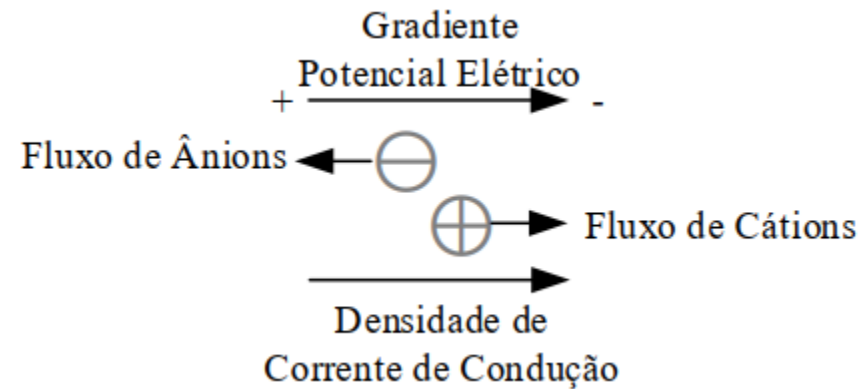
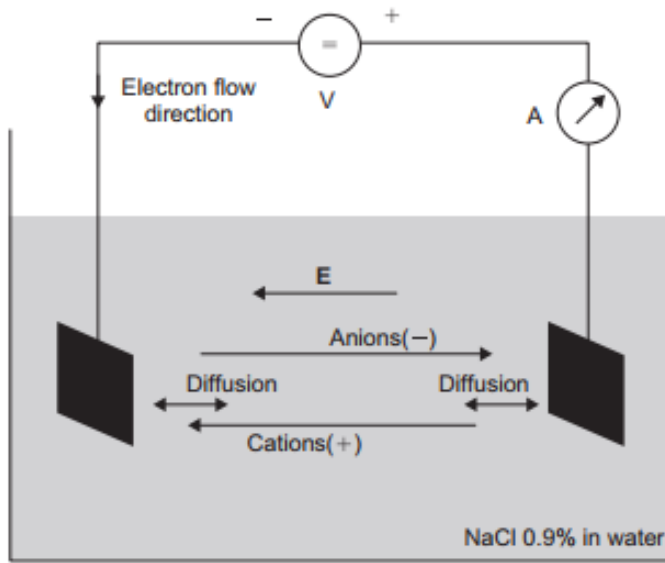


Figure 2.1: The basic bipolar electrolytic experiment, shown with material transport directions.

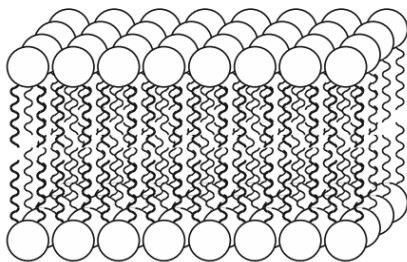
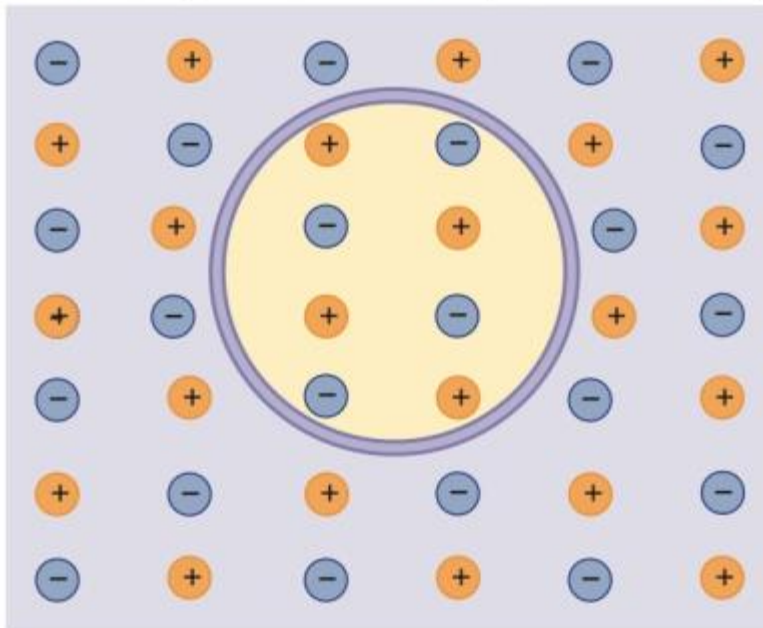
Table 2.6: Concentration of Electrolytes in Body Liquids [meq/L] is Ion Concentration

	Cations, meq/L		Anions, meq/L		
	Plasma	Intracellular	Plasma	Intracellular	
Na ⁺	142	10	Cl ⁻	103	4
K ⁺	4	140	HCO ₃ ⁻	24	10
Ca ²⁺	5	10 ⁻⁴	Protein ⁻	16	36
Mg ²⁺	2	30	HPO ₄ ⁻ + SO ₄ ⁻ +	10	130
H ⁺ (pH = 7.4)	4 × 10 ⁻⁵	4 × 10 ⁻⁵	organic acids		
Sum	153	180	Sum	153	180

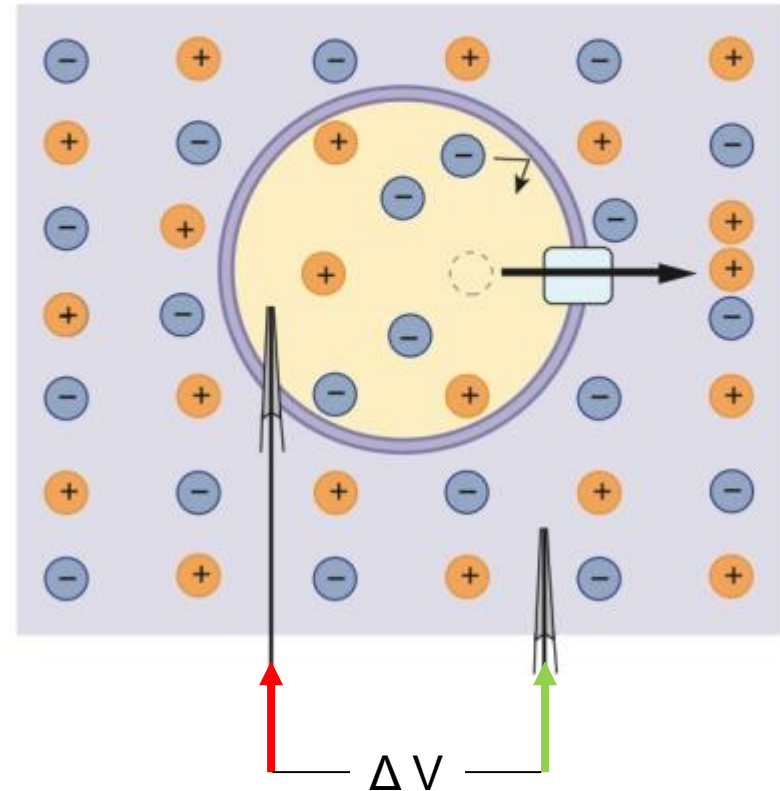
Milliequivalents [mmol × valency z] per liter, and 0.9% NaCl is 154 mmol.

Membrana Isolante (Dielétrico)

(a) A célula e a solução estão elétrica e quimicamente em equilíbrio

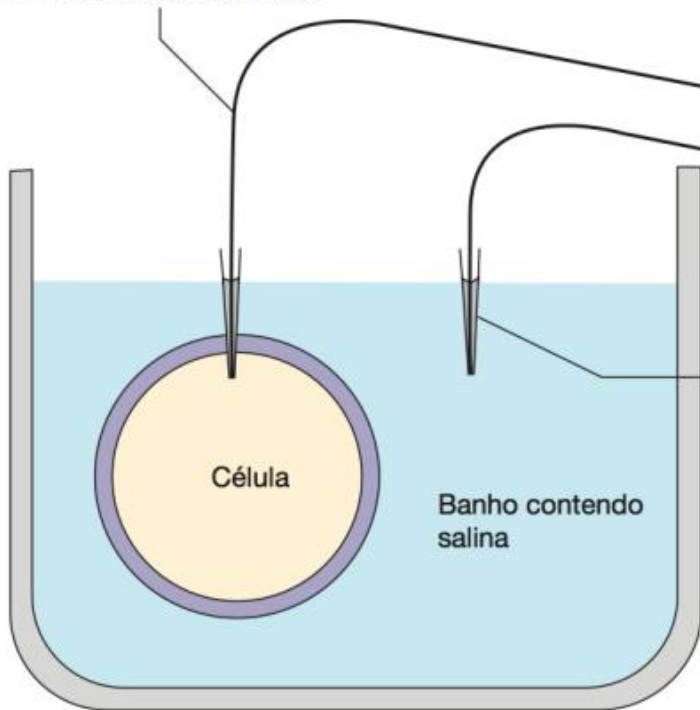


(b) A célula e a solução estão em desequilíbrio químico e elétrico. É usada energia para bombear um cátion para fora da célula, deixando uma carga resultante de -1 na célula e $+1$ fora dela.

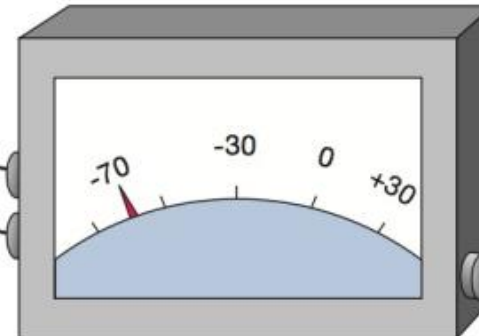


Membrana Isolante (Dielétrico)

Um eletrodo de registro é colocado dentro da célula.

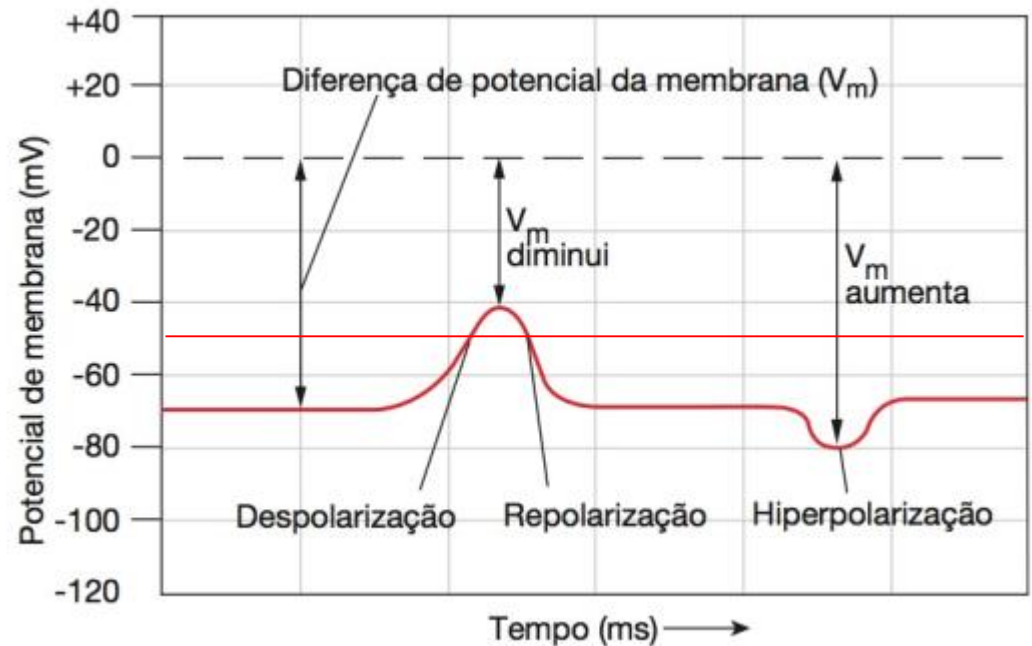


Entrada

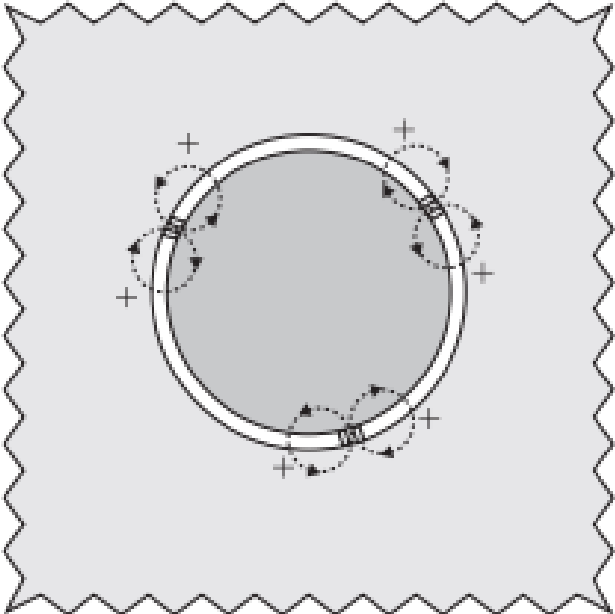
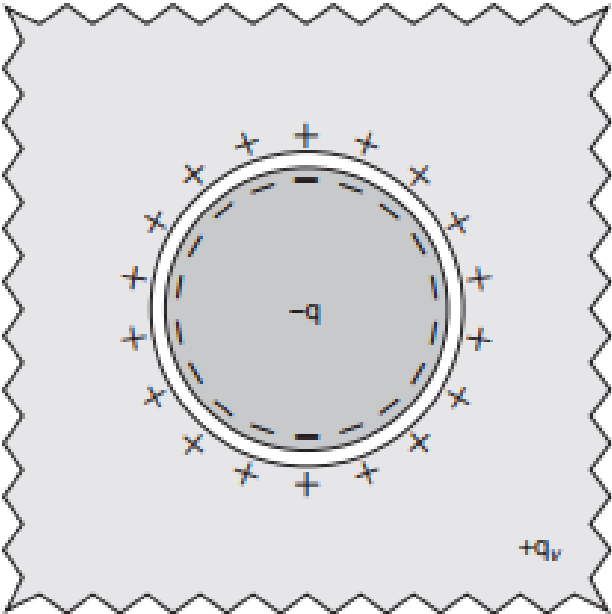


O voltímetro mede a diferença de cargas elétricas entre o interior de uma célula e a solução que a circunda. Este valor é a diferença de **potencial da membrana**, ou V_m .

Saída



Características Elétricas da Membrana



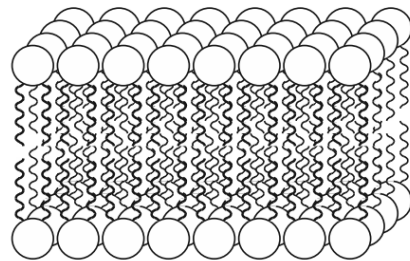
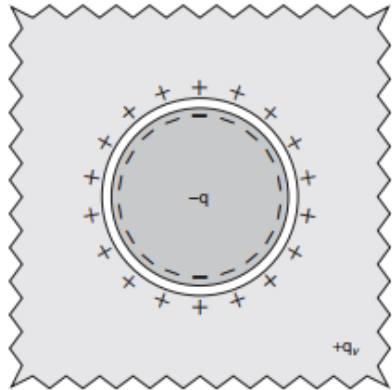
Passive channels



Chemically-gated channels

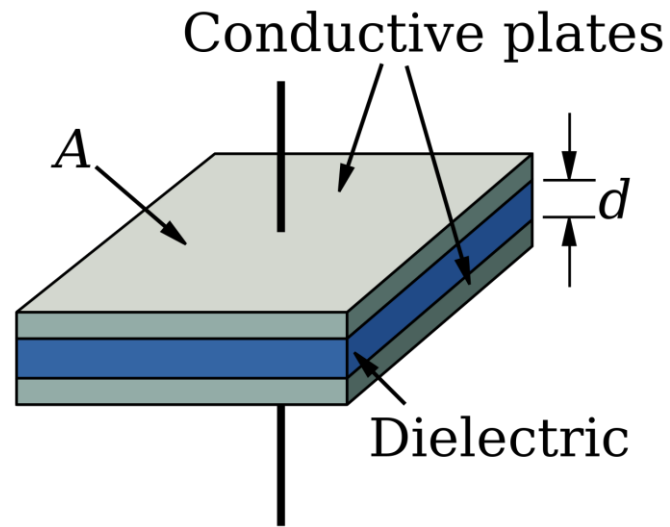
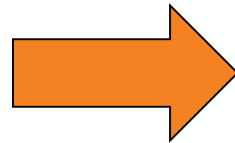


Voltage-gated channels

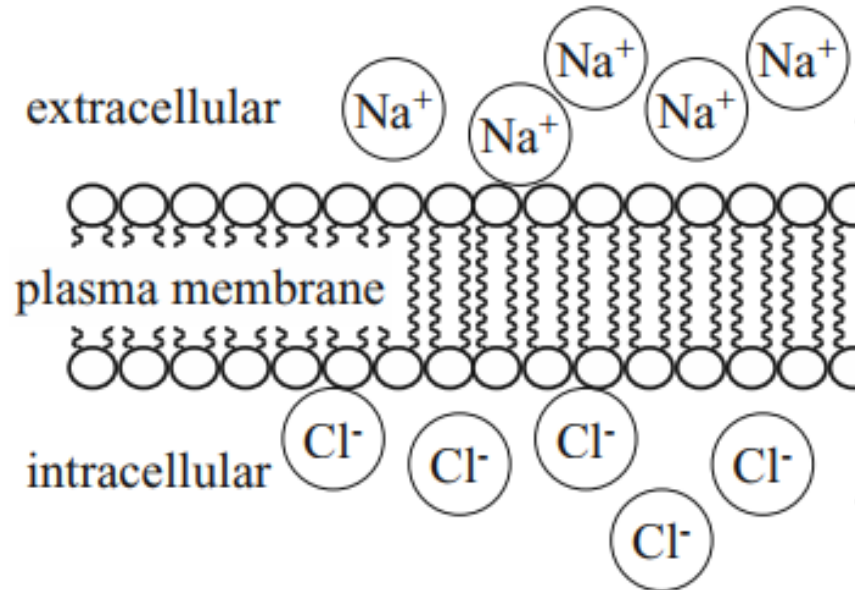
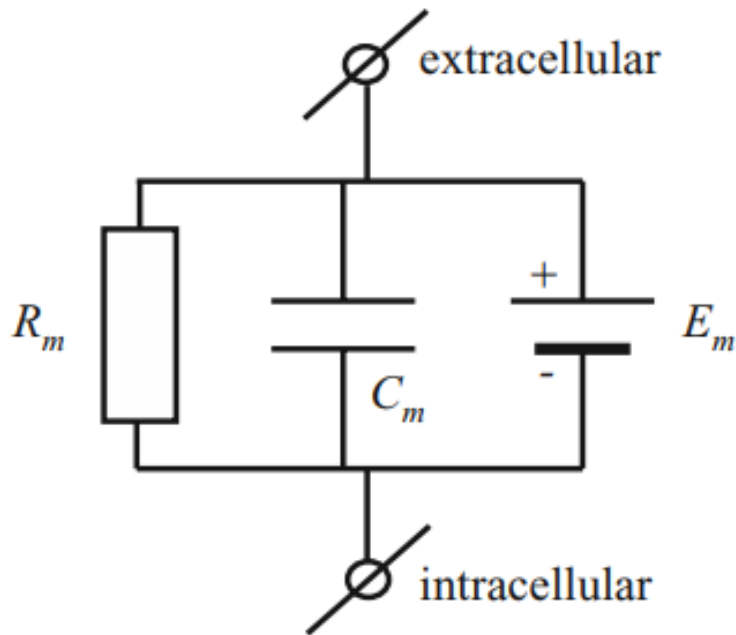


$$C = \frac{A\epsilon_r}{d}$$

- Farad (F, SI)



Características Elétricas da Membrana



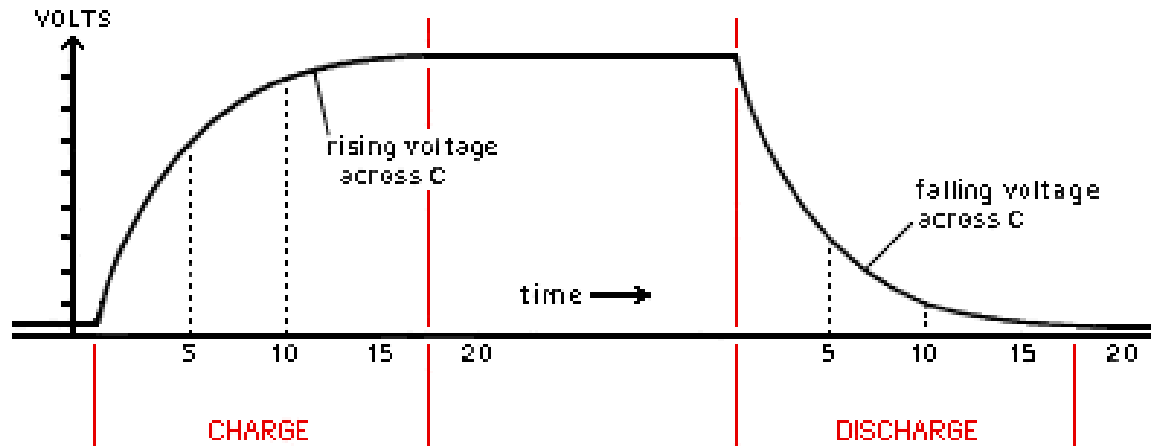
Equação de Goldman-Hodgkin-Katz:

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

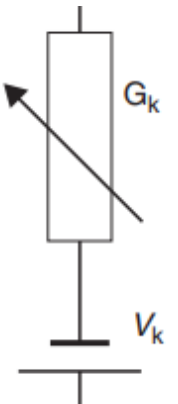
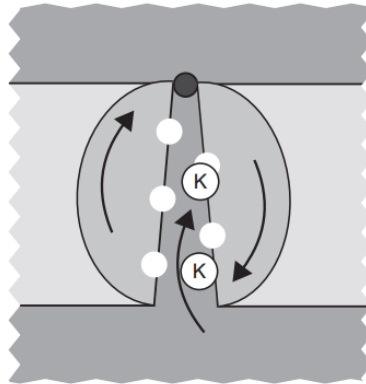
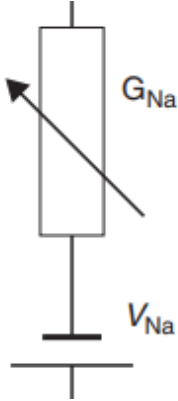
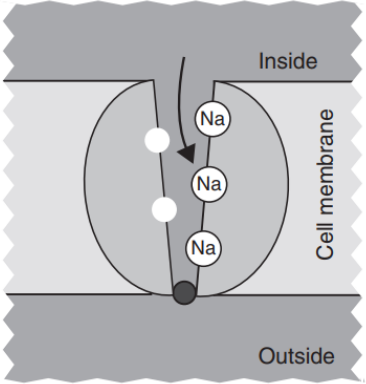
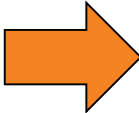
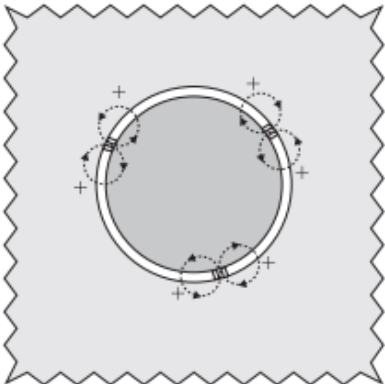
Características Elétricas da Membrana

Efeito da capacitância

- Acrescenta *delays!*



Características Elétricas da Membrana



Modelo Hodgkin-Huxley

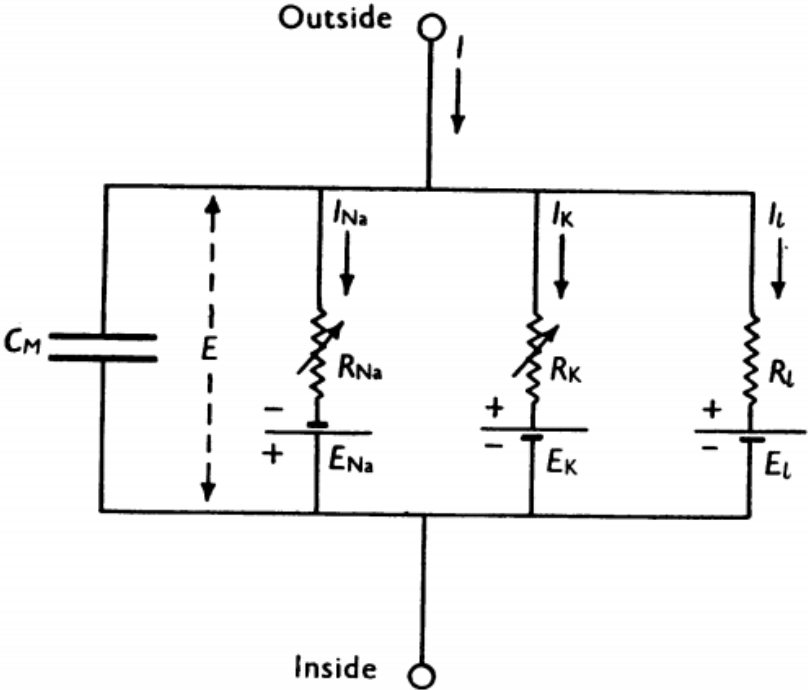
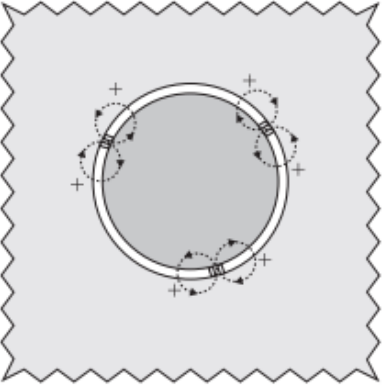
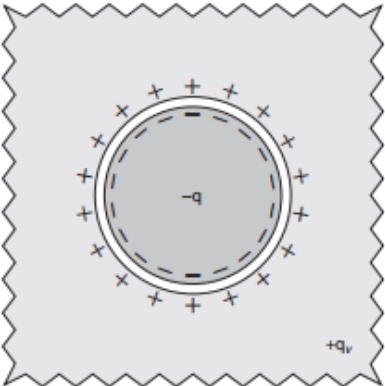
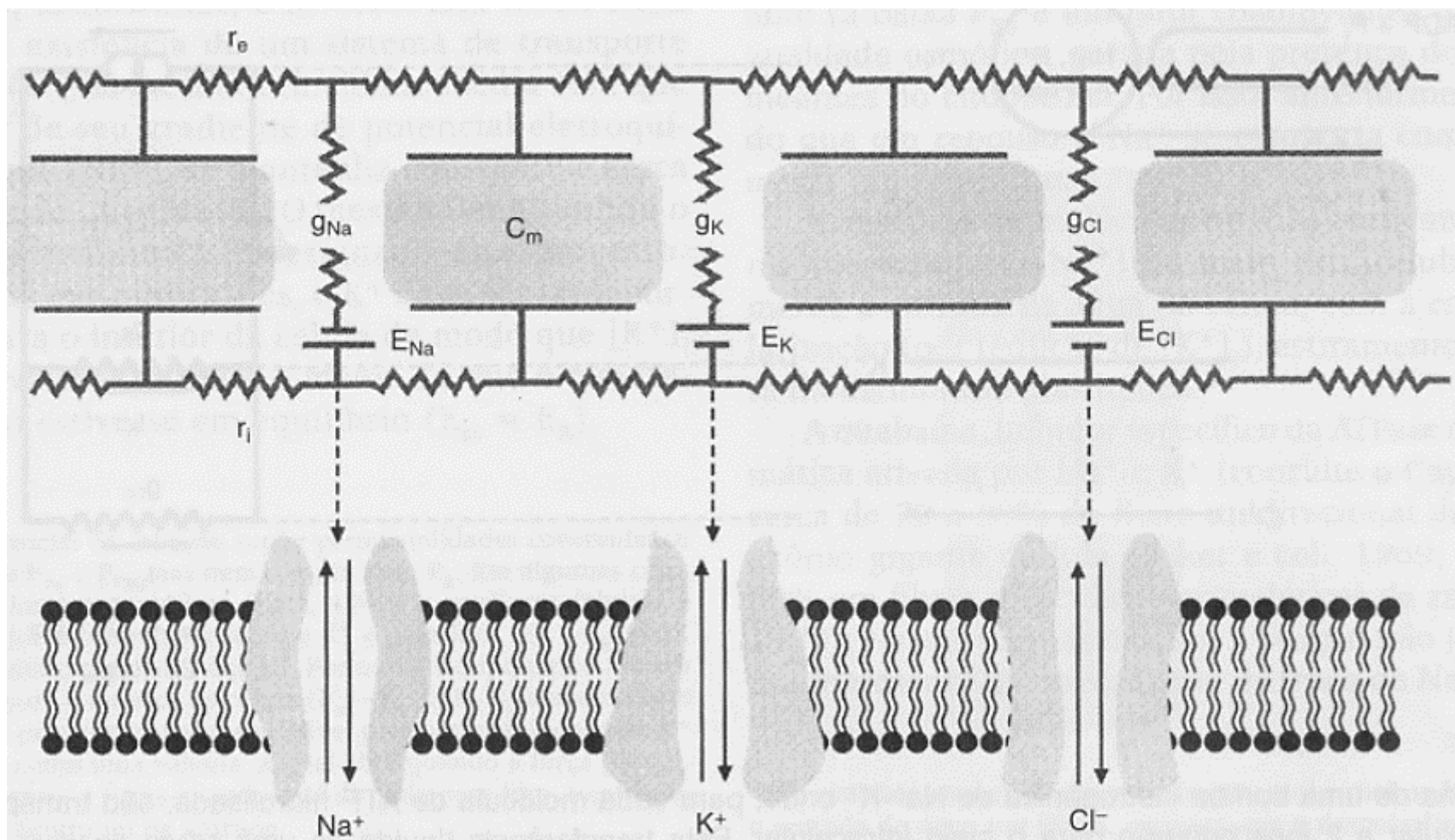
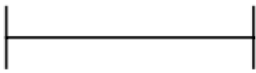
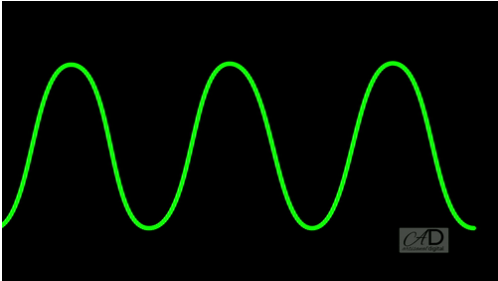


Fig. 1. Electrical circuit representing membrane. $R_{Na} = 1/g_{Na}$; $R_K = 1/g_K$; $R_i = 1/\bar{g}_i$. R_{Na} and R_K vary with time and membrane potential; the other components are constant.

Características Elétricas da Membrana



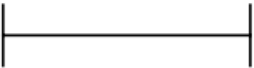
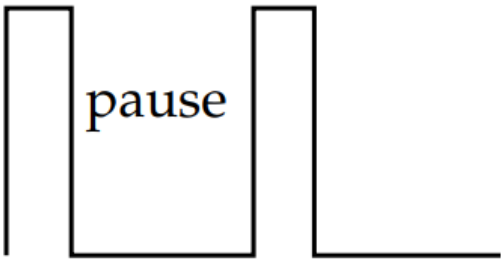
Corrente Direta e Alternada; Frequência



period T

$$\text{frequency} = 1/T$$

duration



interval T

$$\text{rate} = 1/T$$

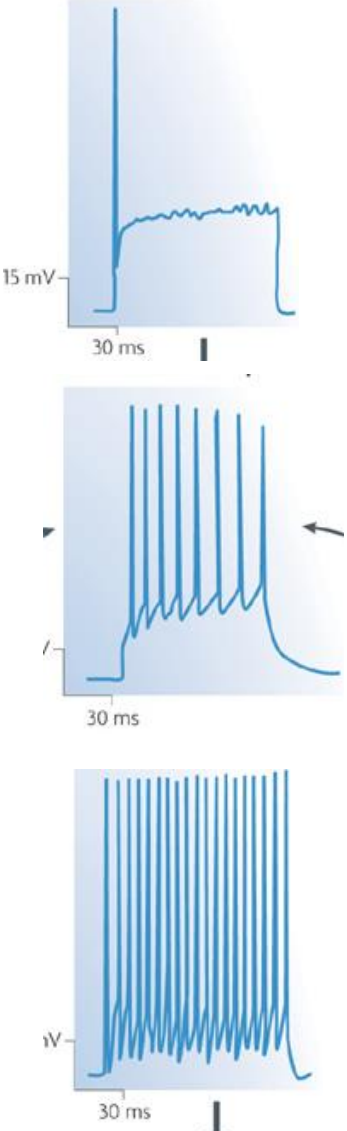
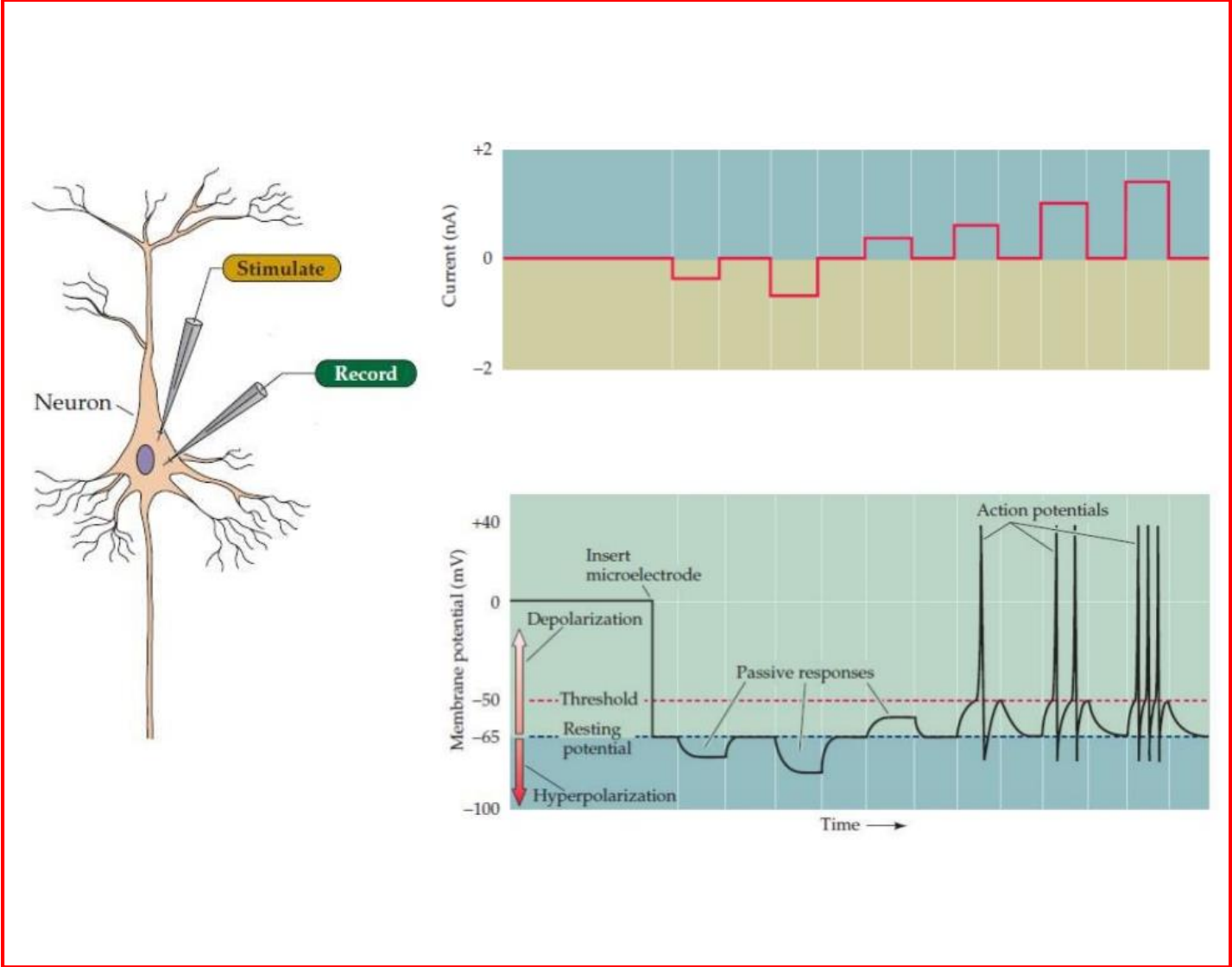
Direta



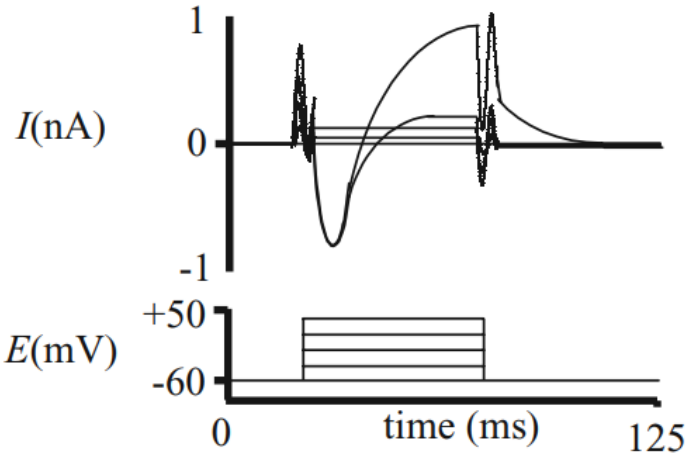
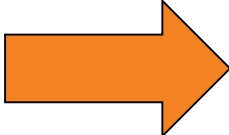
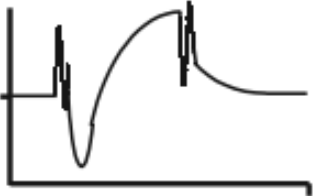
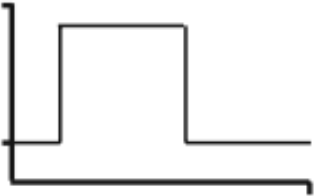
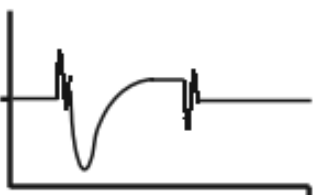
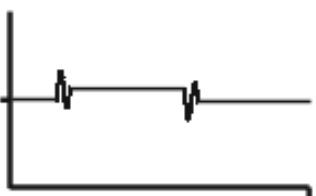
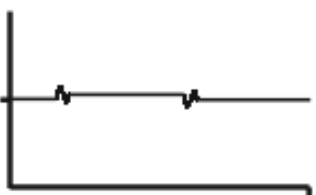
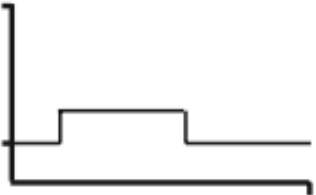
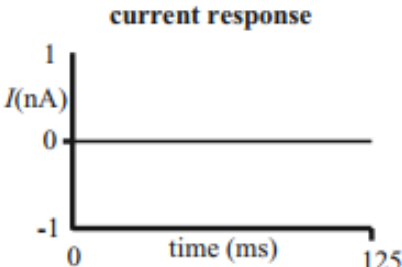
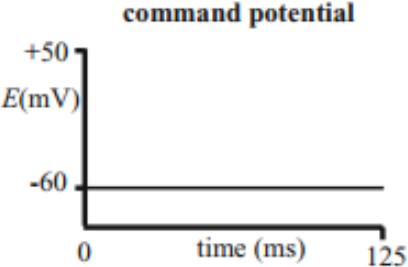
Alternada



Comando e Resposta



Comando e Resposta

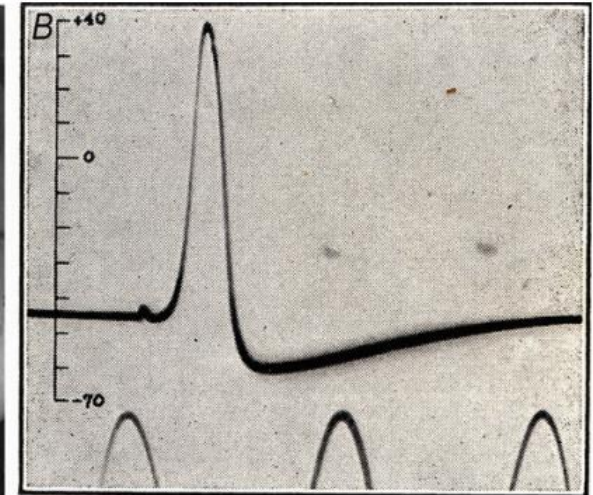
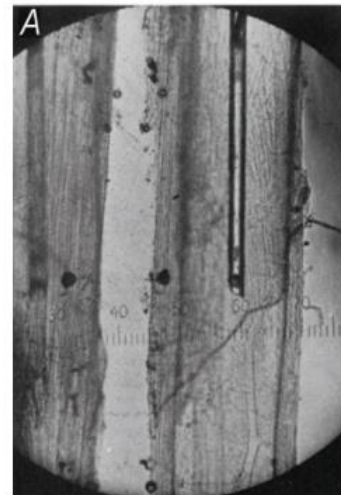
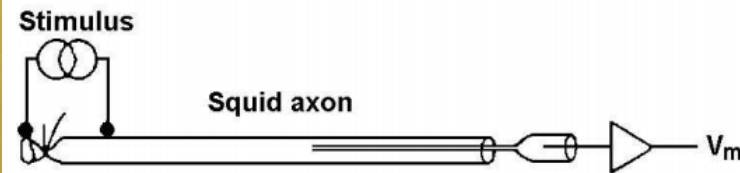
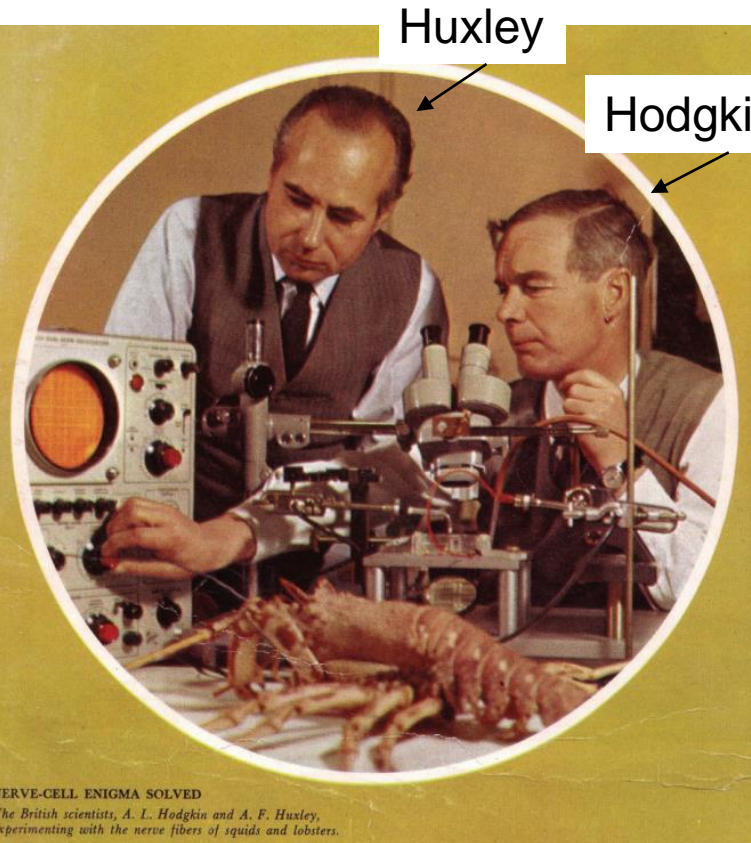
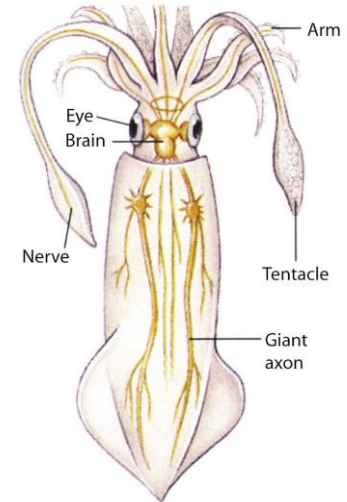


Registros Eletrofisiológicos



Registros Eletrofisiológicos

- Hodgkin and Huxley, 1939 (Nobel 1963)



ACTION POTENTIAL RECORDED BETWEEN INSIDE AND OUTSIDE OF AXON. TIME MARKER, 500 CYCLES/SEC. THE VERTICAL SCALE INDICATES THE POTENTIAL OF THE INTERNAL ELECTRODE IN MILLIVOLTS, THE SEA WATER OUTSIDE BEING TAKEN AT ZERO POTENTIAL.

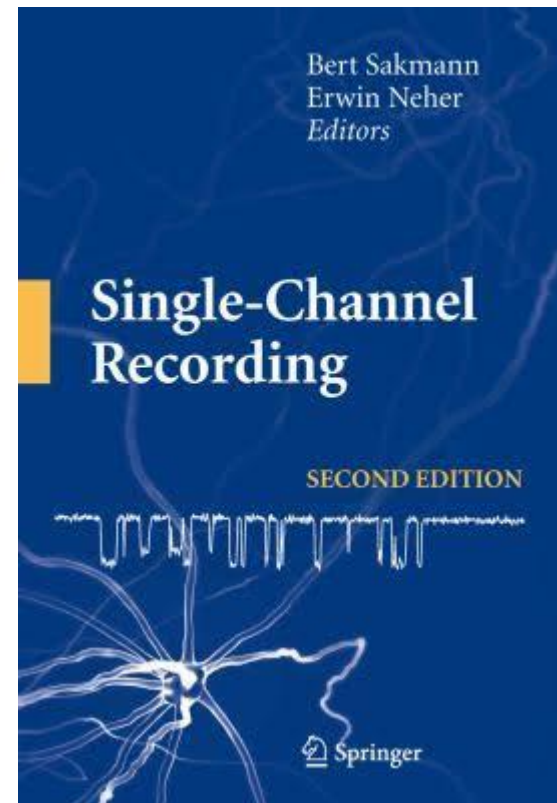
The Nobel Prize in Physiology or Medicine 1991



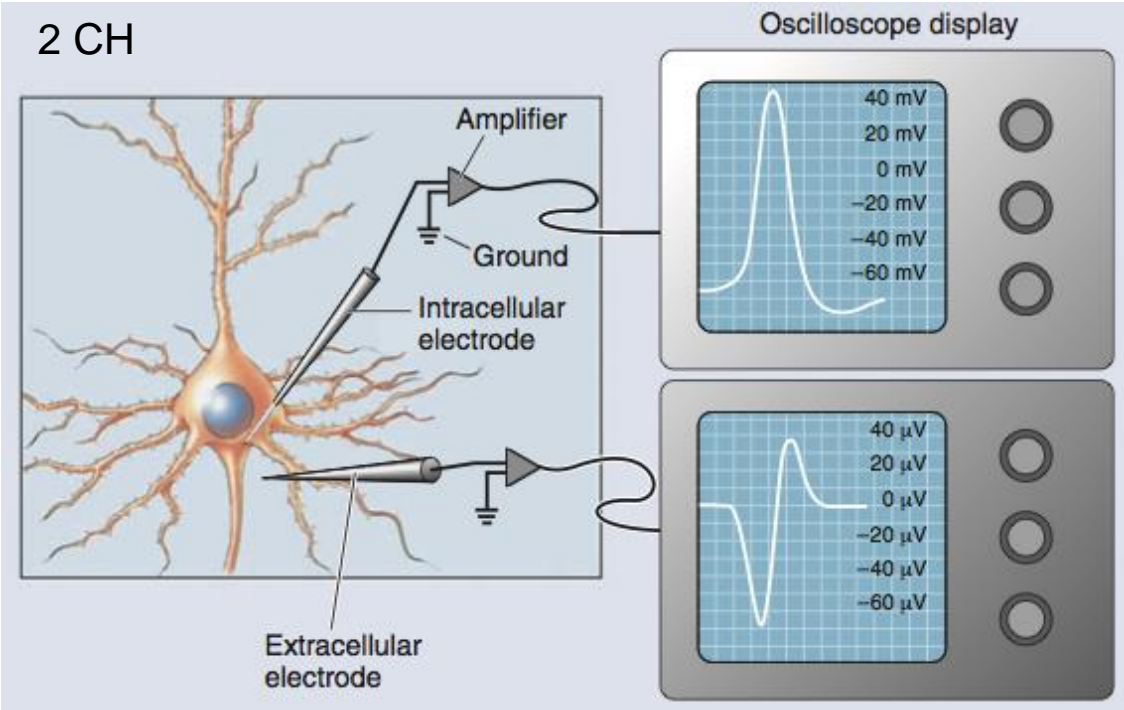
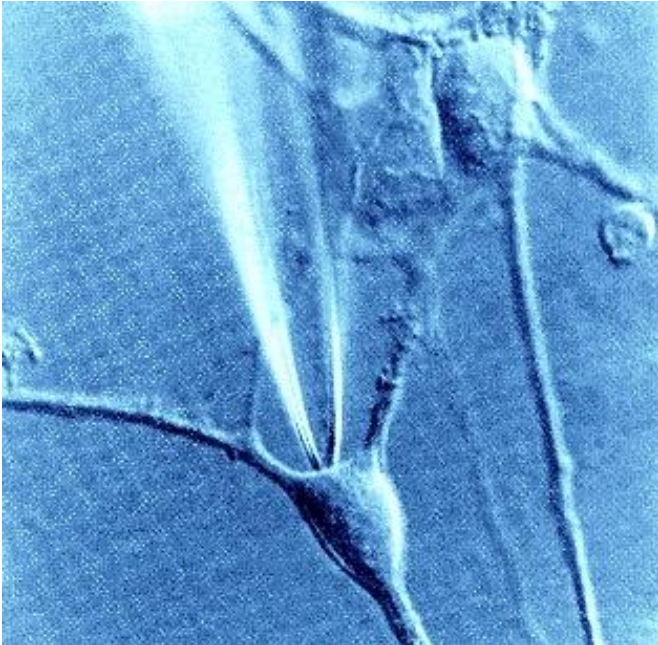
Erwin Neher
Prize share: 1/2



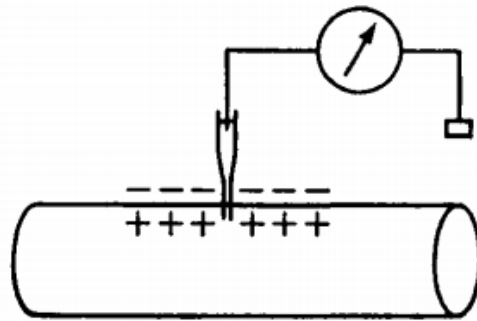
Bert Sakmann
Prize share: 1/2



Registros Eletrofisiológicos



Tipos de Registros



1 Intracellular recording

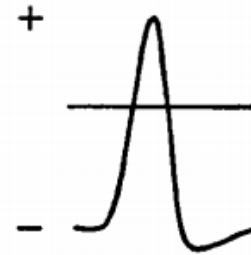
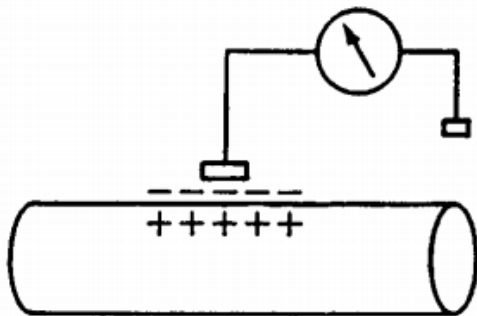
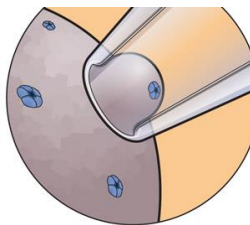


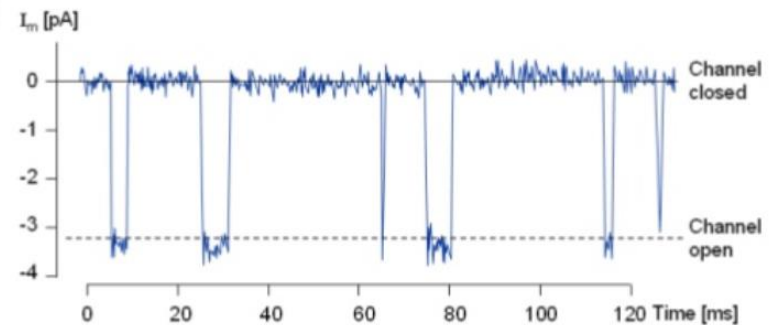
Figure 4.6. Diagram to show the difference in sign of action potentials recorded by intracellular and by extracellular electrodes. Extracellular records are in fact frequently shown with negative potentials upwards.



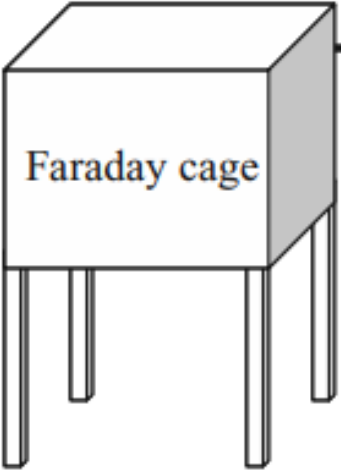
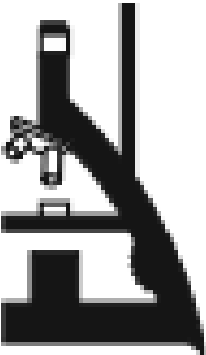
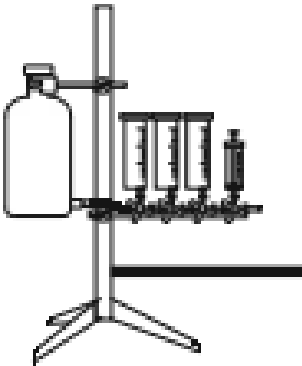
2 Extracellular recording



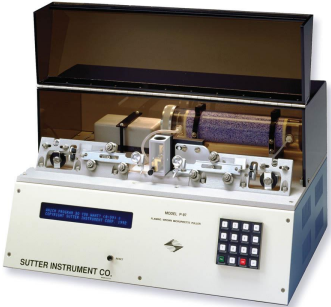
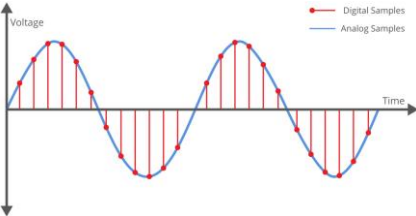
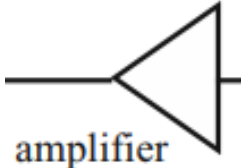
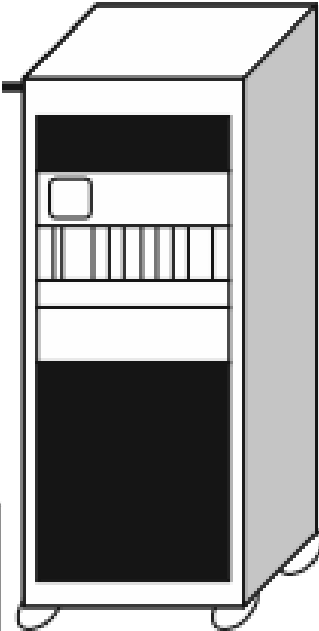
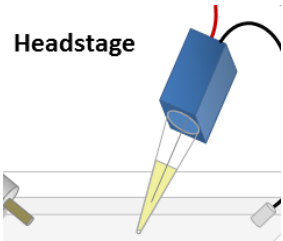
3 Patch Clamp



Equipamentos para Patch-Clamp



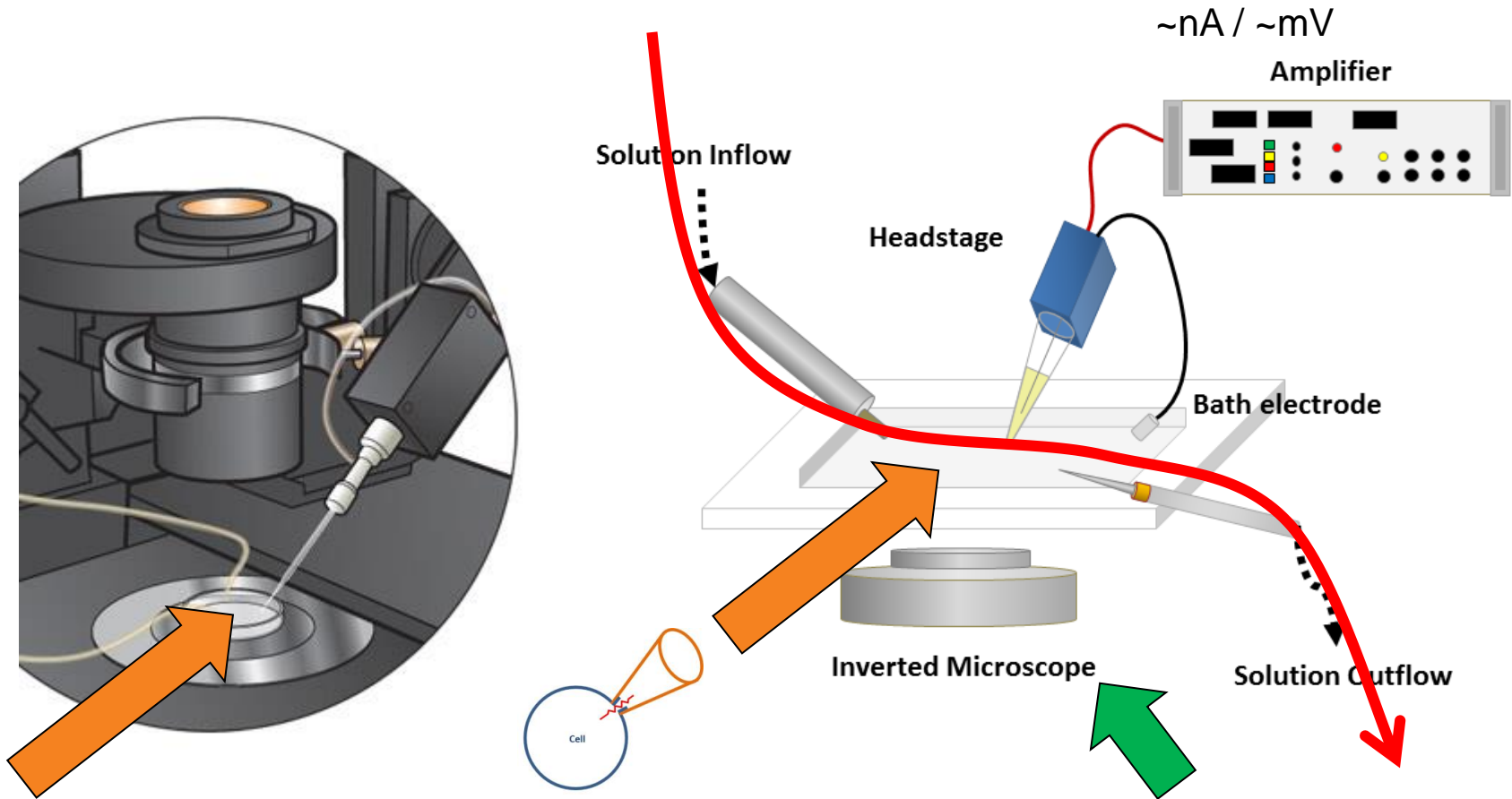
Headstage



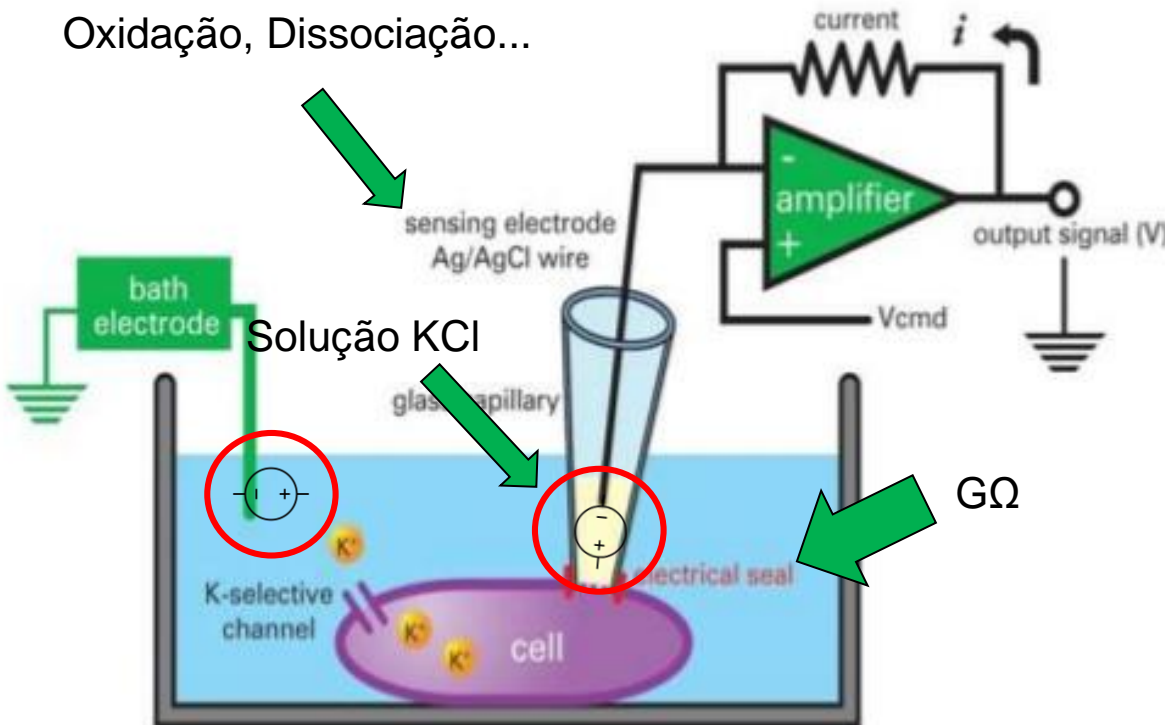
Instrumentação

T	G	M	k	(none)	m	μ	n	p
tera	giga	mega	kilo	(none)	milli	micro	nano	pico
10^{12}	10^9	10^6	10^3	10^0	10^{-3}	10^{-6}	10^{-9}	10^{-12}
			10 ²	10 ¹	10 ⁻¹	10 ⁻²		
			hecto	deca	deci	centi		
			h	da	d	c		

~nA / ~mV



Oxidação, Dissociação...



An Outwardly Rectifying Chloride Channel in Human Atrial Cardiomyocytes

MARIE DEMION, Ph.D., ROMAIN GUINAMARD, Ph.D., ANTOUN EL CHEMALY, Ph.D., MOHAMMAD RAHMATI, M.D., and PATRICK BOIS, M.D.

From the Institut de Physiologie et Biologie Cellulaires, CNRS UMR 6187, Université de Poitiers, Poitiers Cedex, France

Measurements

Single-channel currents from patches of isolated cardiomyocytes were recorded under voltage clamp with an RK400 (Biologic, Claix, France) patch-clamp amplifier using the cell-attached and inside-out variations of the patch-clamp technique.⁸ The bath reference was 0.5 M KCl (in a 4% agar bridge) connected to an Ag/AgCl pellet. Liquid junction potentials arising at the inner surface of the membrane patch due to changes in bath solutions were determined using a pipette containing 2.7 M KCl, which allowed the zero-current voltage deflection to be monitored. The measured values were similar to those calculated by the JPCalc program⁹ with Clampex software (version 8.1; Axon instruments, Foster City, CA, USA). Applied potentials ($V_m = V_{bath} - V_{pipette}$) were corrected accordingly. In cell-attached patches, the applied potential (ΔV_m) was superimposed on the spontaneous cell membrane potential that was unknown.

Micropipeta

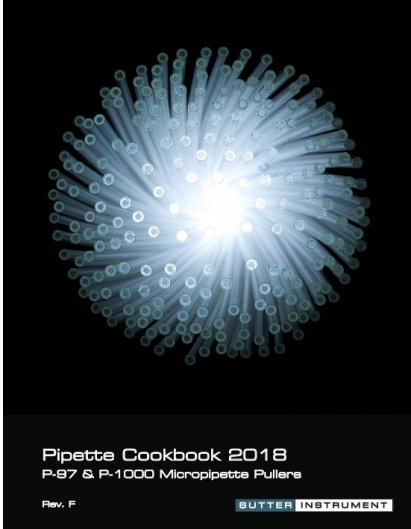
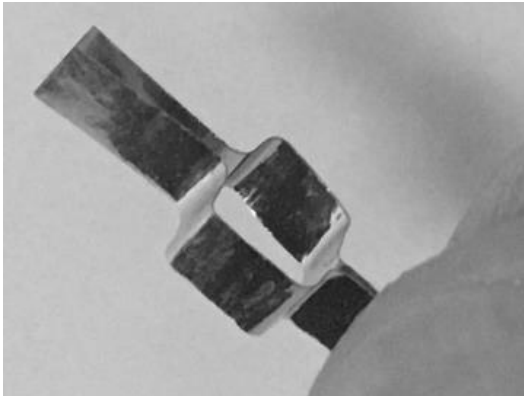
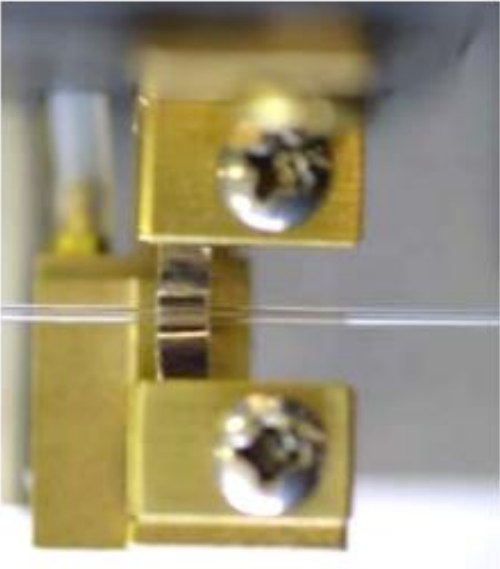
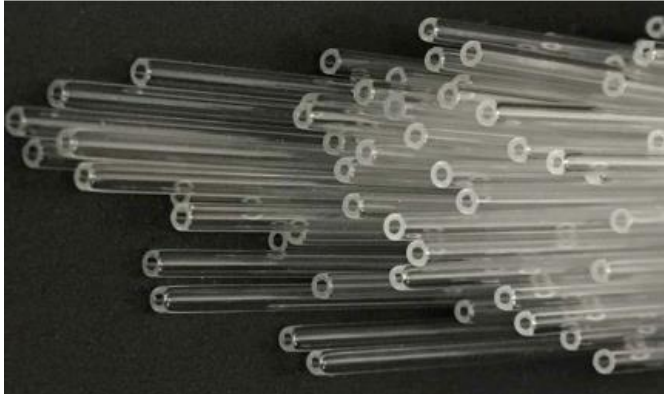
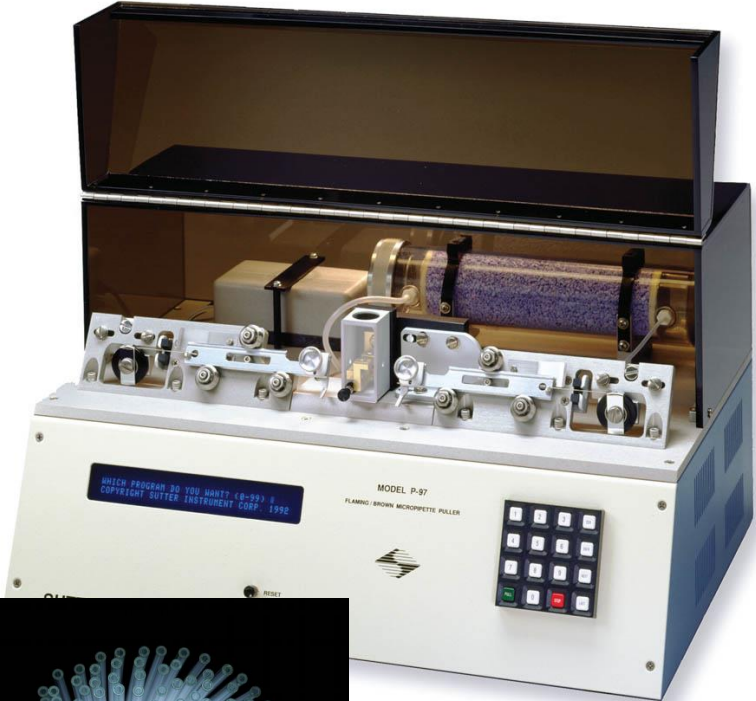


Image A (40x mag.) 1.0 x 0.5 thick walled glass (BF100-50-10)
~0.5 μ m Tip, 4-5mm taper, one line program with 3 loops



1.5mm x 0.86mm thick walled glass, ~2 μ m Tip, 3-4mm taper (400X mag)

Medium/Large Holding Pipette (400x mag.)

Scored and cut with clean break using a ceramic tile, then fire-polished. 15 μ m ID x 80 μ m OD



Medição Intracelular Circuito Equivalente

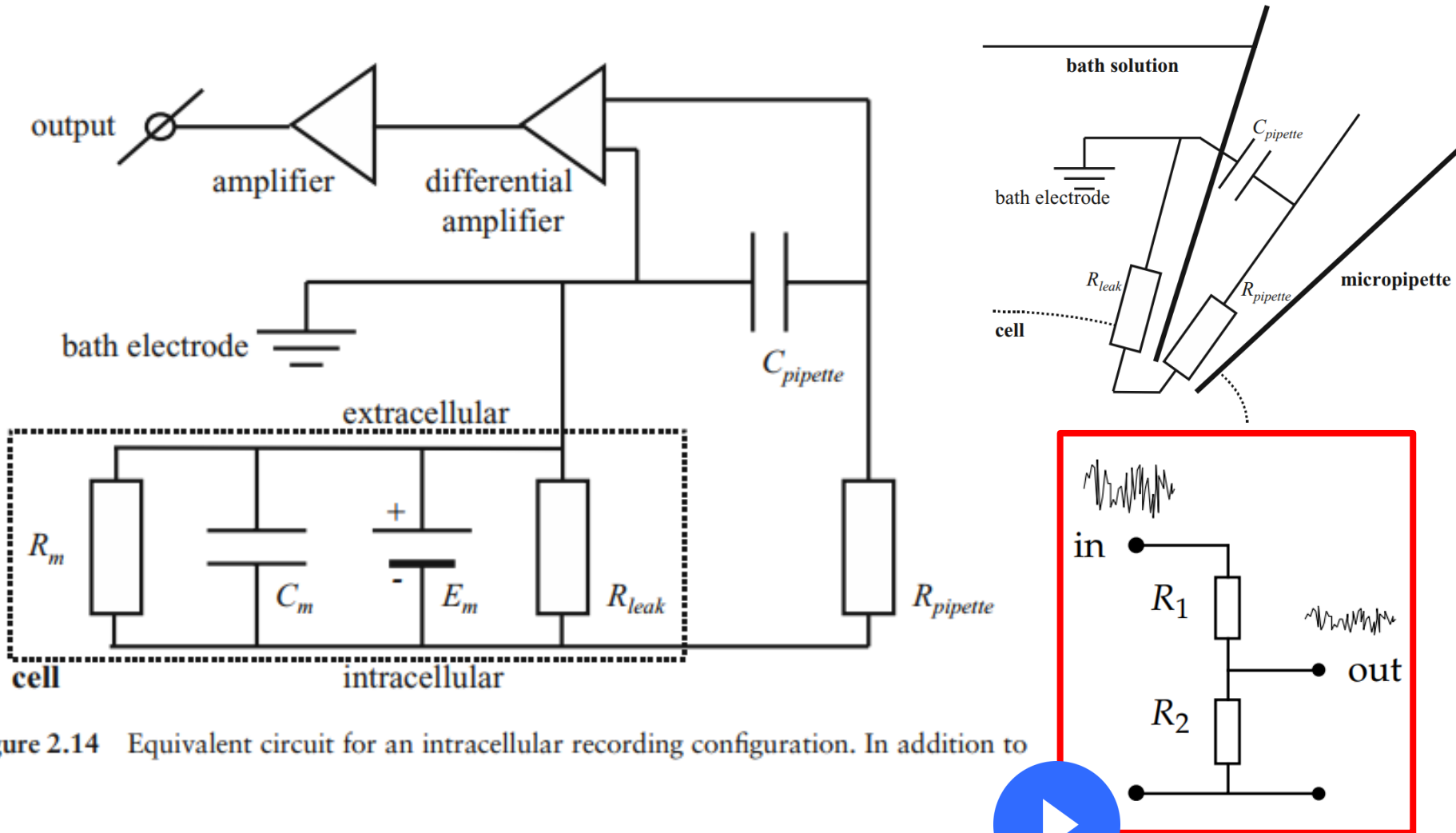
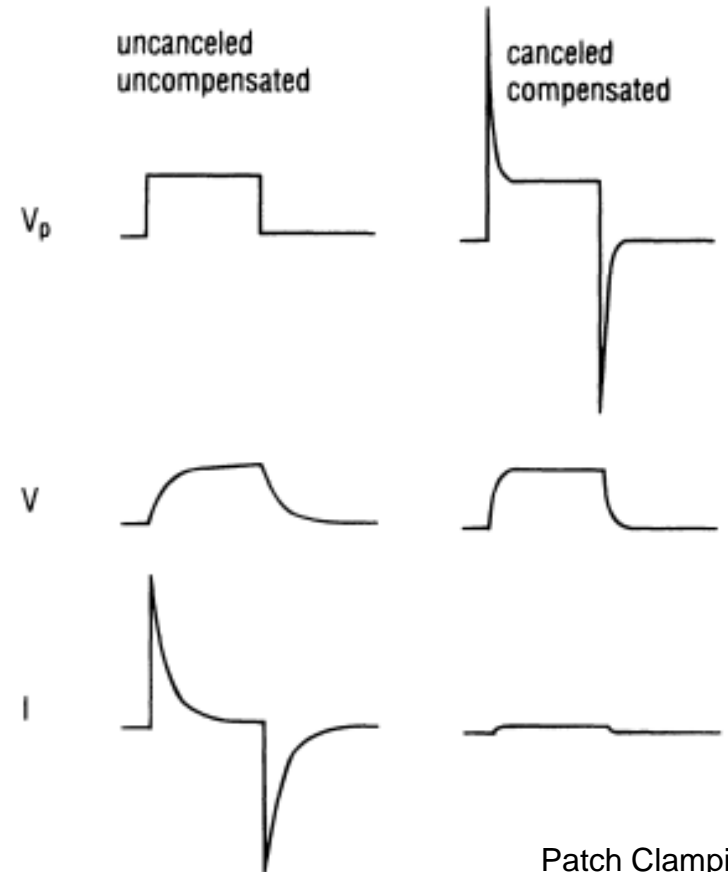
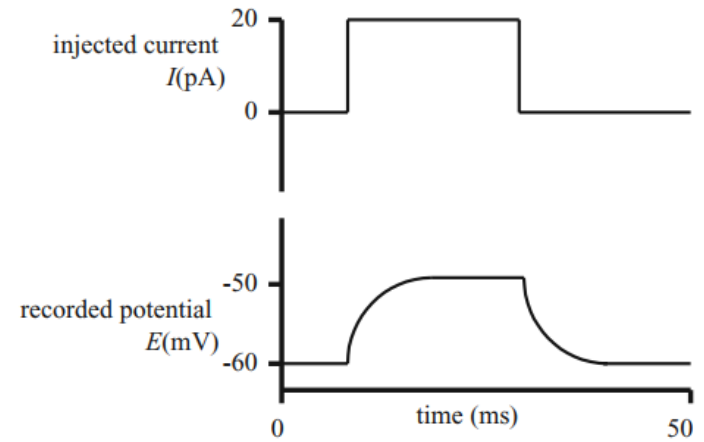
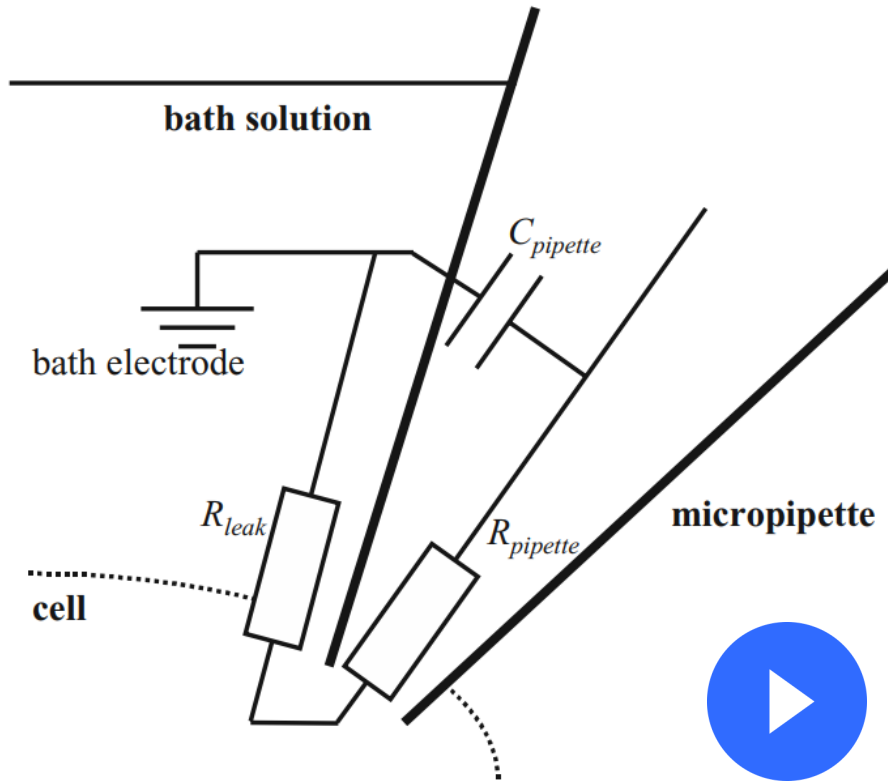


Figure 2.14 Equivalent circuit for an intracellular recording configuration. In addition to

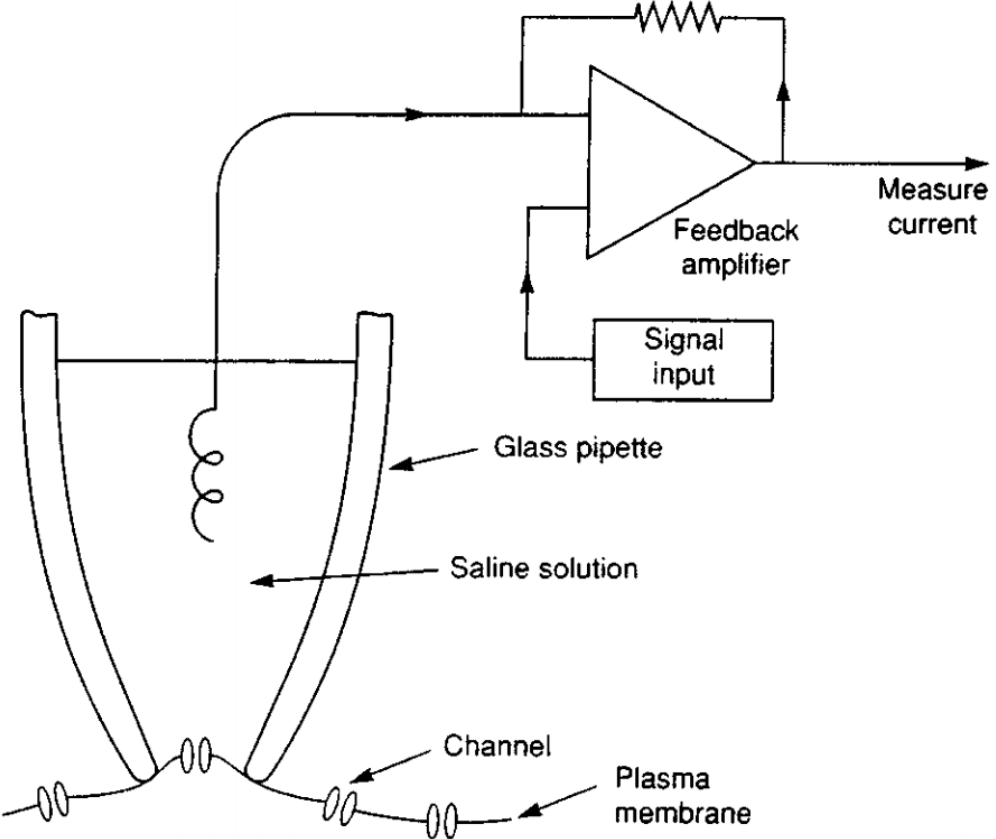
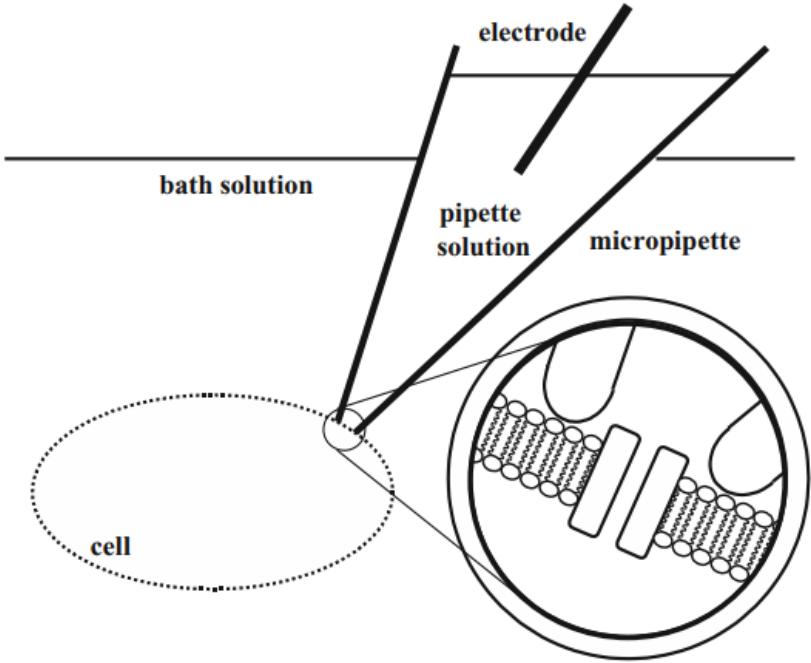


Medição Intracelular

Zoom - Desvios Pipeta



Patch Clamp



Patch Clamping

Patch Clamp Circuito Equivalente

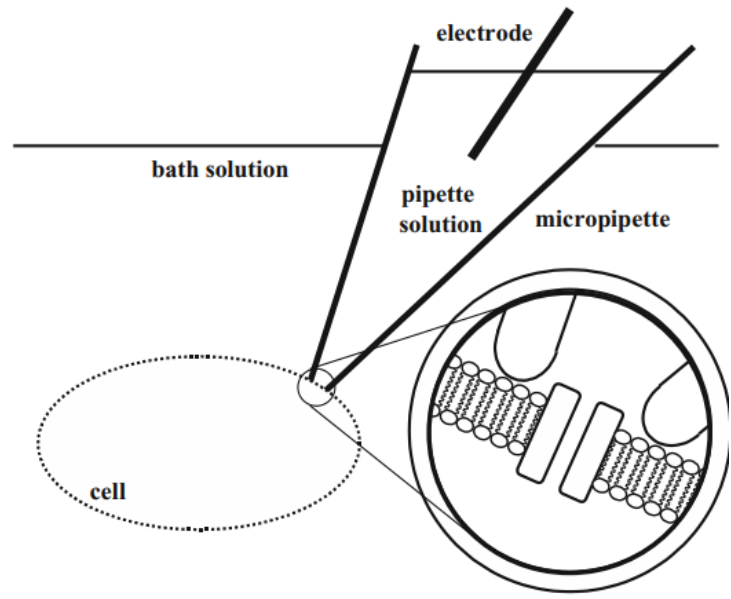
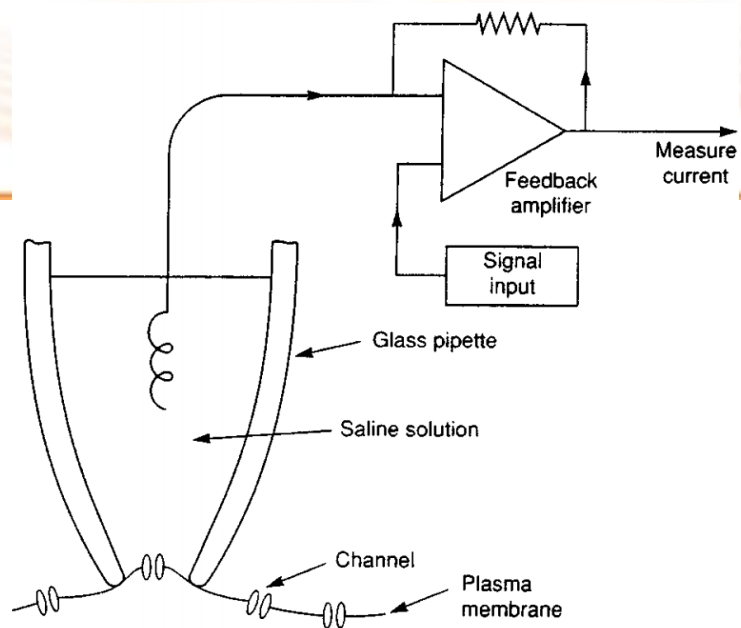
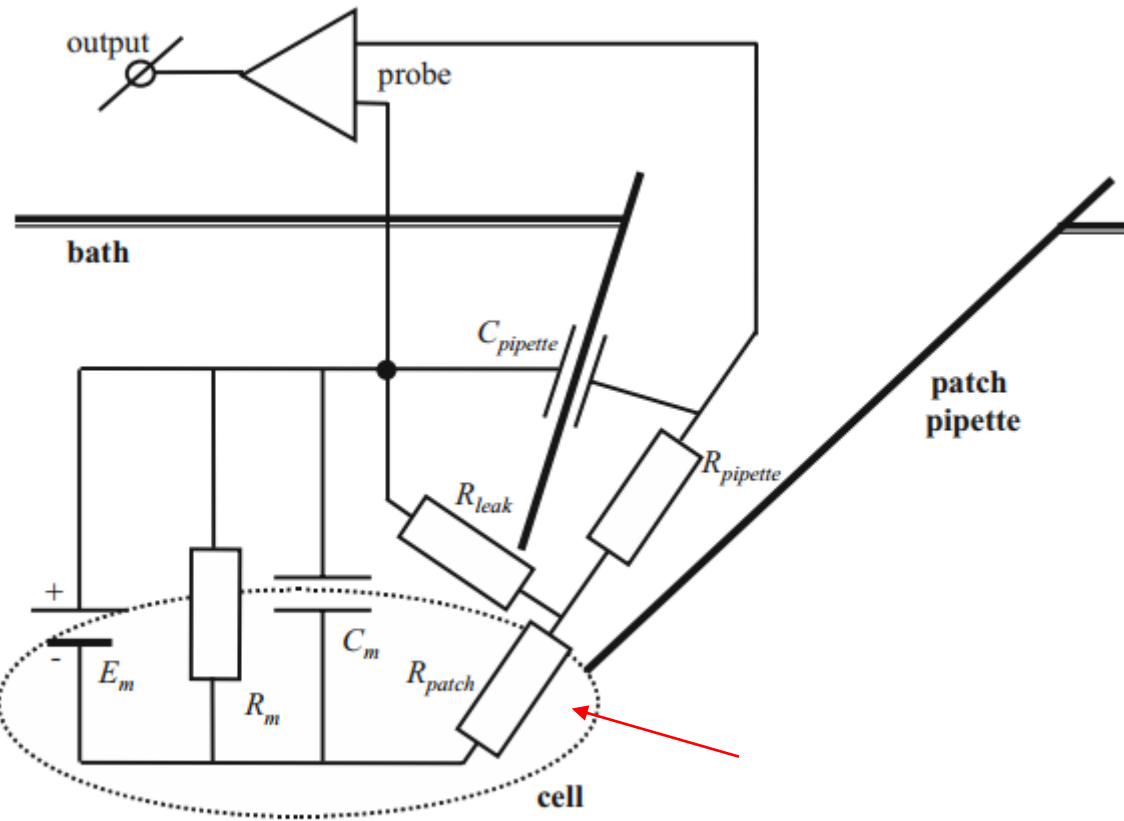
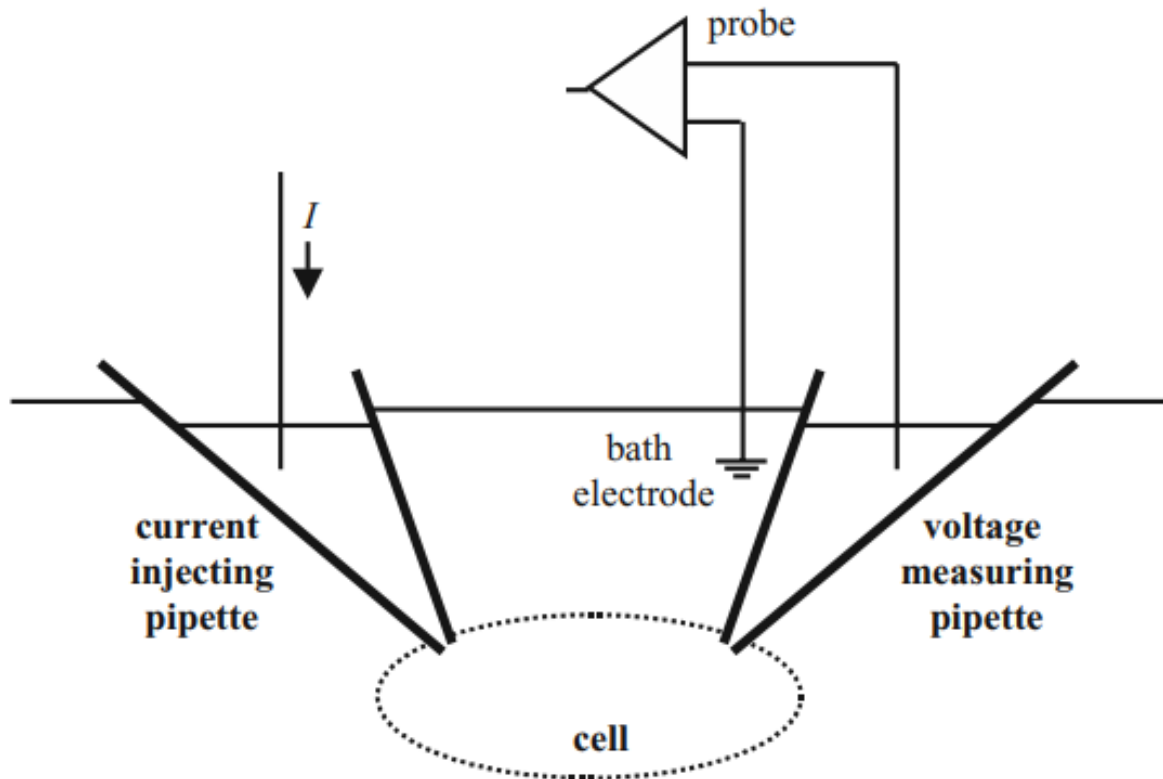
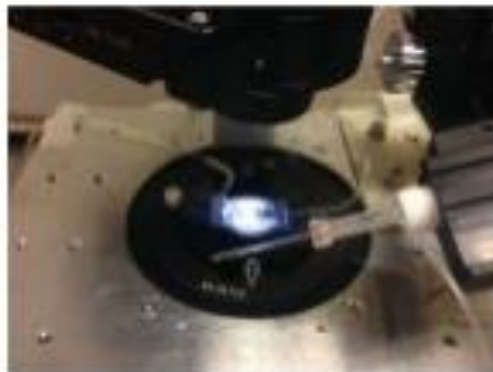


Figure 2.24 Equivalent circuit for the cell-attached patch configuration

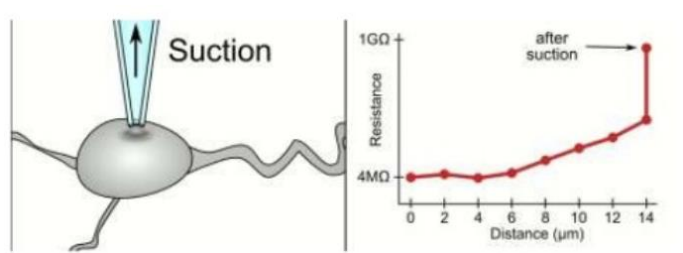
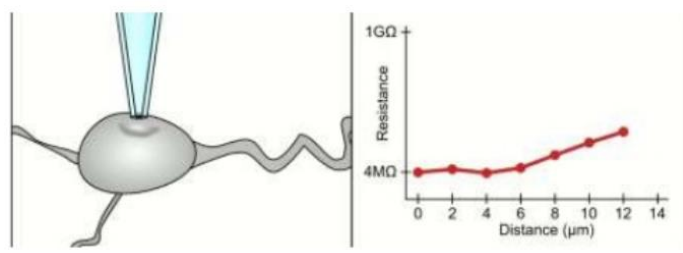
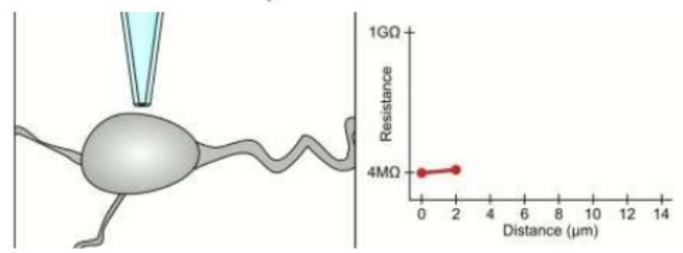
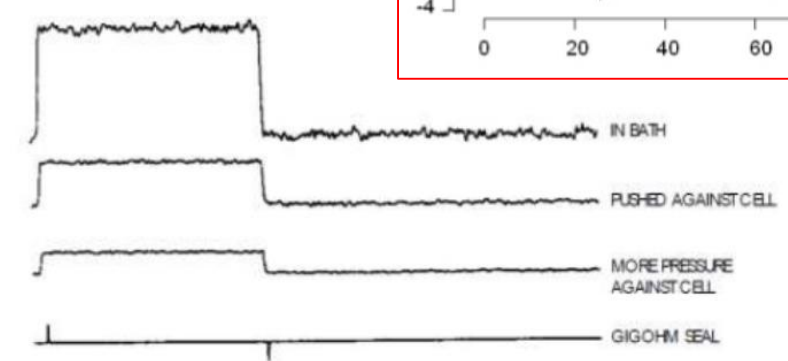
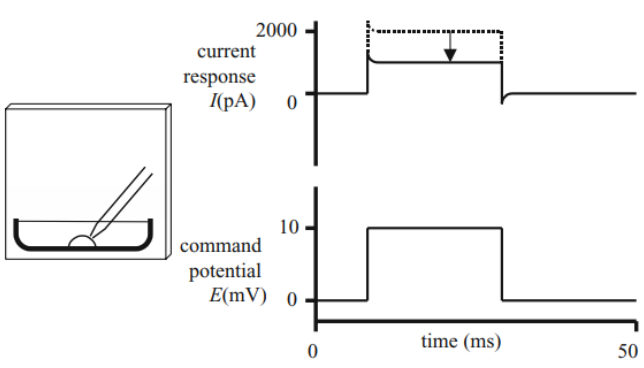
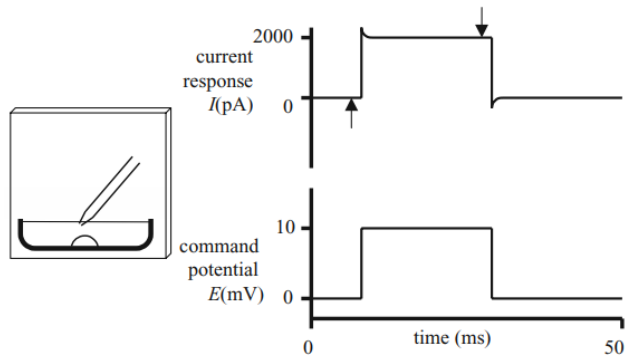
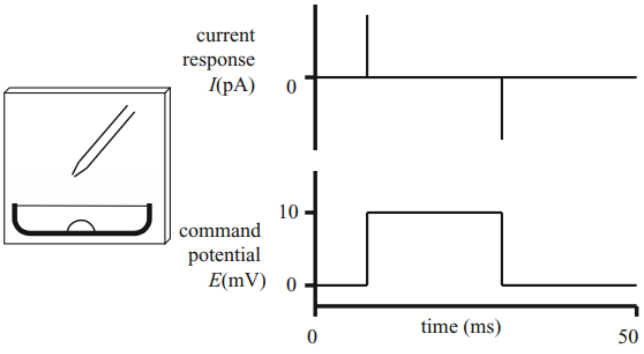
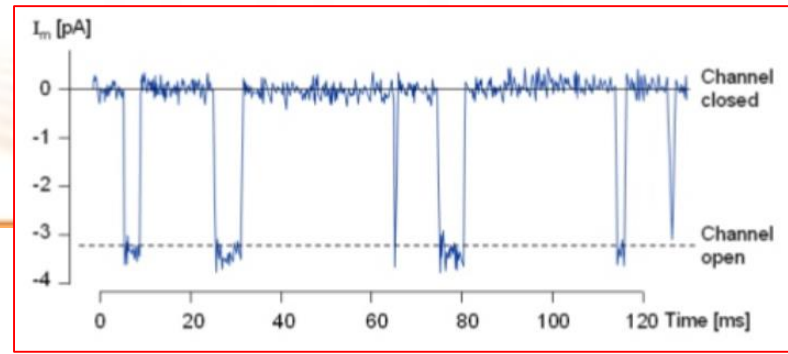
Duplos Eletrodos



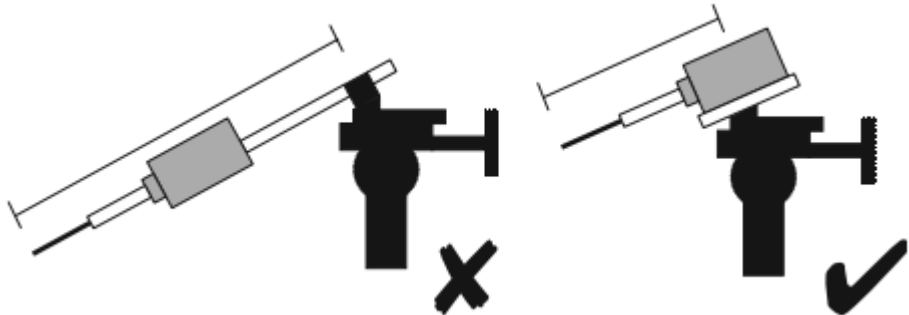
Instrumentação



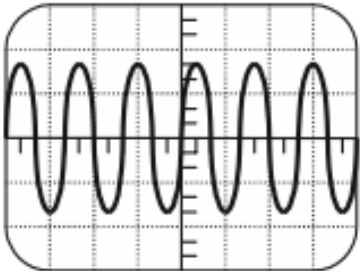
Instrumentação



Ruídos

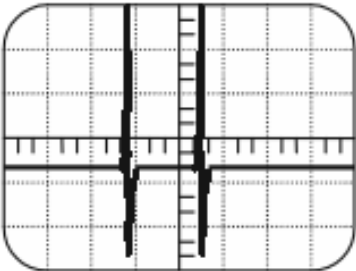


hum



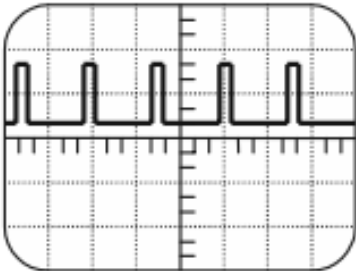
time base = 15 ms/div

switch noise



± 1 ms/div

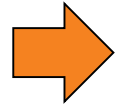
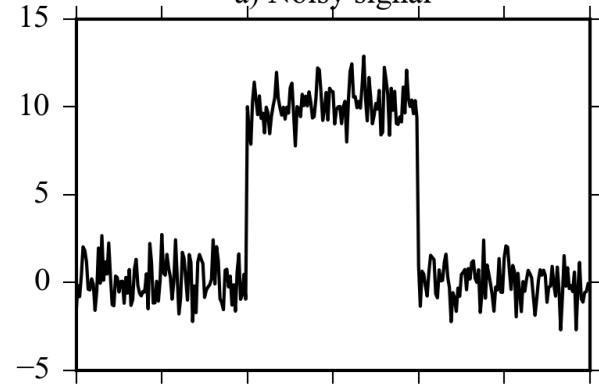
digital noise



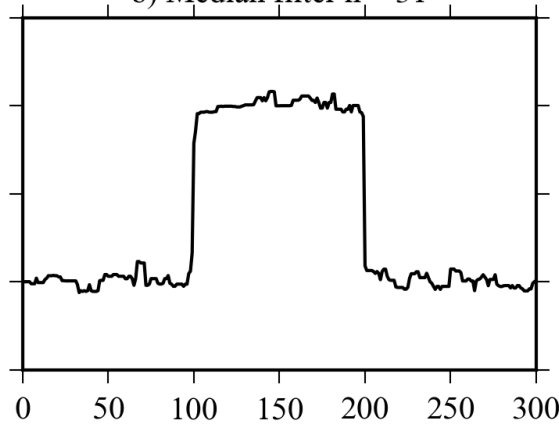
± 0.1 ms/div

Ruídos – Filtro por software

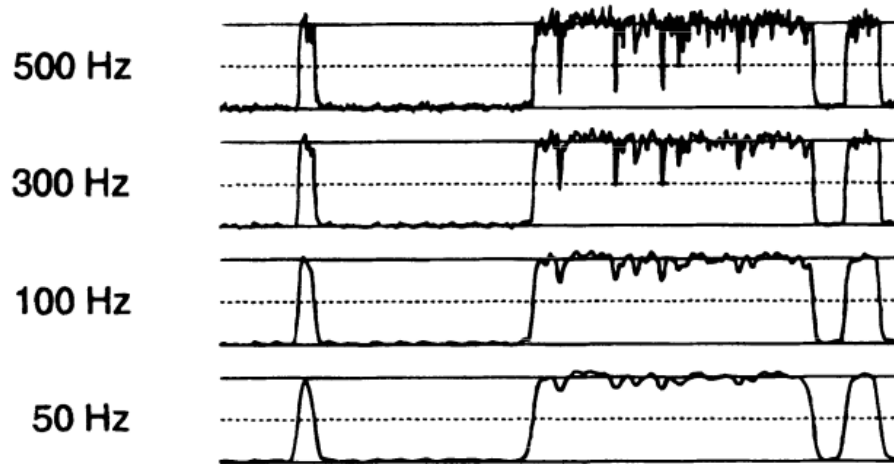
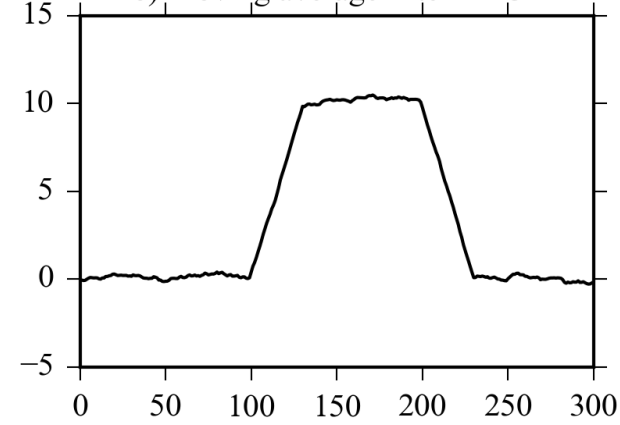
a) Noisy signal



b) Median filter $n = 31$

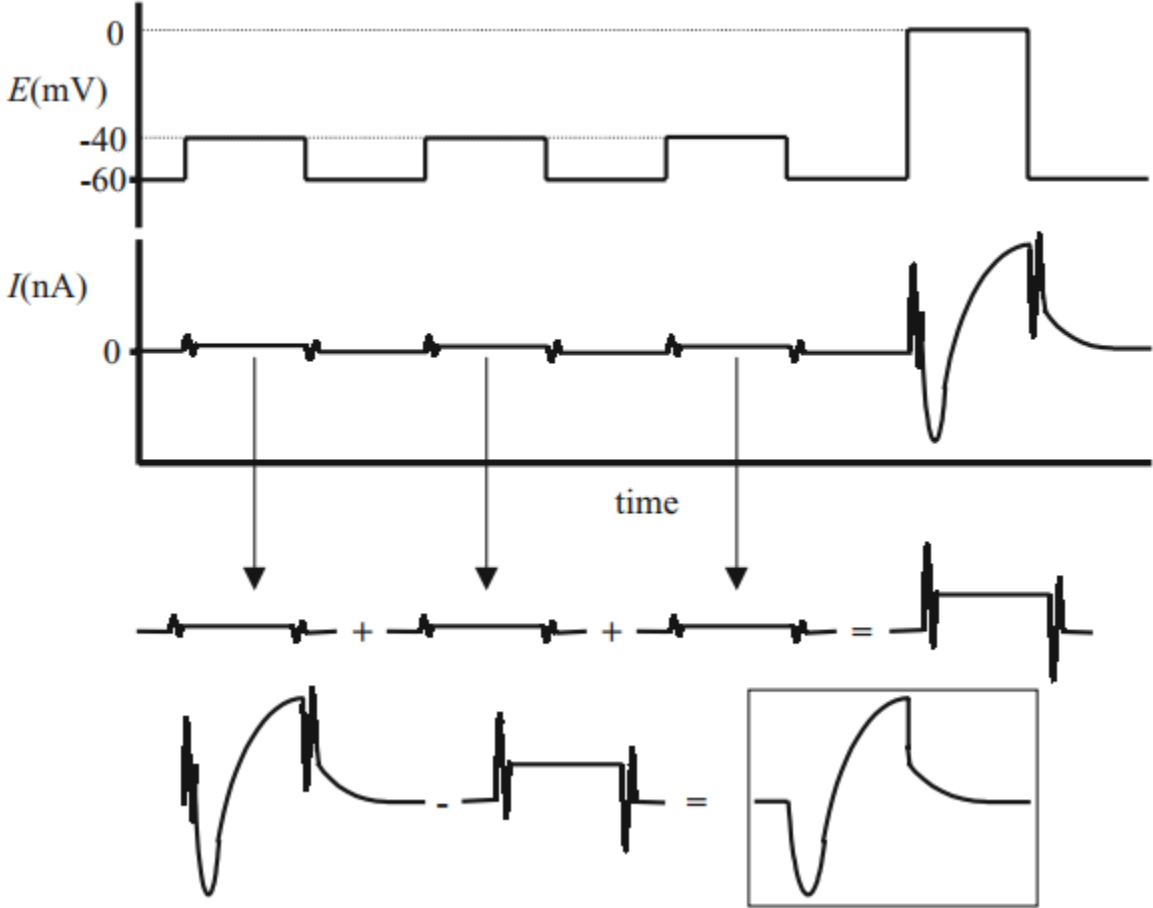


b) Moving average filter $n = 31$

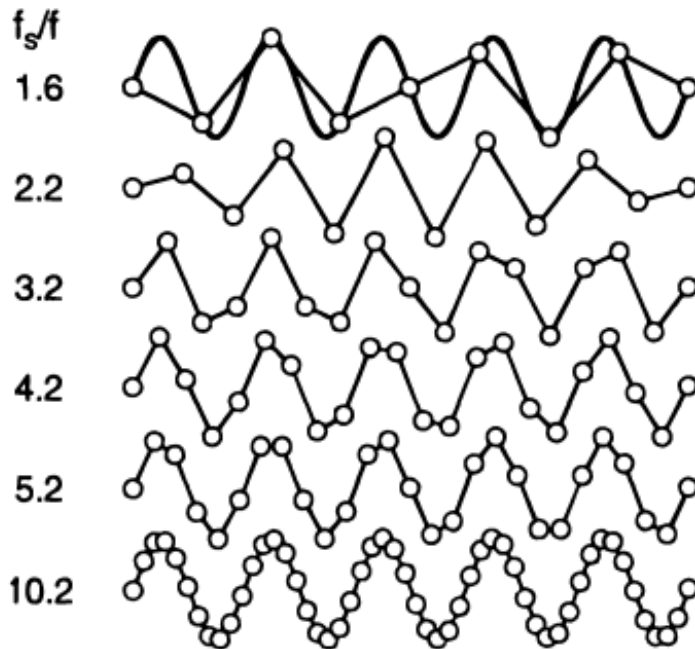
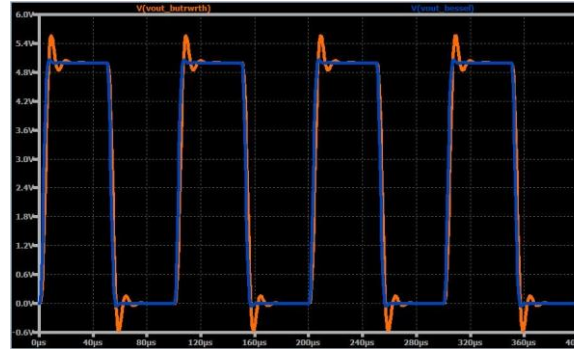
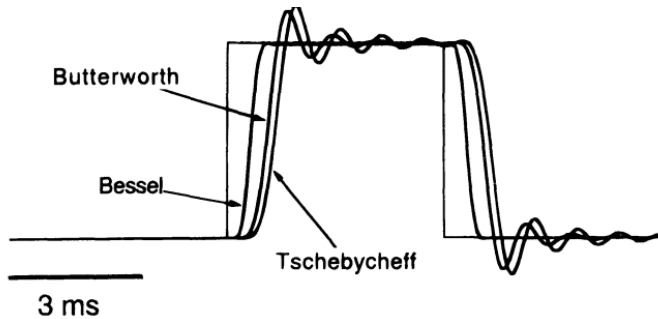


1 pA
100 ms

Ruídos – Filtro por software



Ruídos – Filtro por software e digitalização



An Outwardly Rectifying Chloride Channel in Human Atrial Cardiomyocytes

MARIE DEMION, PH.D., ROMAIN GUINAMARD, PH.D., ANTOUN EL CHEMALY, PH.D.,
MOHAMMAD RAHMATI, M.D., and PATRICK BOIS, M.D.

From the Institut de Physiologie et Biologie Cellulaires, CNRS UMR 6187, Université de Poitiers, Poitiers Cedex, France

Data Analysis

Signals for analysis were stored on digital audiotapes and then played back through a filter (Bessel model 902LPF, Frequency Devices, Inc., Haverhill, MA, USA) and digitized at 1 kHz using a Digidata 1,200 A analog-digital interface and Fetchex software (version 6.02; Axon instruments). Currents were analyzed with Bio-patch software (version 3.30; Biologic, Claix, France), with amplitude histograms generated for the construction of I/V curves and for the estimation of channel open probability (P_o). Because the channel conductance rectifies, I/V curves could not be fitted to a straight line. We therefore fitted the data points to a curve describing exponential growth. In some cases this might have induced

Curvas I/V (Relação Corrente/Tensão)

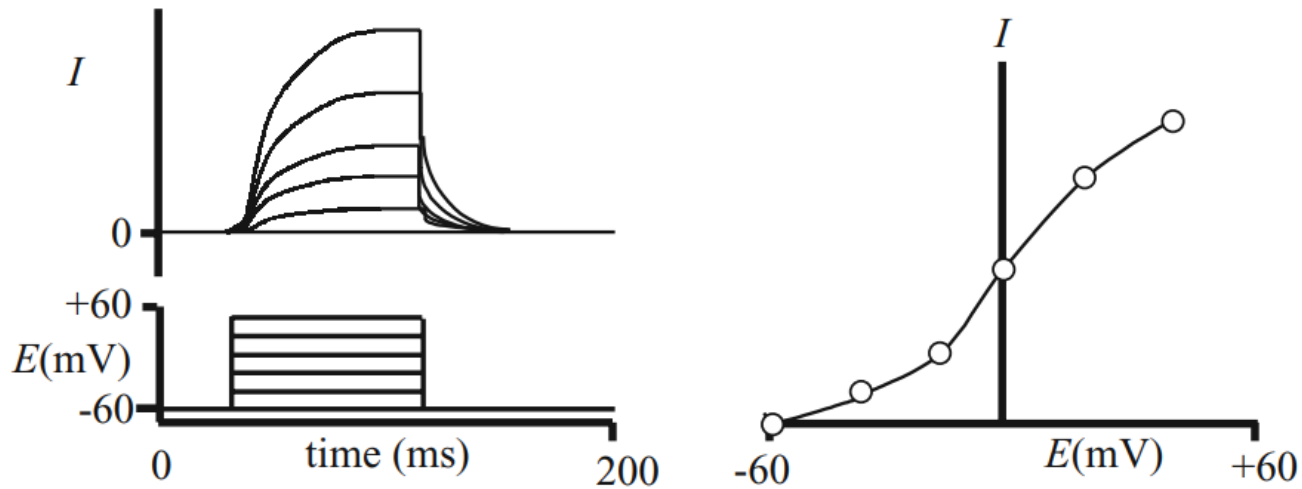


Figure 5.13 The outward current responses to a standard voltage step protocol are shown in the left-hand panel, with the maxima plotted versus step potential in the right-hand panel

Curvas I/V (Relação Corrente/Tensão) Outras

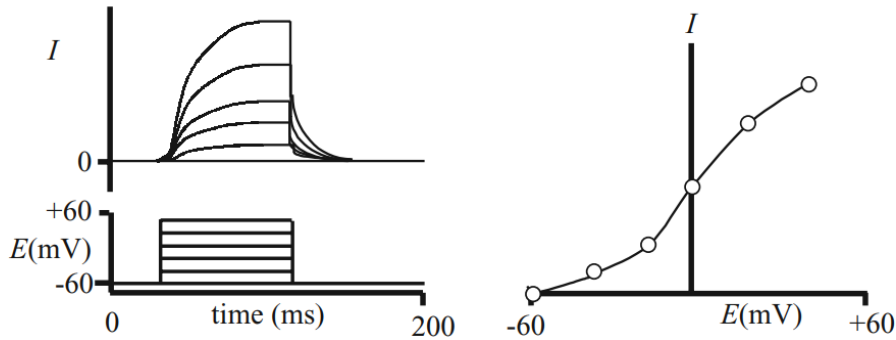


Figure 5.13 The outward current responses to a standard voltage step protocol are shown in the left-hand panel, with the maxima plotted versus step potential in the right-hand panel

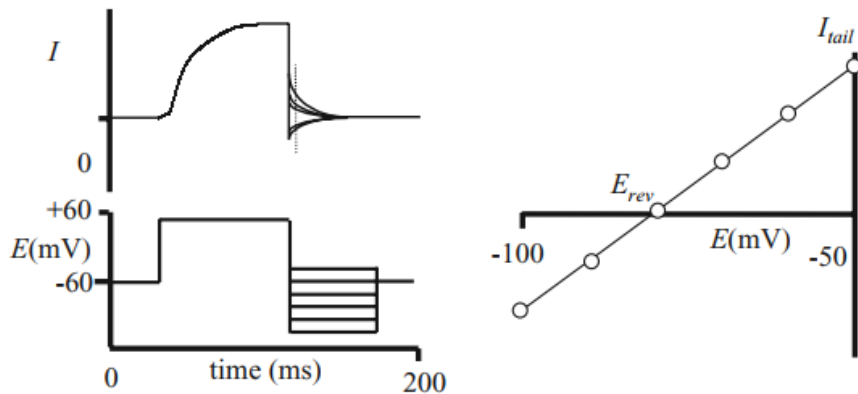


Figure 5.14 Application of a tail current protocol. Tail current amplitudes are measured at the dotted line in the left-hand panel and plotted versus step voltage in the right-hand panel

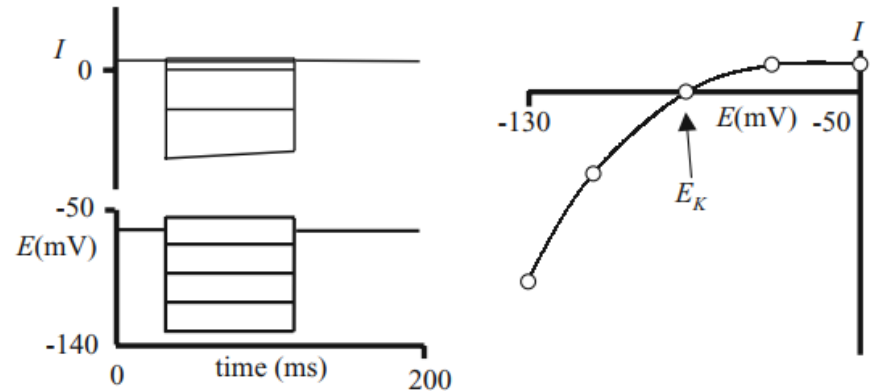
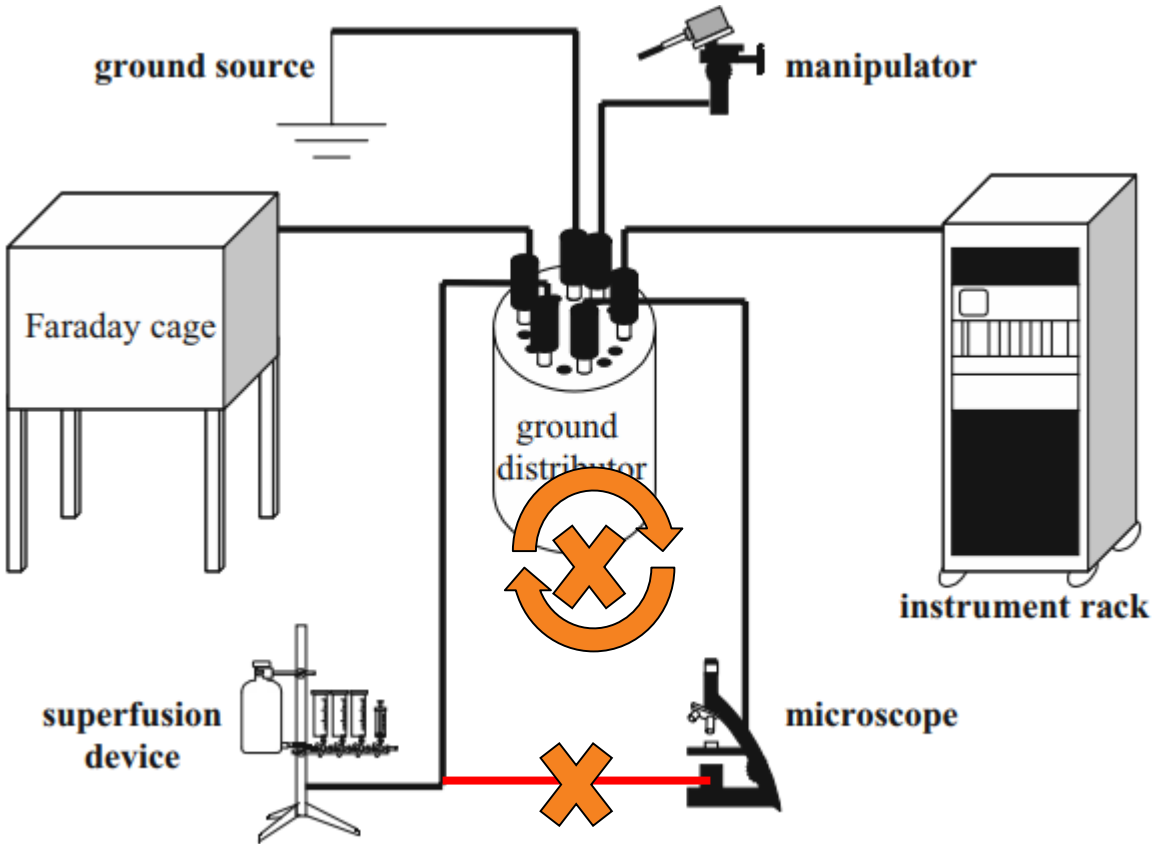


Figure 5.17 Gating of inward rectifying potassium channels is controlled by G proteins, but hyperpolarisation relieves magnesium and polyamine block. In a step protocol this has the appearance of an increase in leak current at very negative membrane potentials

Equipotencialização



Aterramento



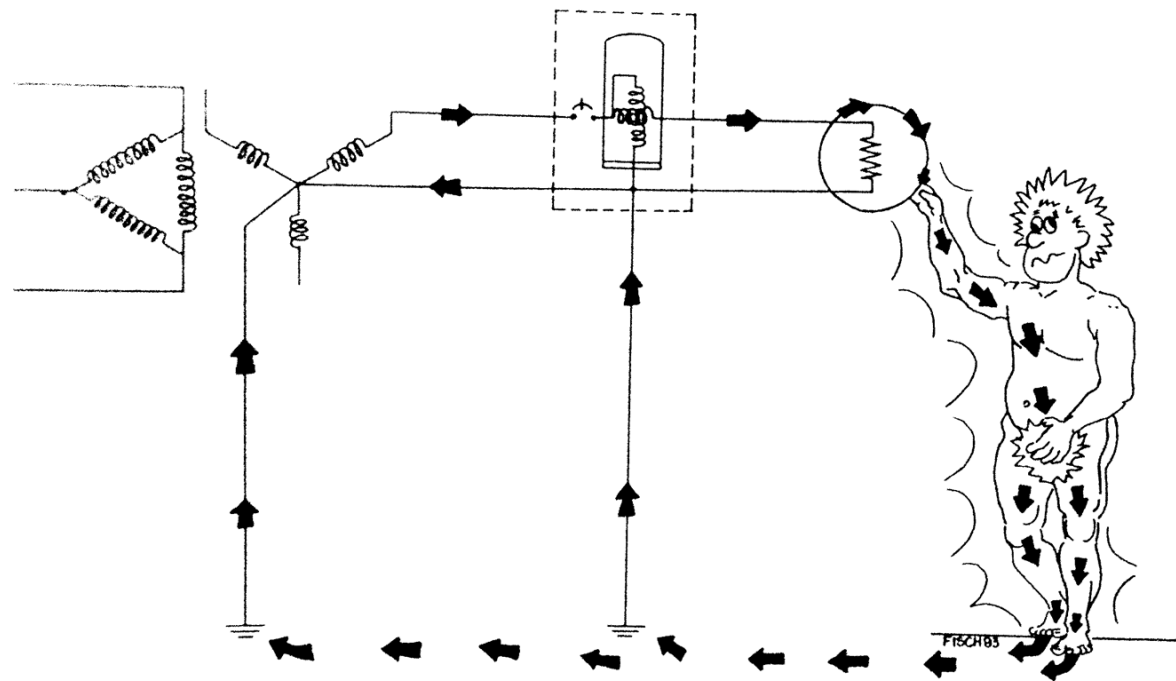
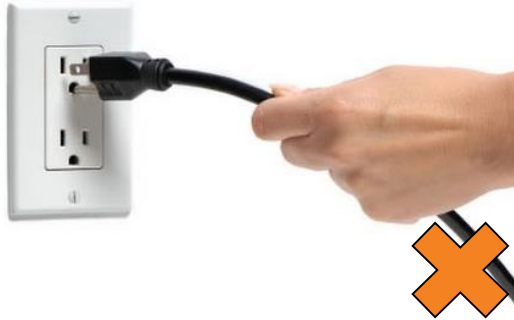


Figura 1.2.3 – Trajeto da corrente do choque elétrico

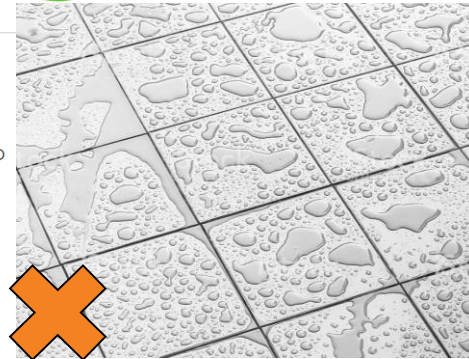
Riscos Equipamentos/Instalações Elétricas



Acidentes com origem elétrica causaram 622 mortes em 2018

Publicado em 02/05/2019 - 21:18 Por Elaine Patricia Cruz - Repórter da Agência Brasil São Paulo

Em 2018, foram registrados 1.424 acidentes com origem elétrica em todo o país, sendo 836 choques, 537 incêndios por sobrecarga ou curto-circuito e 51 descargas atmosféricas (raios). Isso representou um aumento de 2,67% em comparação ao ano anterior e de 37,2% em relação a 2013, início da série histórica.





**UNIVERSIDADE FEDERAL
DE SANTA CATARINA**



PÓS-GRADUAÇÃO
ENGENHARIA ELÉTRICA
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Eletricidade básica, medidas elétricas e instrumentos aplicados aos estudos de eletrofisiologia

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electroporation.ufsc.br