



**Universidad  
de Valparaíso  
C H I L E**

# Biopotenciales, electrodos y amplificador de bioinstrumentación.

Mediciones Biomédicas

Ingeniería Civil Biomédica

Alejandro Veloz

[alejandro.veloz@uv.cl](mailto:alejandro.veloz@uv.cl)

## Lectura complementaria:

Capítulo 4, 5 y 6, J.G. Webster. Medical Instrumentation: Application and Design. 4th Edition, 2010.

# Contenidos

Los potenciales bioeléctricos

Electrodos

Amplificador biológico

# **Los potenciales bioeléctricos**

# Estudio de los potenciales bioeléctricos

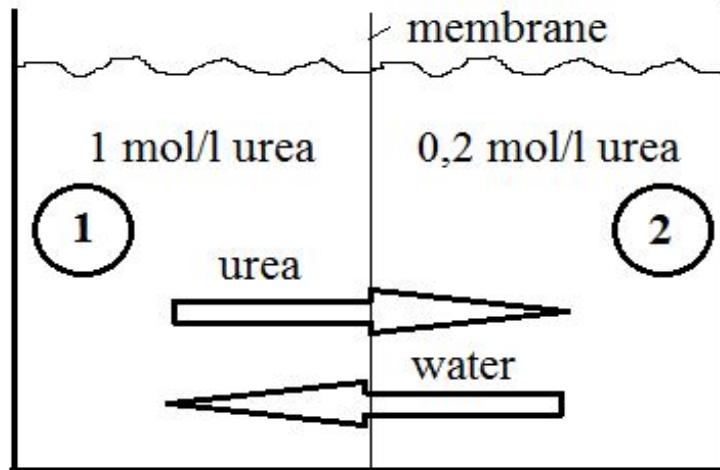
Biopotenciales: Se originan a nivel microscópico producto de la actividad electroquímica de **células excitables**.

Se manifiestan a nivel macroscópico (distribución de potenciales en la superficie del cuerpo).



# Difusión de moléculas no cargadas

- Consideremos un contenedor con dos cámaras de igual volumen separadas por una membrana.
- En la cámara uno hay 1 mol/l de urea y en la cámara 2 hay 0.2 mol/l.



- Las moléculas de urea se moverán a través de la membrana de la cámara con mayor concentración hacia la cámara de menor concentración.
- Este proceso se llama difusión.
- Este proceso termina cuando la concentración de urea es la misma en ambas cámaras, i.e. 0.6 mol/l.
- La Ley de Fick describe este proceso:

$$(1) J_d = -D \frac{dC}{dx}$$

donde  $J_d$  es el flujo de difusión [en  $(\text{mol}/\text{cm}^2)/\text{s}$ ], D es la constante de difusión [en  $\text{cm}^2/\text{s}$ ] y  $dC/dx$  es el gradiente de concentración [en  $(\text{mol}/\text{cm}^3)/\text{cm}$ ].

- La constante de difusión D está dada por:

$$D = \frac{RT}{f}$$

donde R es la constante de los gases [8.31 (J/°K)/mol], T es la temperatura absoluta y f es el coeficiente friccional [en (J/mol) (s/cm<sup>2</sup>)].

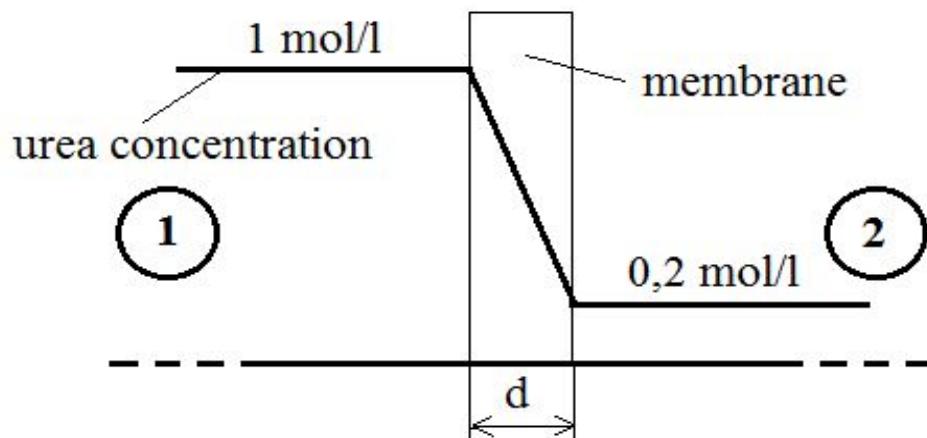
- Sustituyendo D en (1):

$$J_d = -\frac{RT}{f} \frac{dC}{dx}$$

- Sea  $d$  el grosor de la membrana.
- Considerando un gradiente de concentración constante entre la membrana de la ecuación anterior, se puede reemplazar  $dC/dx$  por  $([C_1] - [C_2])/d$ , donde  $[C_1]$  y  $[C_2]$  son las concentraciones de urea en las cámaras 1 y 2, respectivamente.
- El flujo de difusión se puede escribir entonces como:

$$J_d = -P_u([C_1] - [C_2])$$

donde  $P_u = D/d$  (en cm/s) es la permeabilidad de la membrana a la urea.



# Movimiento de iones

- Si en las cámaras ahora hay iones.
- Supongamos 1 mol/l de KCl en la cámara uno y 0.3 mol/l en la dos.
- Y que la membrana es sólo permeable a iones de K<sup>+</sup>.
- Los iones de K<sup>+</sup> se moverán de la cámara uno a la dos.
- Esto ocasionará que la cámara dos sea más positiva que la uno, generando una diferencia de potencial a través de la membrana:

$$J_e = -\frac{dV}{dx} (zCF) \frac{1}{f}$$

donde z es la carga de un mol de iones, C es la concentración, F es la constante de Faraday (96500 C/mol), f es el coeficiente friccional y dV/dx es el campo eléctrico. **En estado de equilibrio, el flujo de difusión J<sub>d</sub> y el flujo eléctrico J<sub>e</sub> son iguales** □ Ecuación de Nernst:  
 $V_1 - V_2 = -58 \ln(C_1/C_2) \text{ mV}$

$$E_K = \frac{RT}{nF} \ln \frac{[K]_o}{[K]_i} = 0.0615 \log_{10} \frac{[K]_o}{[K]_i} \quad (\text{V})$$

$$E = \frac{RT}{F} \ln \left\{ \frac{P_K[K]_o + P_{Na}[Na]_o + P_{Cl}[Cl]_i}{P_K[K]_i + P_{Na}[Na]_i + P_{Cl}[Cl]_o} \right\}$$

**EXAMPLE 4.1** For frog skeletal muscle, typical values for the intracellular and extracellular concentrations of the major ion species (in millimoles per liter) are as follows.

Species	Intracellular	Extracellular
Na <sup>+</sup>	12	145
K <sup>+</sup>	155	4
Cl <sup>-</sup>	4	120

# Estado de reposo

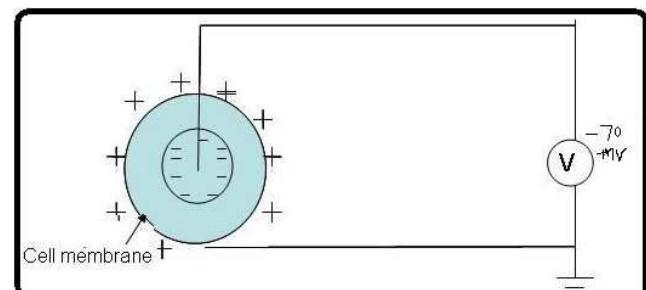
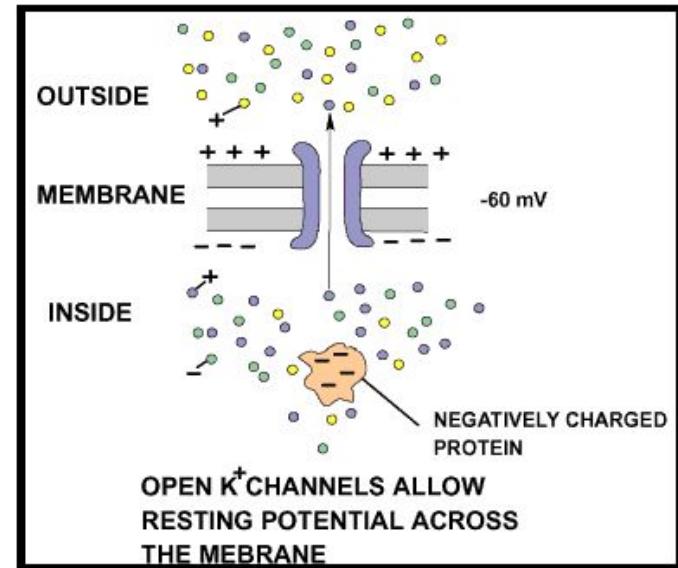
Los iones presentes en los medios intra y extracelulares buscan un balance electroquímico, el cual se consigue variando concentraciones y carga eléctrica neta en dichos medios.

Las membranas celulares son encargadas de posibilitar dicho balance, permitiendo el intercambio de iones entre los medios intra y extra-celulares.

- Permeables a Potasio ( $K^+$ ) y Cloro ( $Cl^-$ ).
- No permeables a Sodio ( $Na^+$ ).

Como consecuencia de la impermeabilidad de las membranas celulares a  $Na^+$ :

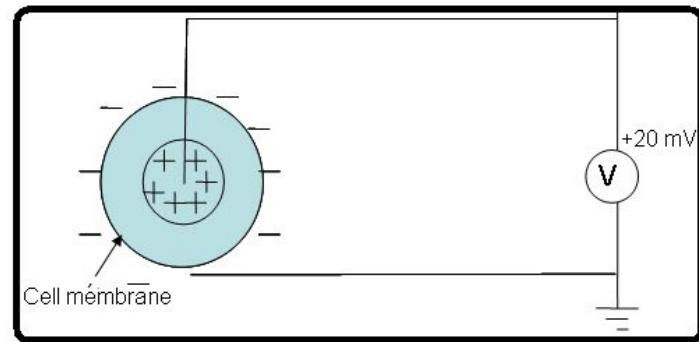
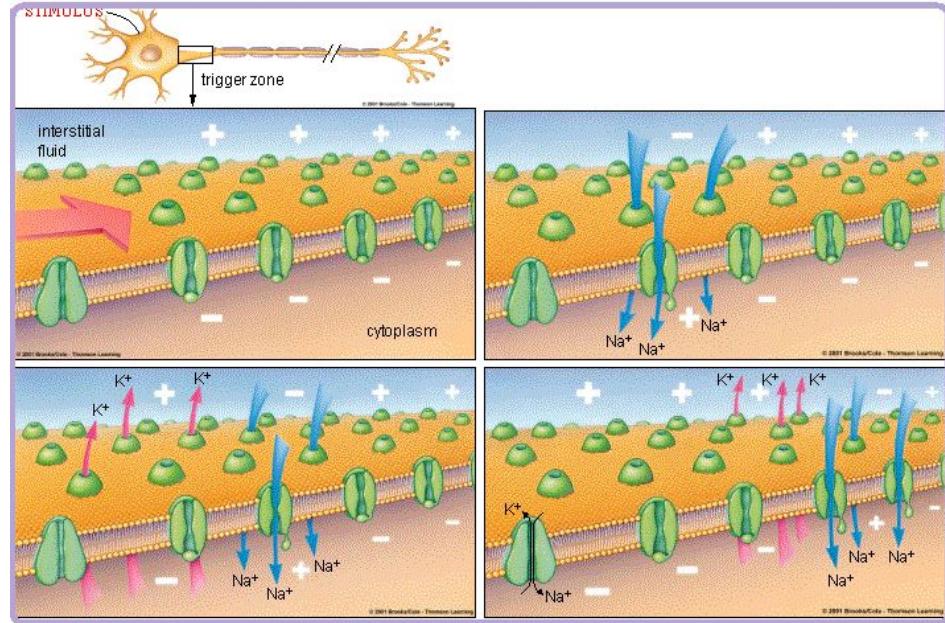
- La concentración de  $Na^+$  dentro de la célula es mucho menor que en el exterior.
- El interior de la célula tendrá carga neta negativa respecto del exterior.
- Como un mecanismo de balance de carga, iones de  $K^+$  entran a la célula, produciendo incremento en la concentración de dicho ion.
- El balance de carga no se consigue.
- La condición de equilibrio entonces consiste la diferencia de potencial negativo en el interior de la célula y positivo en el medio extra-celular.
- Esta condición se conoce como **potencial de reposo**.



# El potencial de acción

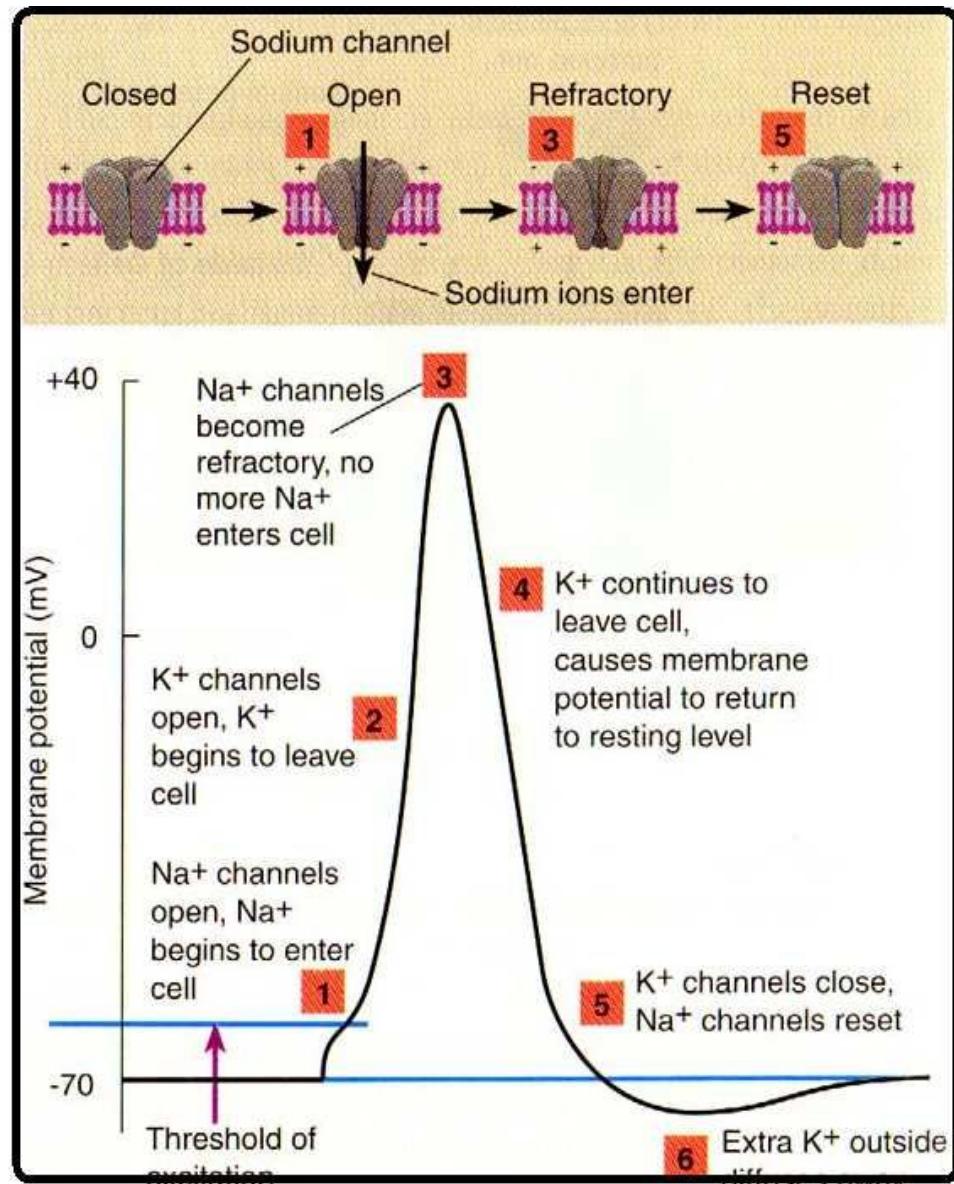
Cuando una sección de la membrana celular es excitada por algún tipo de energía aplicada externamente, las características de dicha membrana cambian:

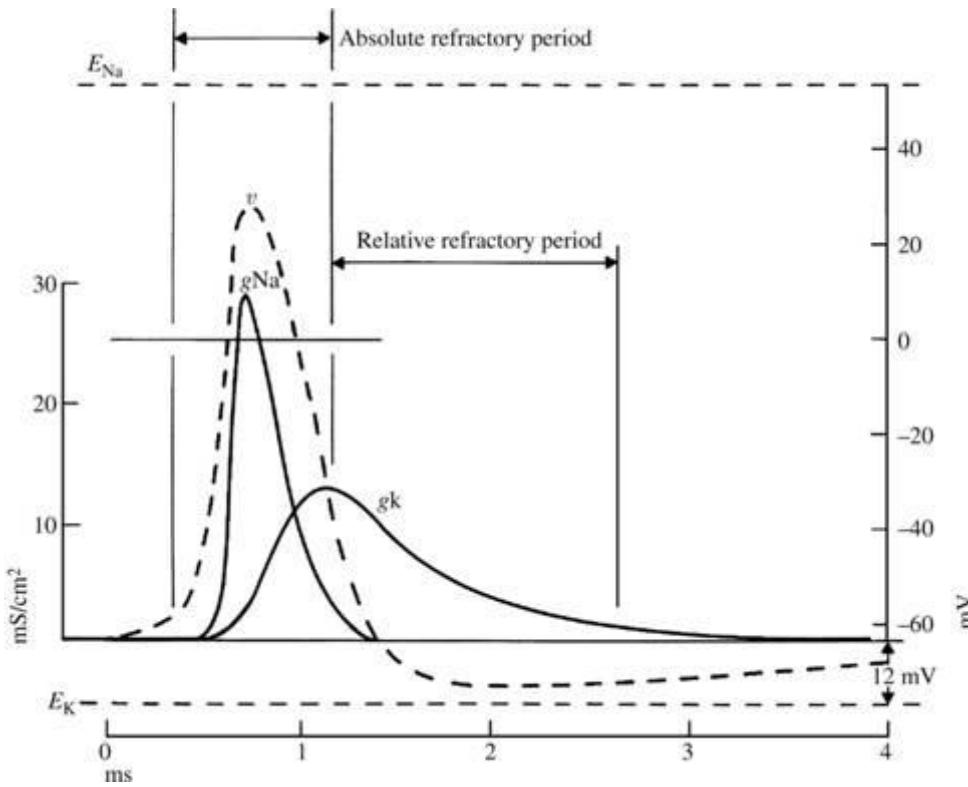
- Permite el ingreso de  $\text{Na}^+$ .
- Esta corriente iónica reduce el potencial de membrana y otros iones de  $\text{Na}^+$  ingresan al medio intracelular, resultando en un efecto avalancha.
- Al mismo tiempo, iones  $\text{K}^+$  salen de la célula para mantener el balance electroquímico.
- En consecuencia, se tiene un potencial positivo dentro de la célula debido al desbalance de  $\text{K}^+$ .
- El potencial resultante se denomina **potencial de acción**.



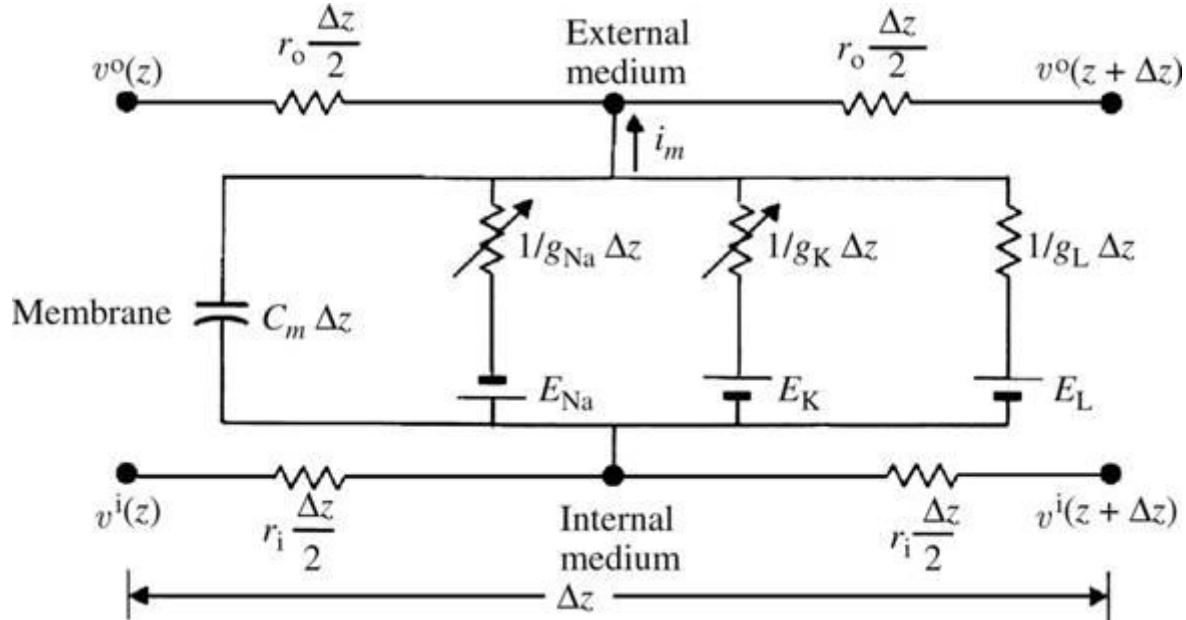
# El potencial de acción

- El proceso de conmutación del estado de reposo al potencial de acción se denomina despolarización.
- Una vez que la migración de  $\text{Na}^+$  a través de la membrana se detiene, la misma membrana revierte las concentraciones de  $\text{Na}^+/\text{K}^+$  a la condición de reposo (repolarización).





**Figure 4.2 Model-generated transmembrane potential ( $v_m$ ) and membrane ionic conductance changes for sodium ( $g_{Na}$ ) and potassium ( $g_K$ ) during the action potential.** These waveforms are obtained by solving the differential equations developed by Hodgkin and Huxley for the giant axon of the squid at a bathing medium temperature of 18.5 °C.  $E_{Na}$  and  $E_K$  are the Nernst equilibrium potentials for  $\text{Na}^+$  and  $\text{K}^+$  across the membrane. (Modified from A. L. Hodgkin and A. F. Huxley, "A Quantitative Description of Membrane Current and Its Application to Conduction and Excitation in Nerve," *Journal of Physiology*, 1952, 117, p. 530.)

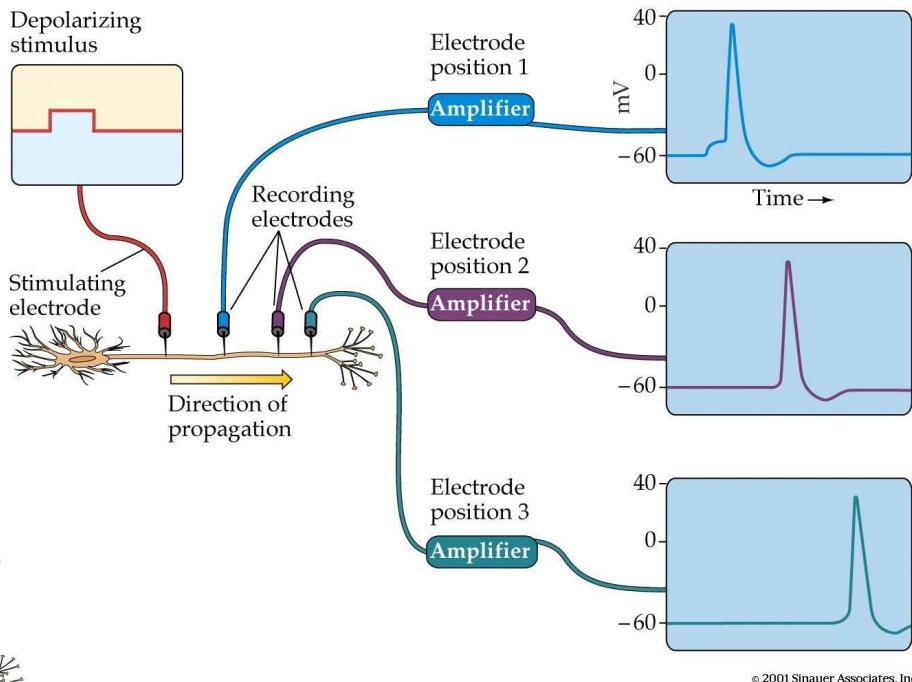


**Figure 4.3 Diagram of network equivalent circuit of a small length ( $\Delta z$ ) of a cylindrical cell (unmyelinated nerve fiber or skeletal muscle fiber). The membrane proper is characterized by specific membrane capacitance  $C_m$  ( $\text{mF/cm}^2$ ) and specific membrane conductances  $g_{\text{Na}}$ ,  $g_K$ , and  $g_{\text{Cl}}$  in  $\text{mS/cm}^2$  (millisiemens/ $\text{cm}^2$ ). Here an average specific leakage conductance is included that corresponds to ionic current from sources other than  $\text{Na}^+$  and  $\text{K}^+$  (e.g.,  $\text{Cl}^-$ ). This term is usually neglected. The cell cytoplasm is considered simply resistive, as is the external bathing medium; these media may thus be characterized by the resistance per unit length  $r_i$ , and  $r_o$  ( $\Omega/\text{cm}$ ), respectively. Here  $i_m$  is the transmembrane current per unit length ( $\text{A/cm}$ ), and  $v_i$  and  $v^\circ$  are the internal and external potentials at point  $z$ , respectively. Transmembrane potential at each point in  $z$  is given by  $v_m = v_i - v^\circ$ . (Modified from A. L. Hodgkin and A. F. Huxley, "A Quantitative Description of Membrane Current and Its Application to Conduction and Excitation in Nerve," *Journal of Physiology*, 1952, 117, p. 501.)**

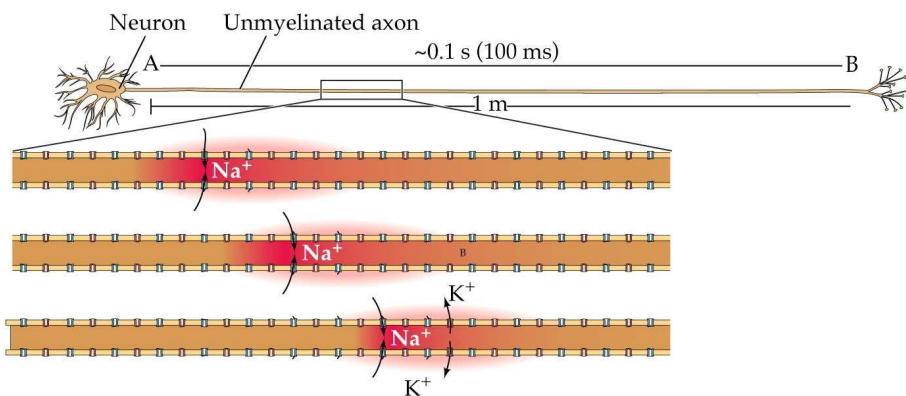
# El potencial de acción

“Viaje” del potencial de acción a través del axón.

En realidad no viaja: el influjo de  $\text{Na}^+$  se dispersa a través del axón, ocasionando potenciales de acción en porciones vecinas de la membrana.

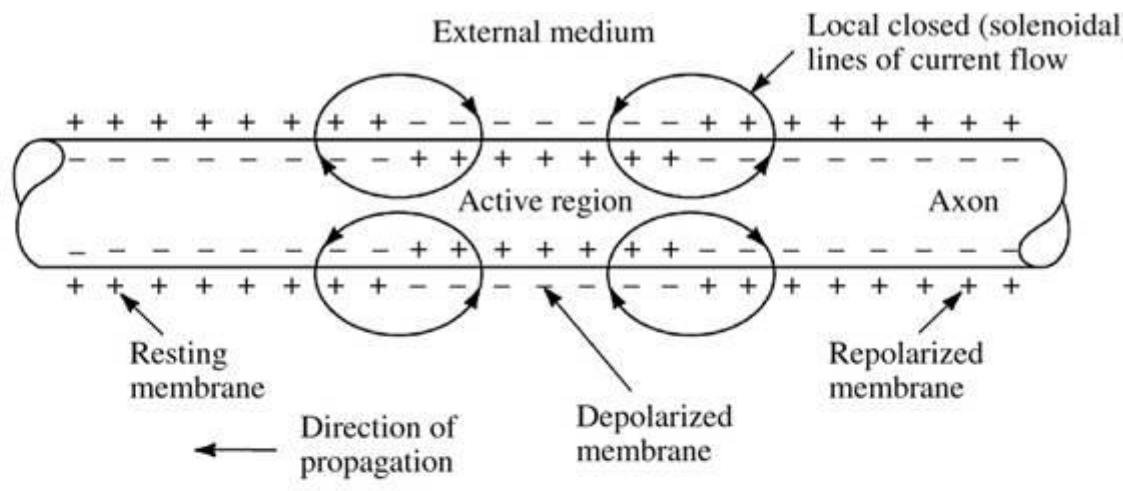


(a) Slow (10 meters per second) conduction of action potential along unmyelinated axon

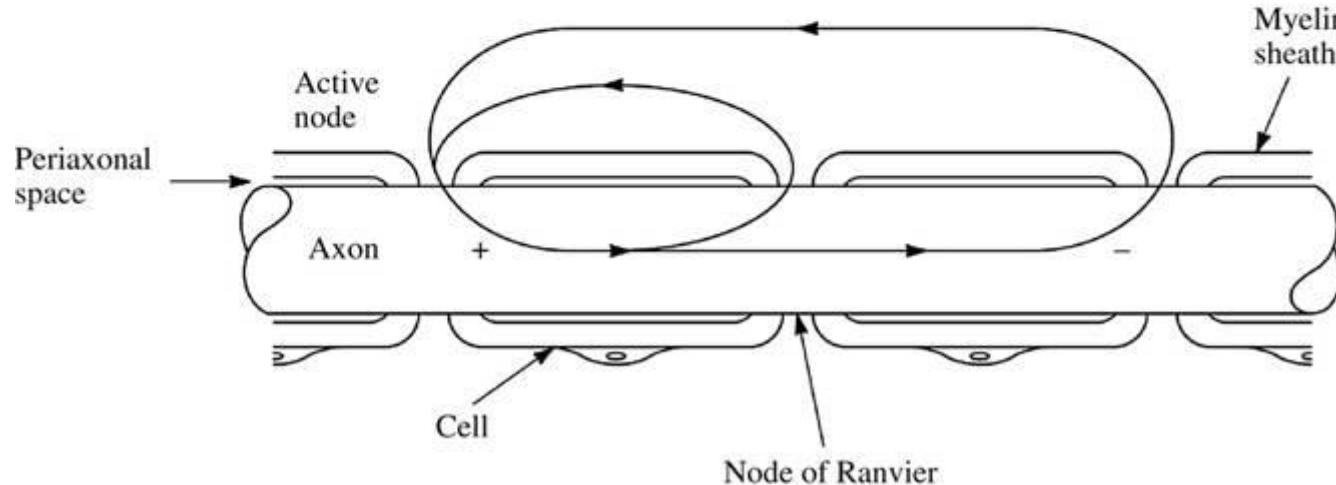


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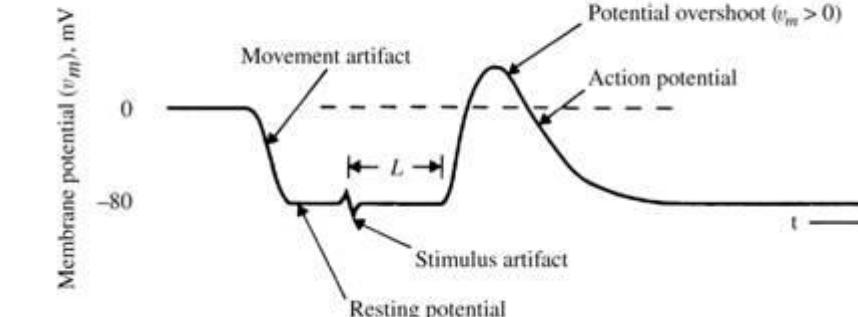
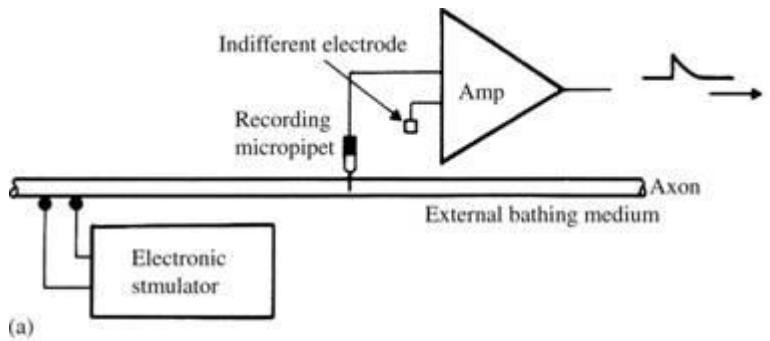


(a)



(b)

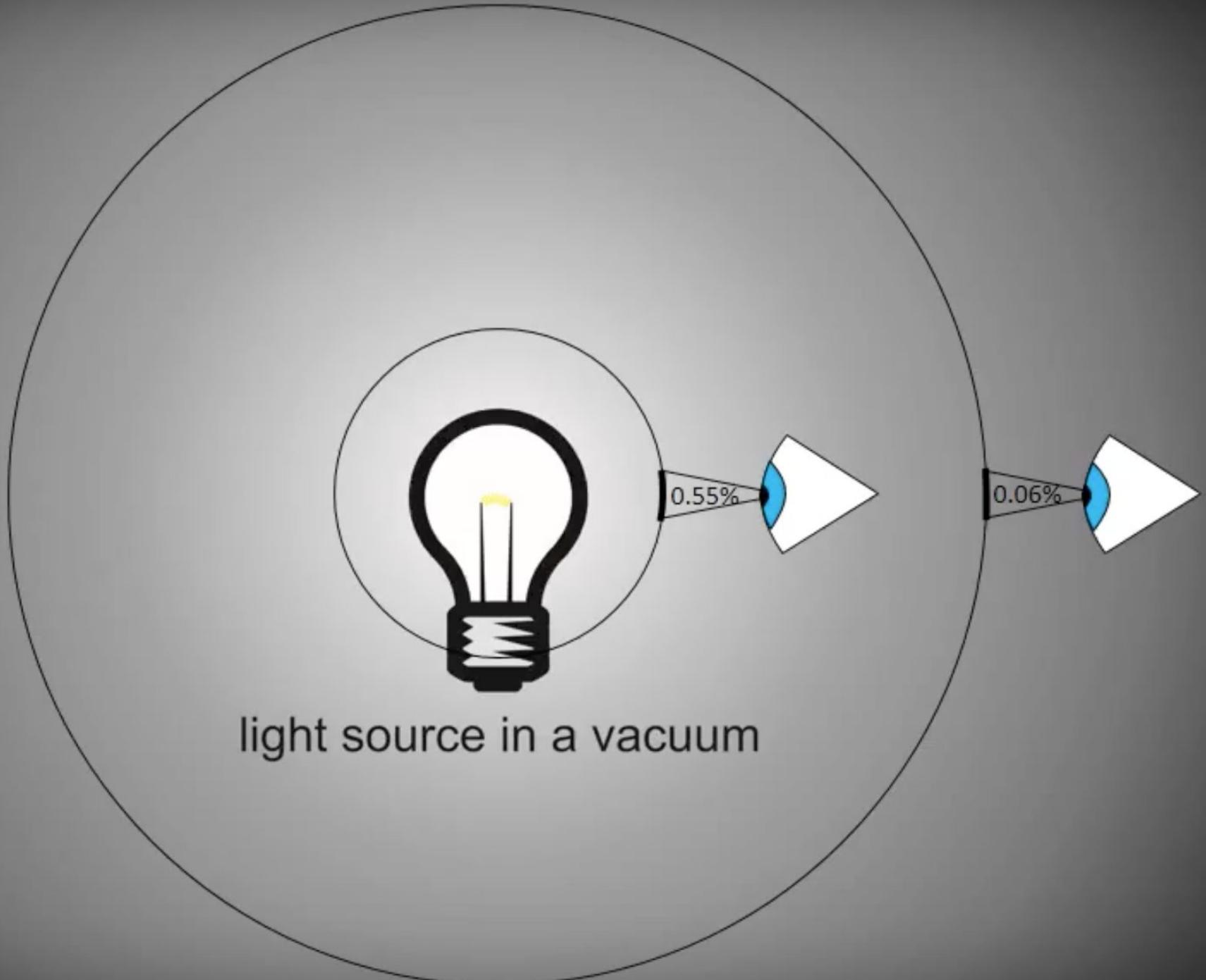
**Figure 4.4 (a) Charge distribution in the vicinity of the active region of an unmyelinated fiber conducting an impulse, (b) Local circuit current flow in the myelinated nerve fiber.**



**Figure 4.1 Recording of action potential of an invertebrate nerve axon** (a) An electronic stimulator supplies a brief pulse of current to the axon, strong enough to excite the axon. A recording of this activity is made at a downstream site via a penetrating micropipet. (b) The movement artifact is recorded as the tip of the micropipet drives through the membrane to record resting potential. A short time later, an electrical stimulus is delivered to the axon; its field effect is recorded instantaneously at downstream measurement site as the stimulus artifact. The action potential however, proceeds along the axon with a constant conduction velocity. The time period  $L$  is the *latent period* or transmission time from stimulus to recording site.

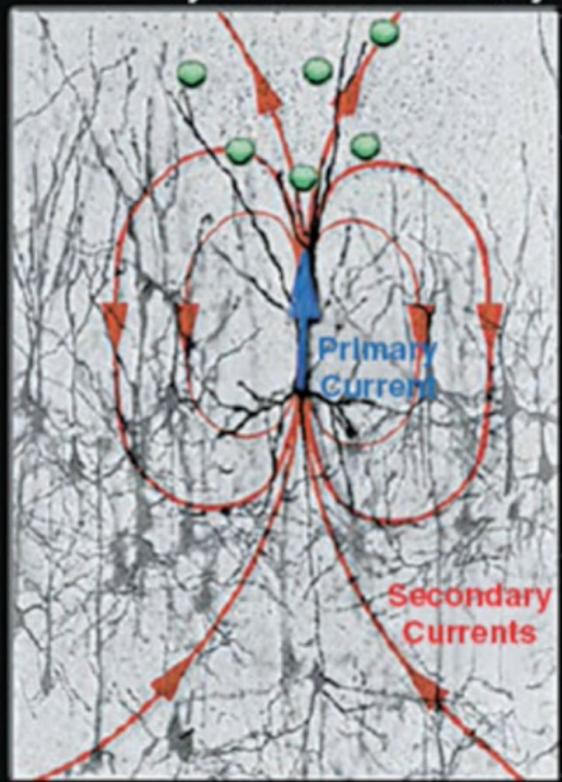
# The volume conduction problem

[http://www.scholarpedia.org/article/Volume\\_conduction](http://www.scholarpedia.org/article/Volume_conduction)



light source in a vacuum

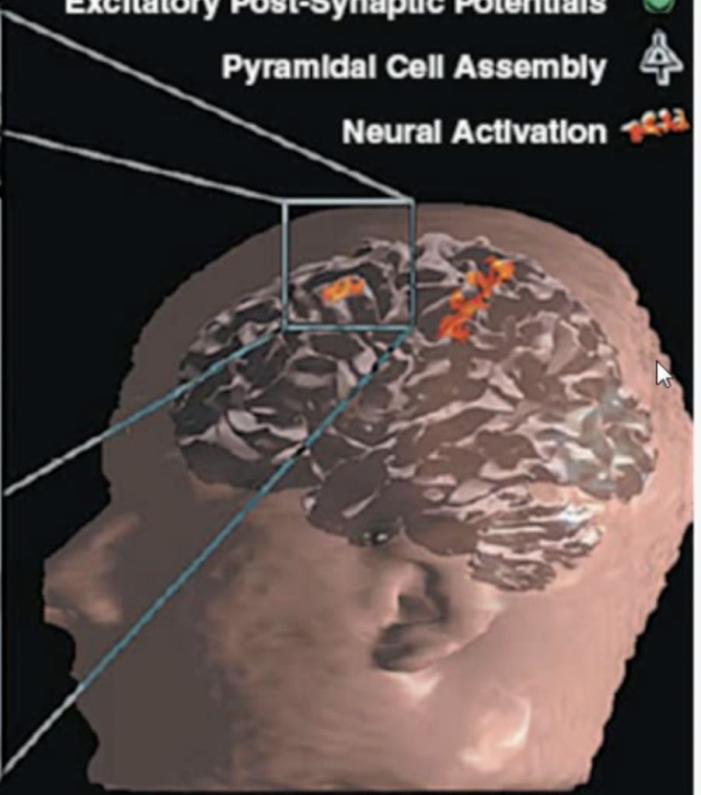
### Pyramidal Cell Assembly

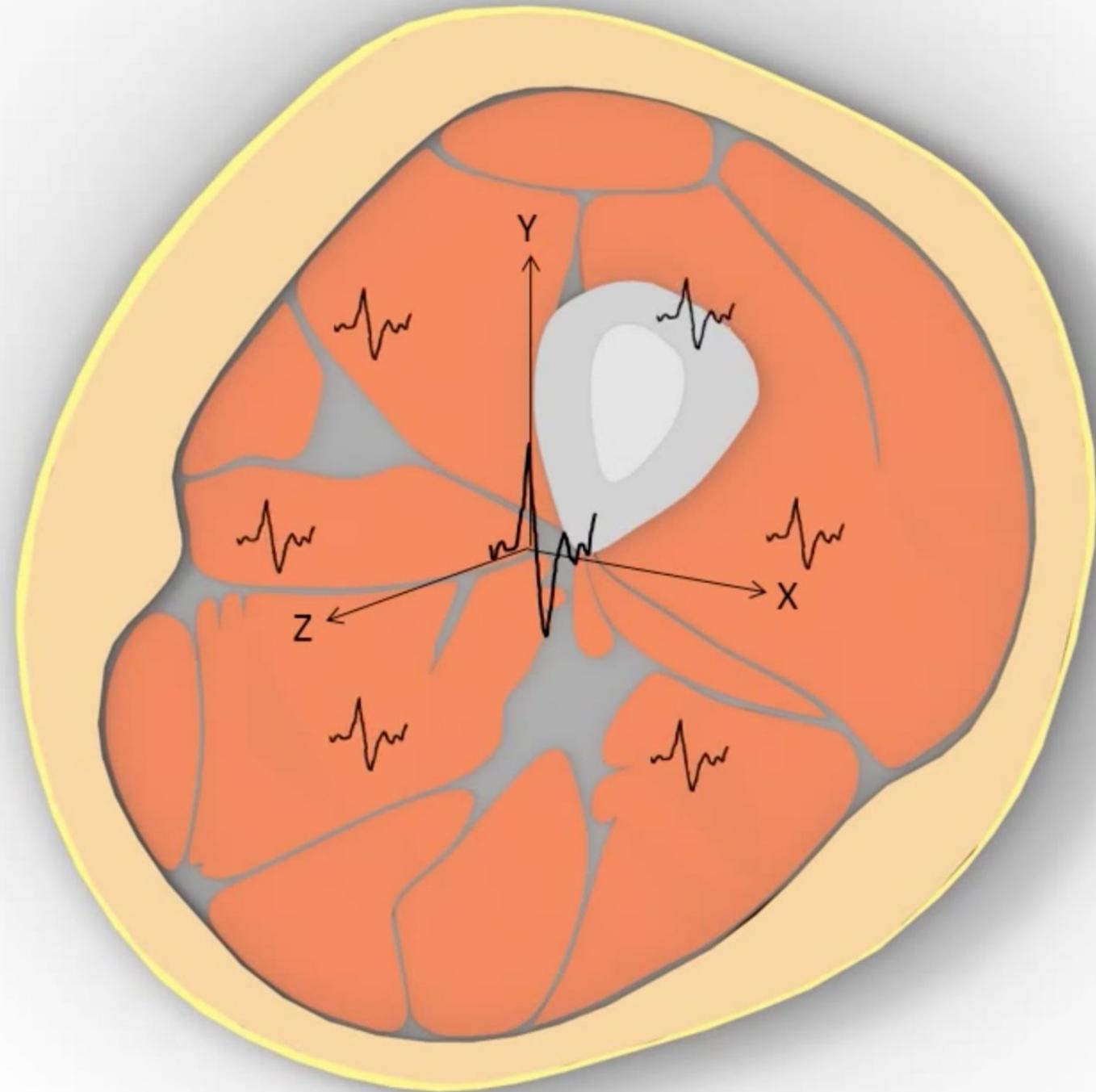


Excitatory Post-Synaptic Potentials

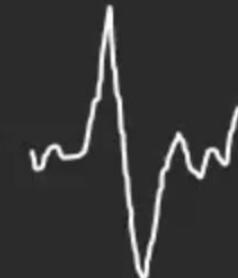
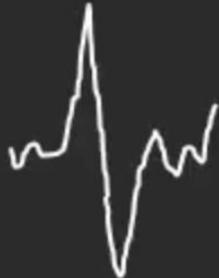
Pyramidal Cell Assembly

Neural Activation

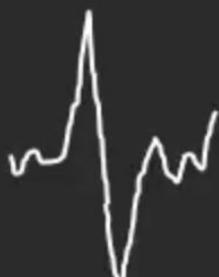




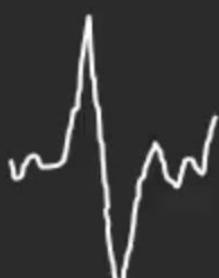
**Low Resistance Tissue**  
(such as muscle)



**Medium Resistance Tissue**  
(such as skin)



**High Resistance Tissue**  
(such as fat)

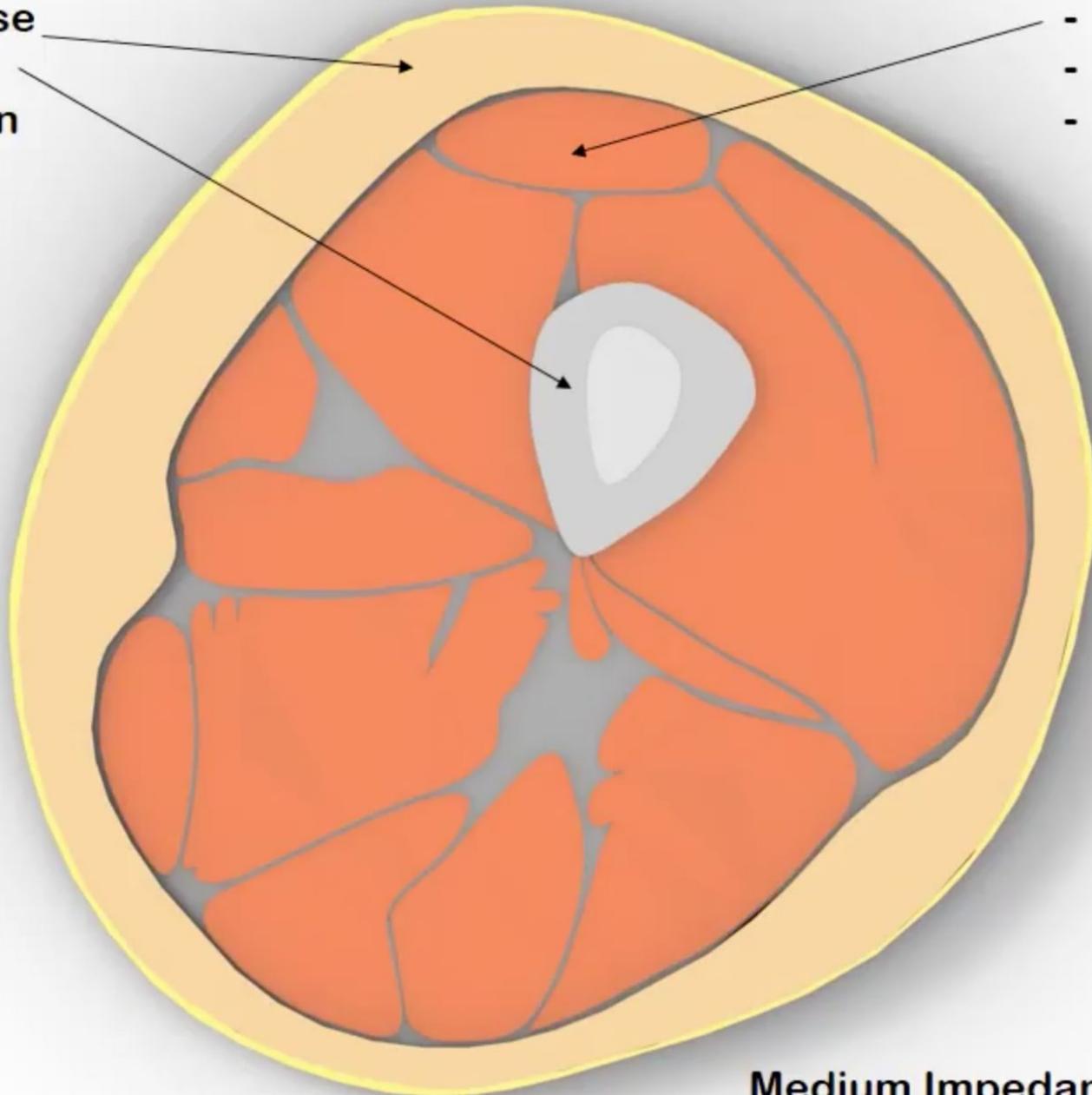


## Very High Impedance ( $>100K\Omega$ )

- Adipose
- Bone
- Tendon

## Low Impedance ( $< 1K\Omega$ )

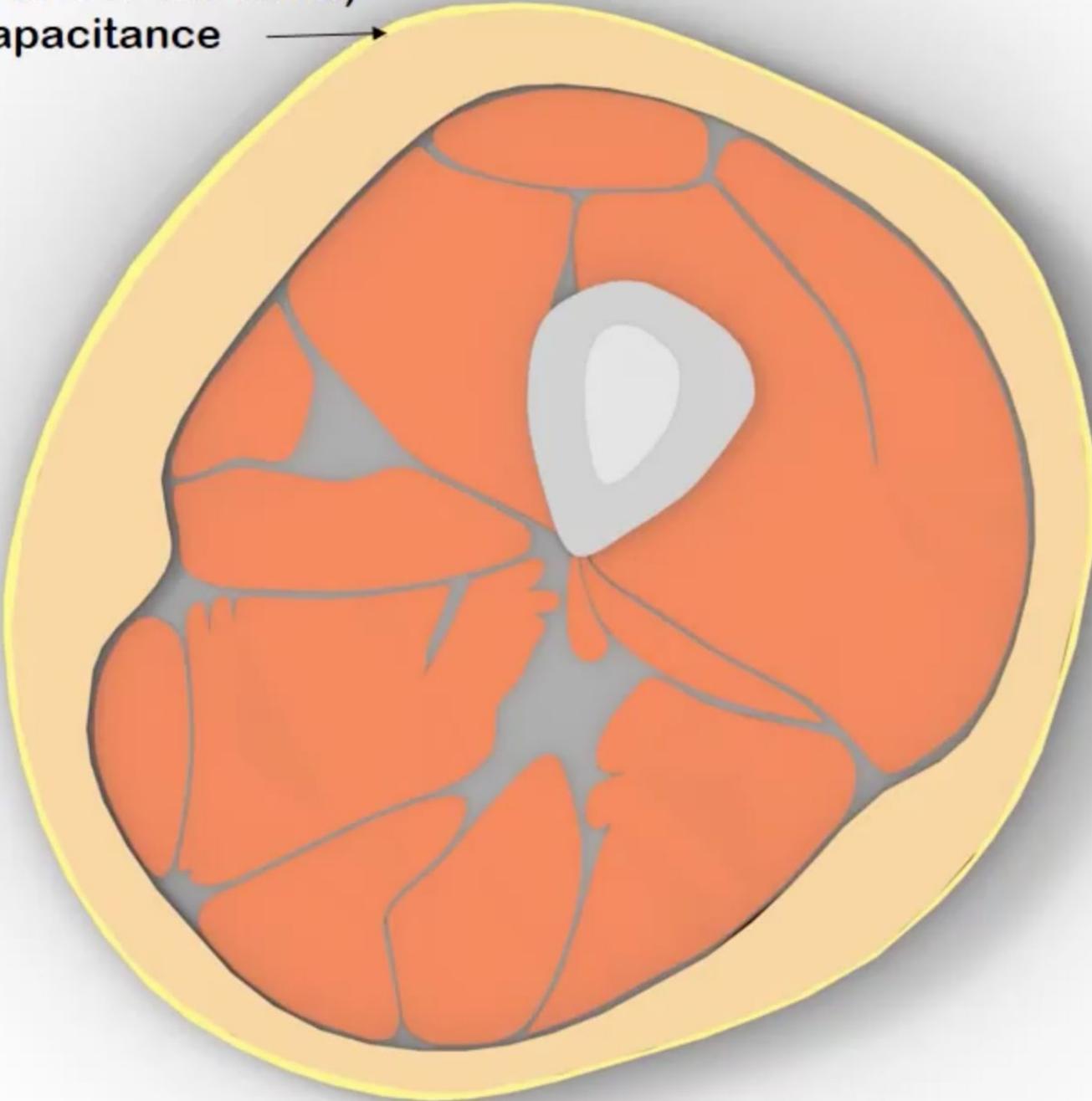
- Muscle
- Blood
- Mucous

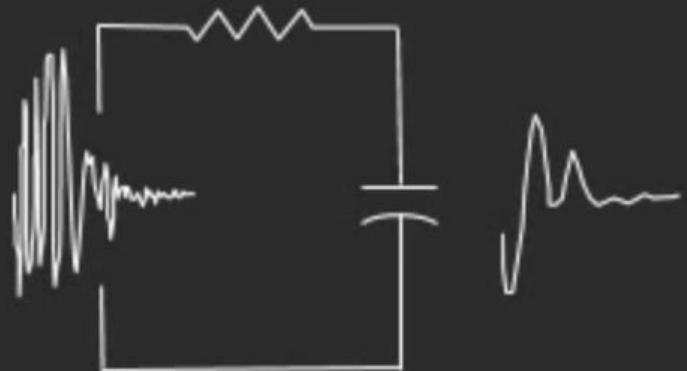


## Medium Impedance ( $\sim 30K\Omega$ )

- Skin

**Skin (and to a lesser extent fat)  
have capacitance**





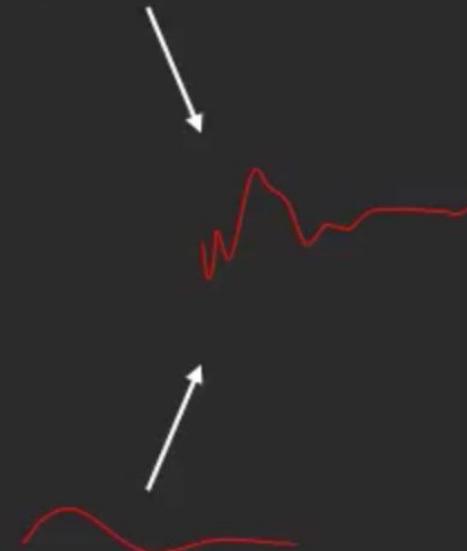
**Adipose Tissue**

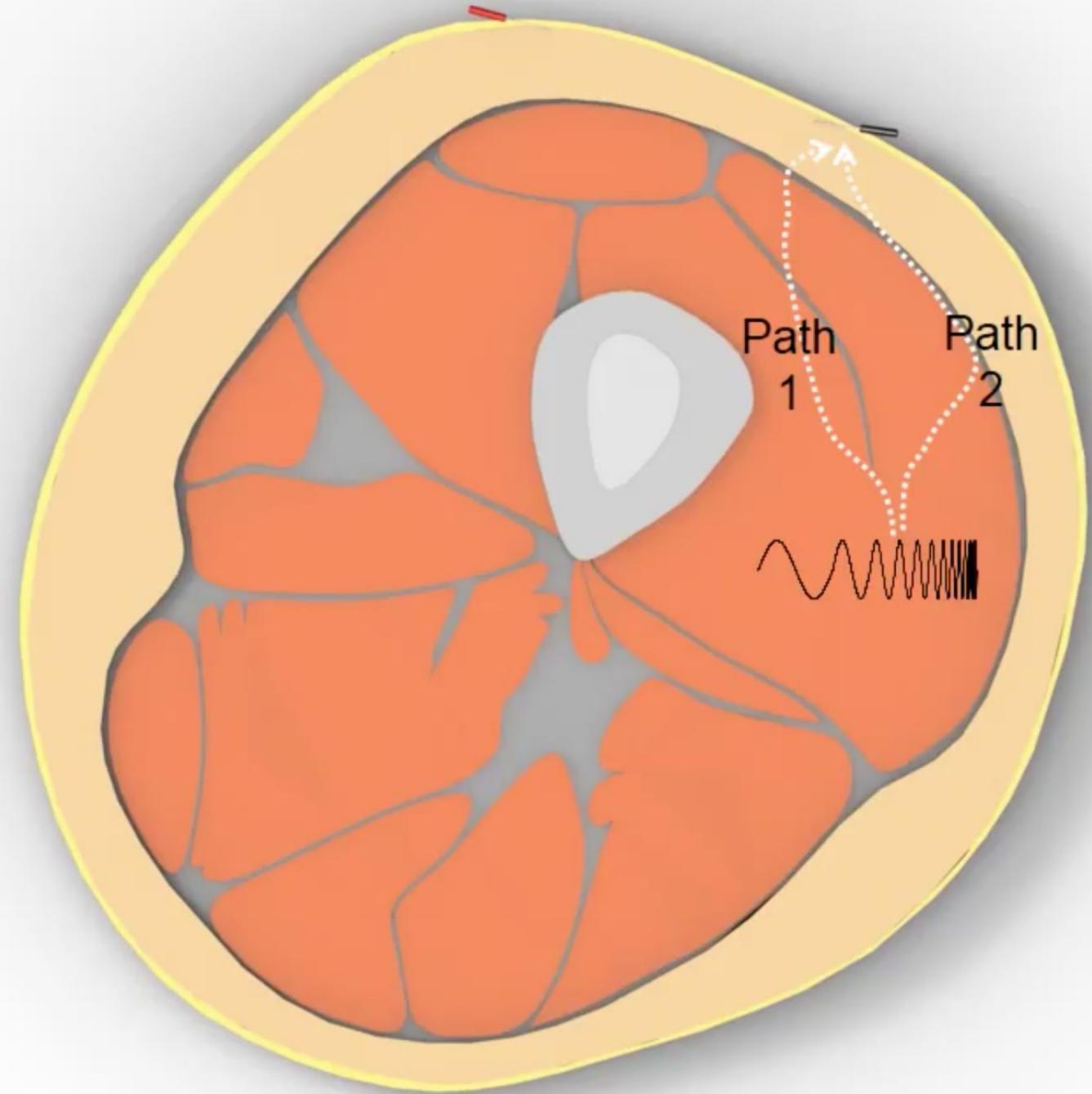


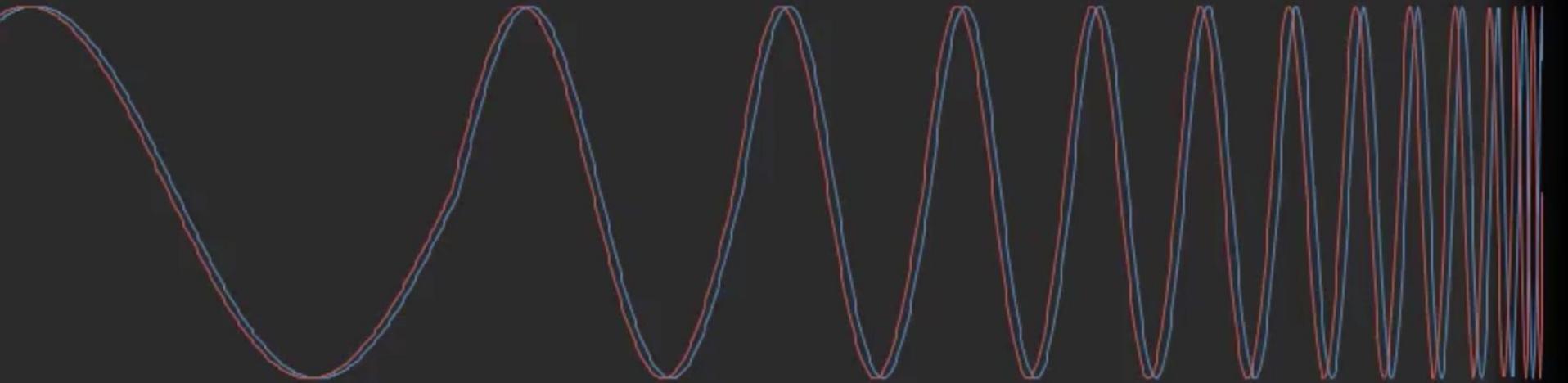
**Resistive  
Component of Impedance**



**Capacitive  
Component of Impedance**

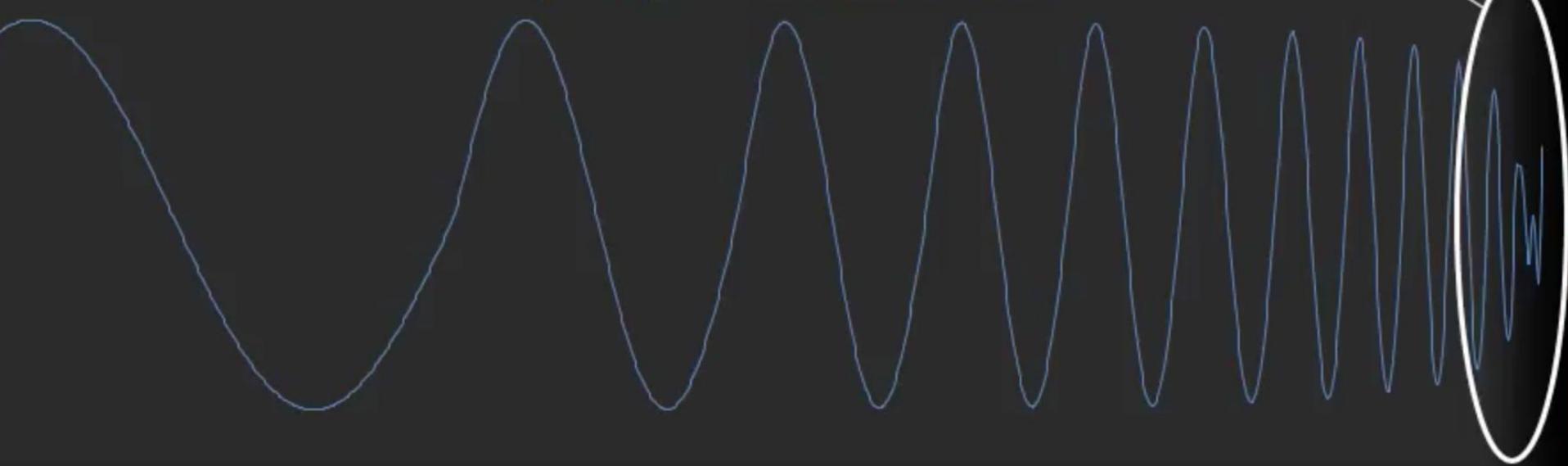


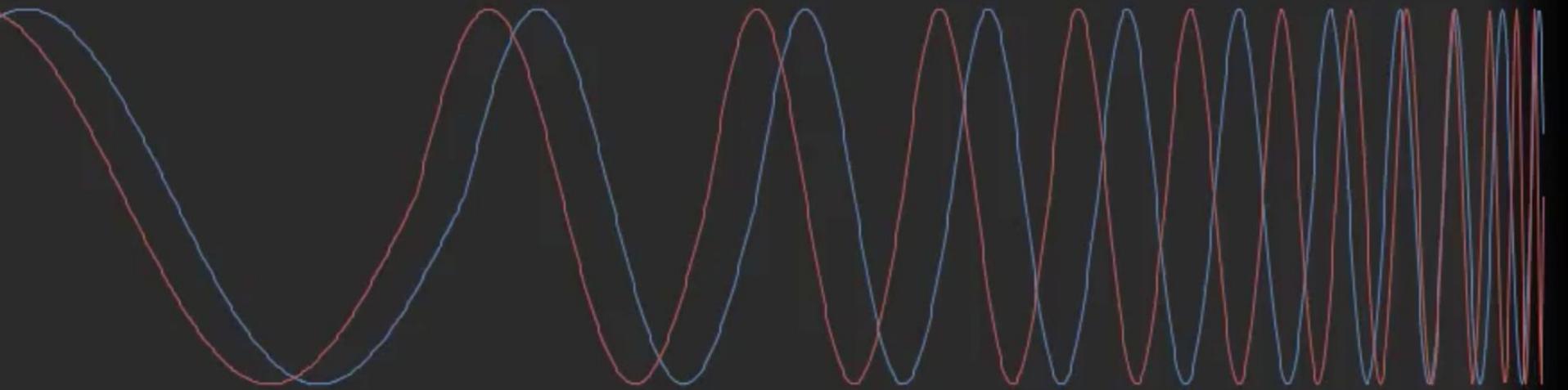




**Distorted area**

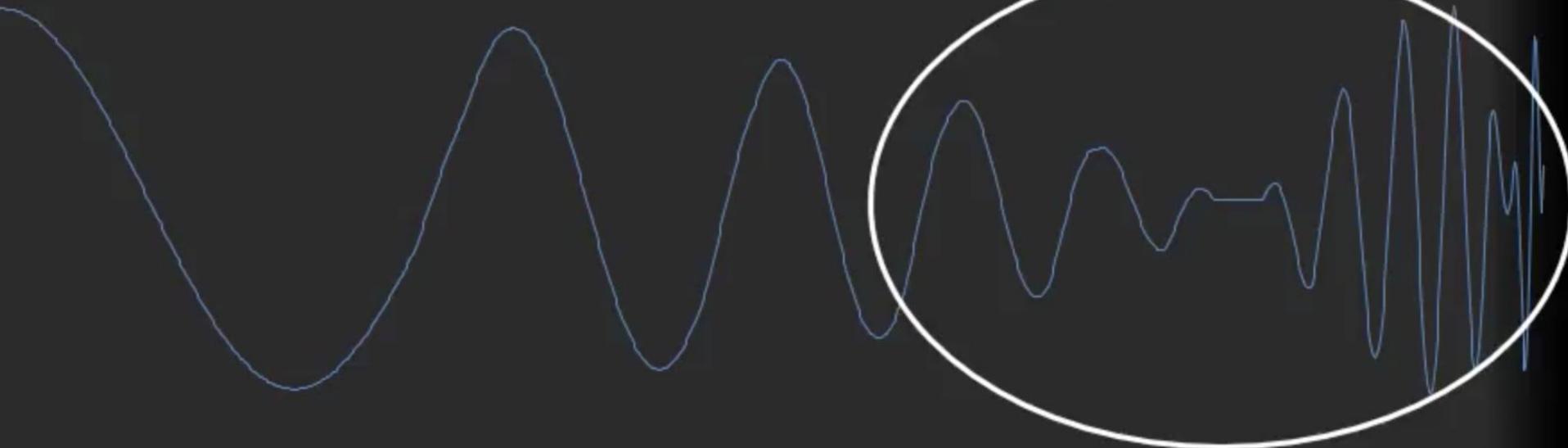
**Tiny Temporal Shift Summation**

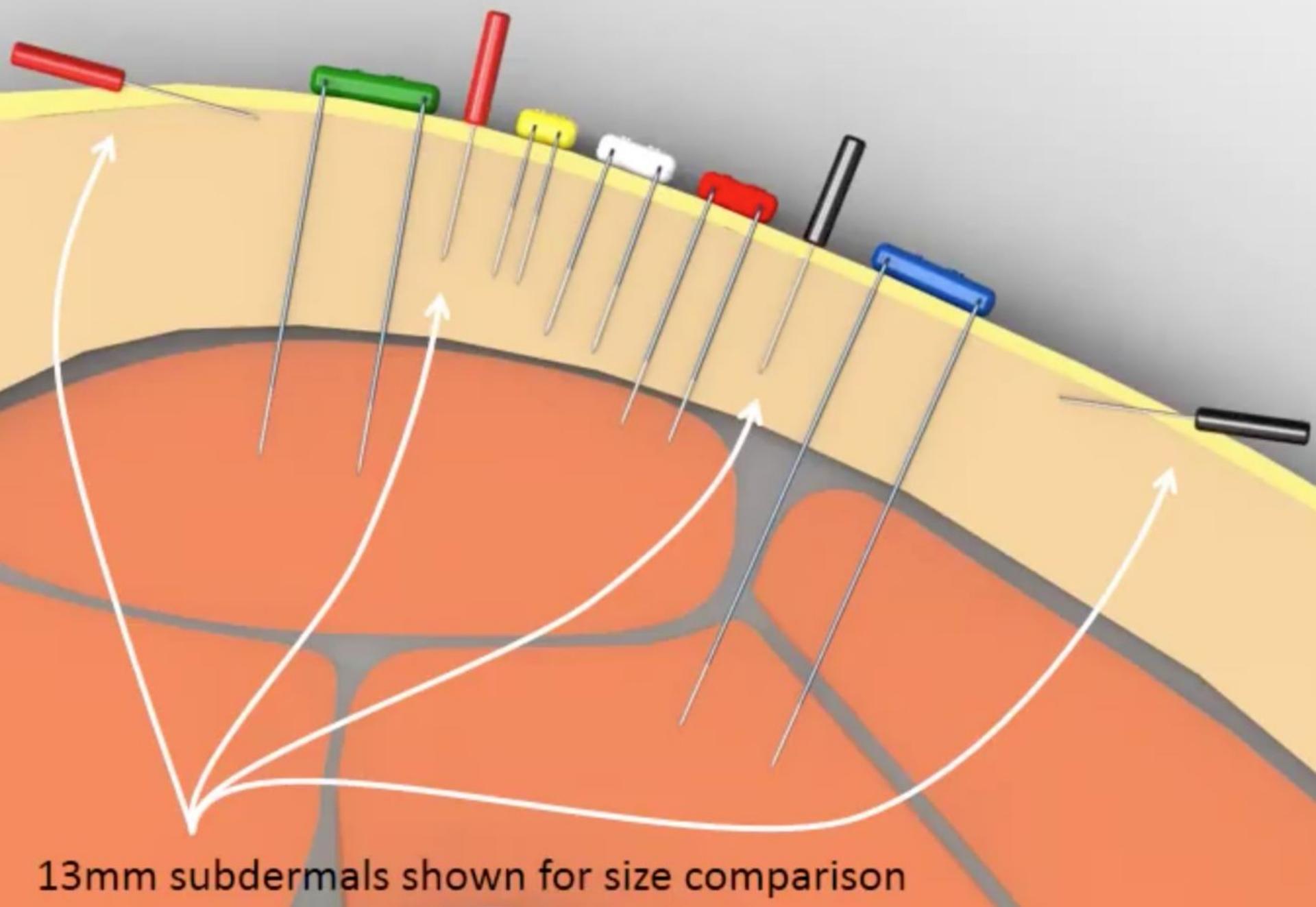


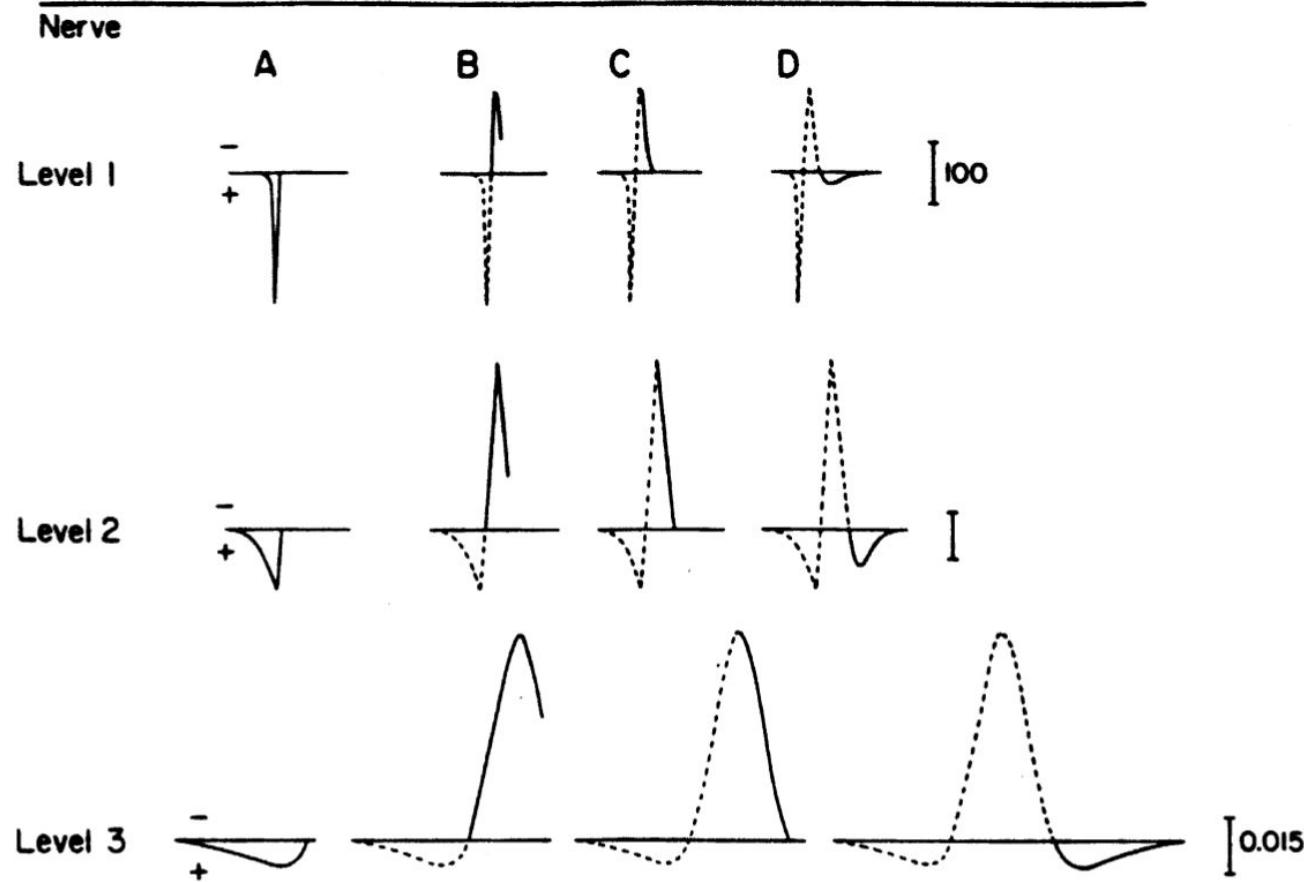
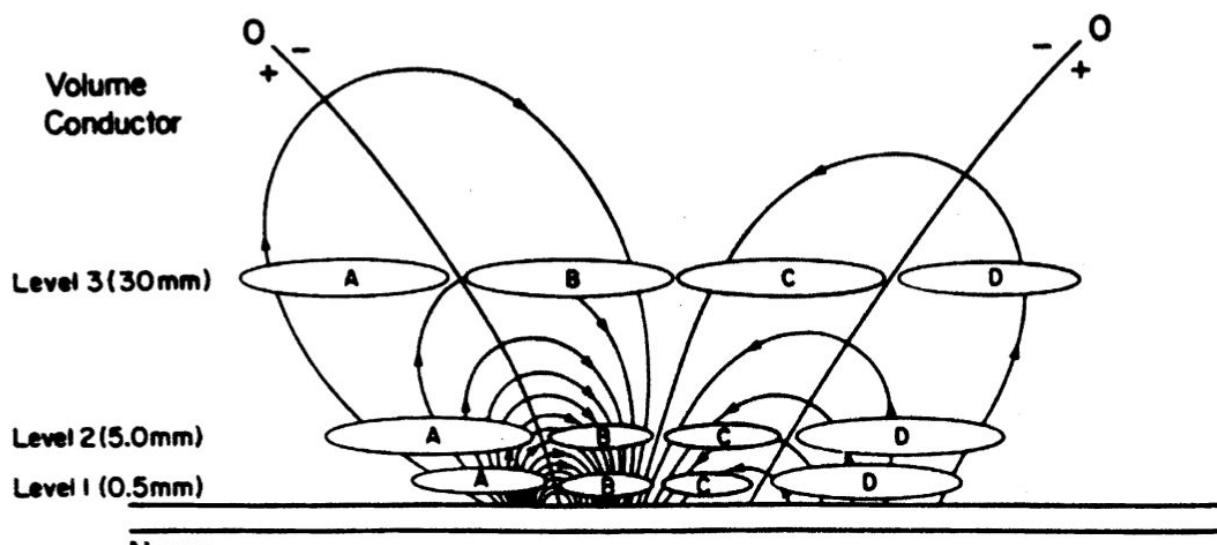


**Distorted area**

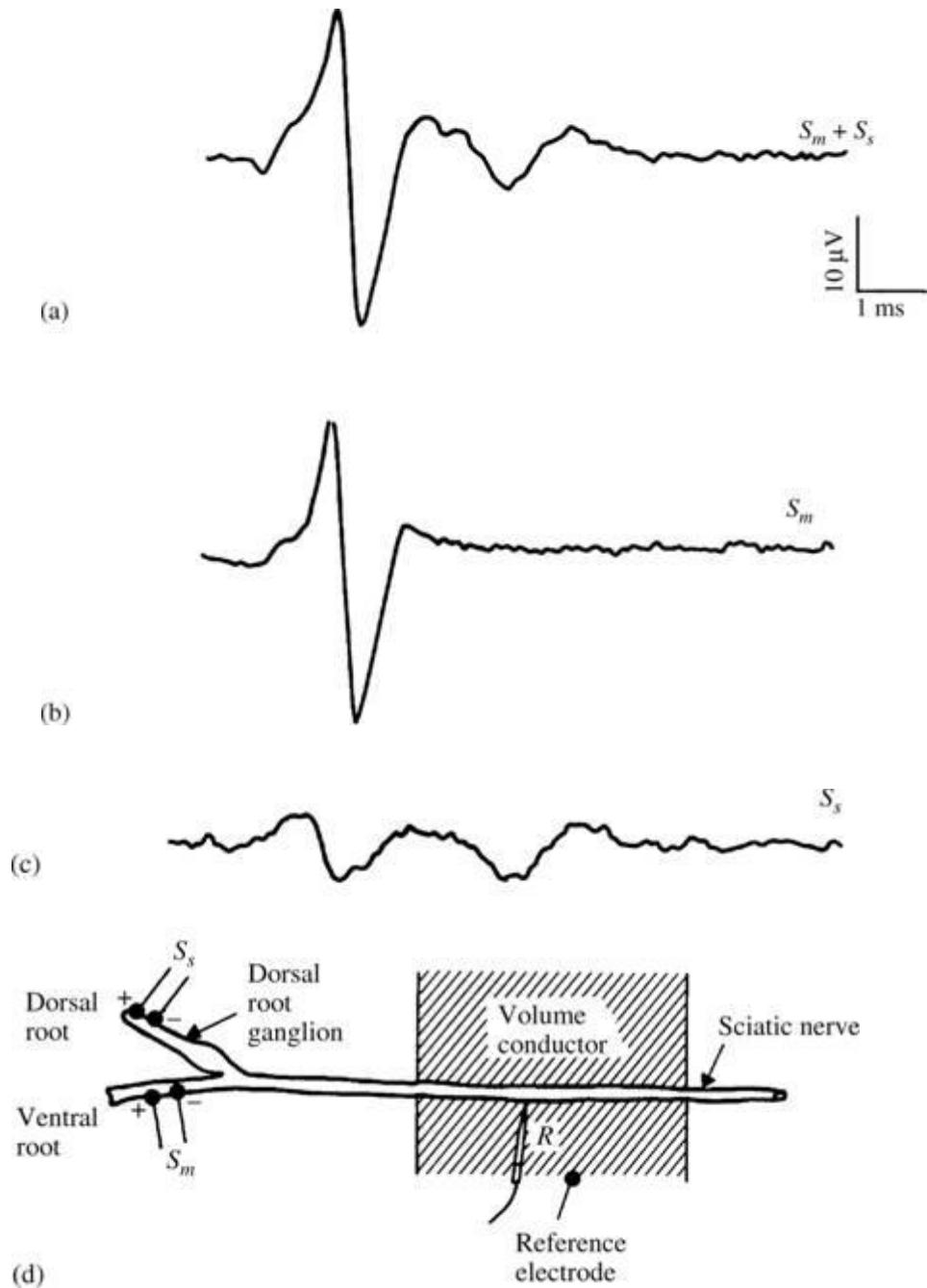
**Large Temporal Shift Summation**

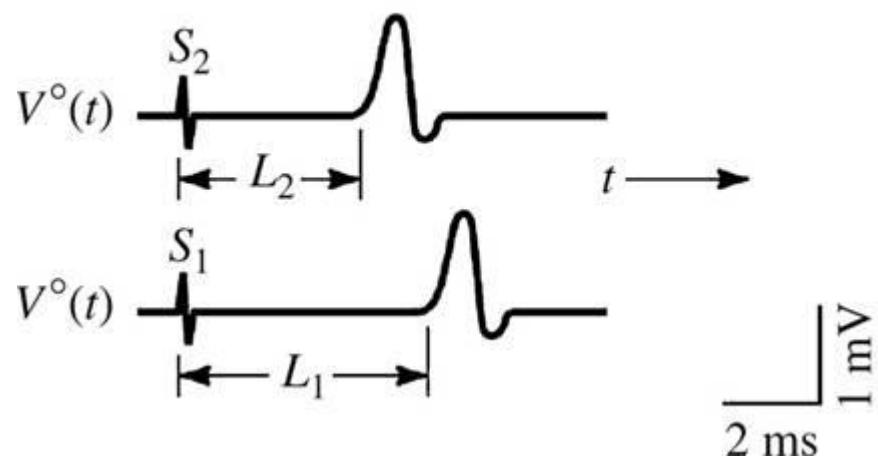
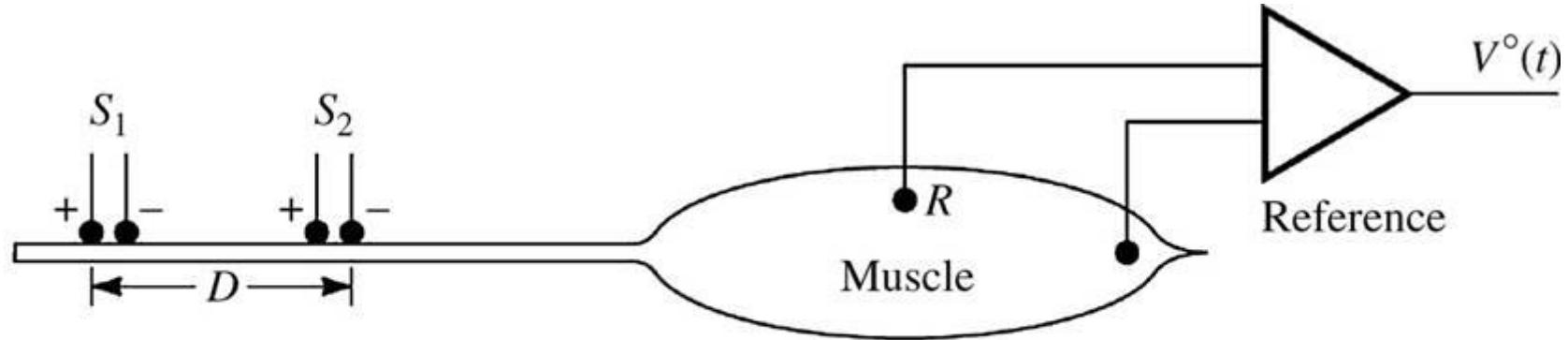






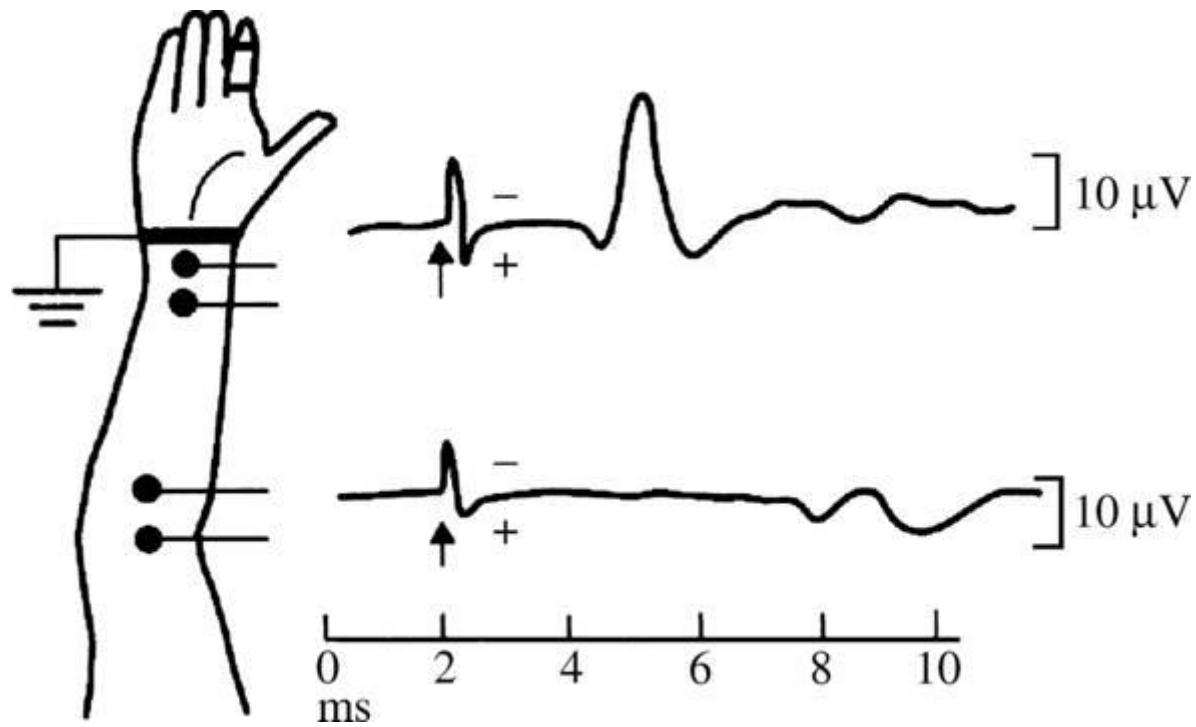
**Figure 4.5**  
**Extracellular field potentials (average of 128 responses) were recorded at the surface of an active (1 mm-diameter) frog sciatic nerve in an extensive volume conductor. The potential was recorded with (a) both motor and sensory components excited ( $S_m + S_s$ ), (b) only motor nerve components excited ( $S_m$ ), and (c) only sensory nerve components excited ( $S_s$ ).**



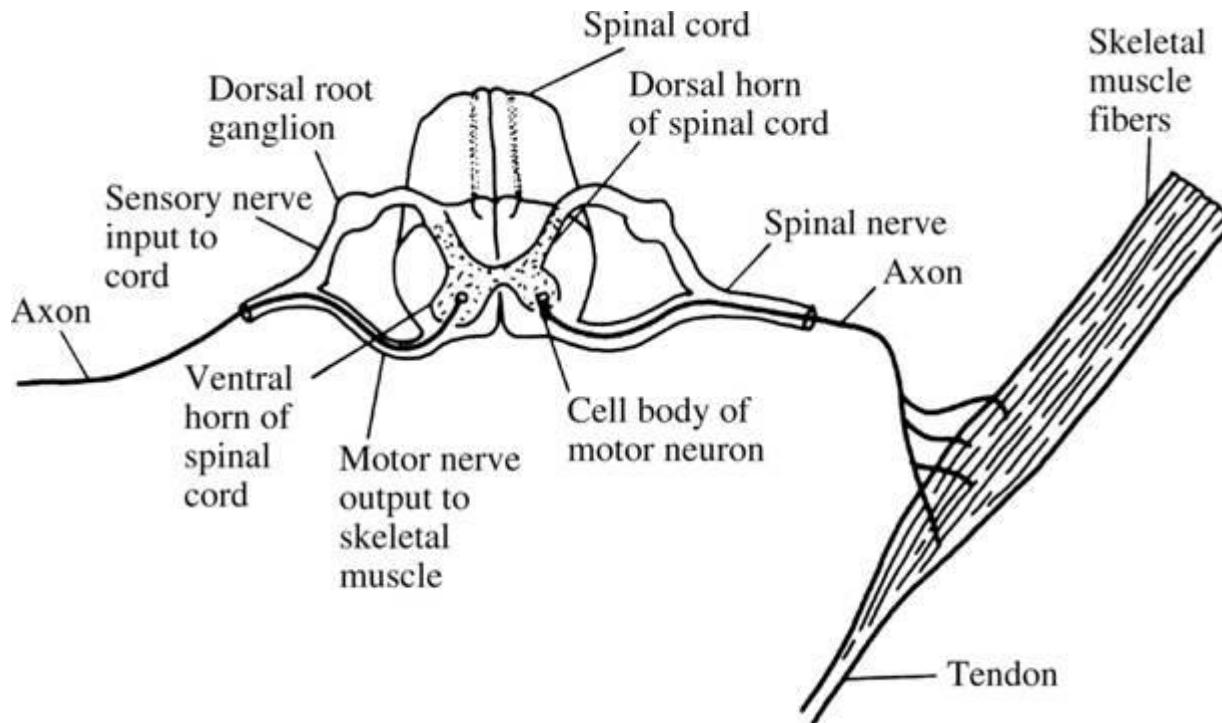


$$\text{Velocity } u = \frac{D}{L_1 - L_2}$$

**Figure 4.7 Measurement of neural conduction velocity via measurement of latency of evoked electrical response in muscle. The nerve was stimulated at two different sites a known distance  $D$  apart.**

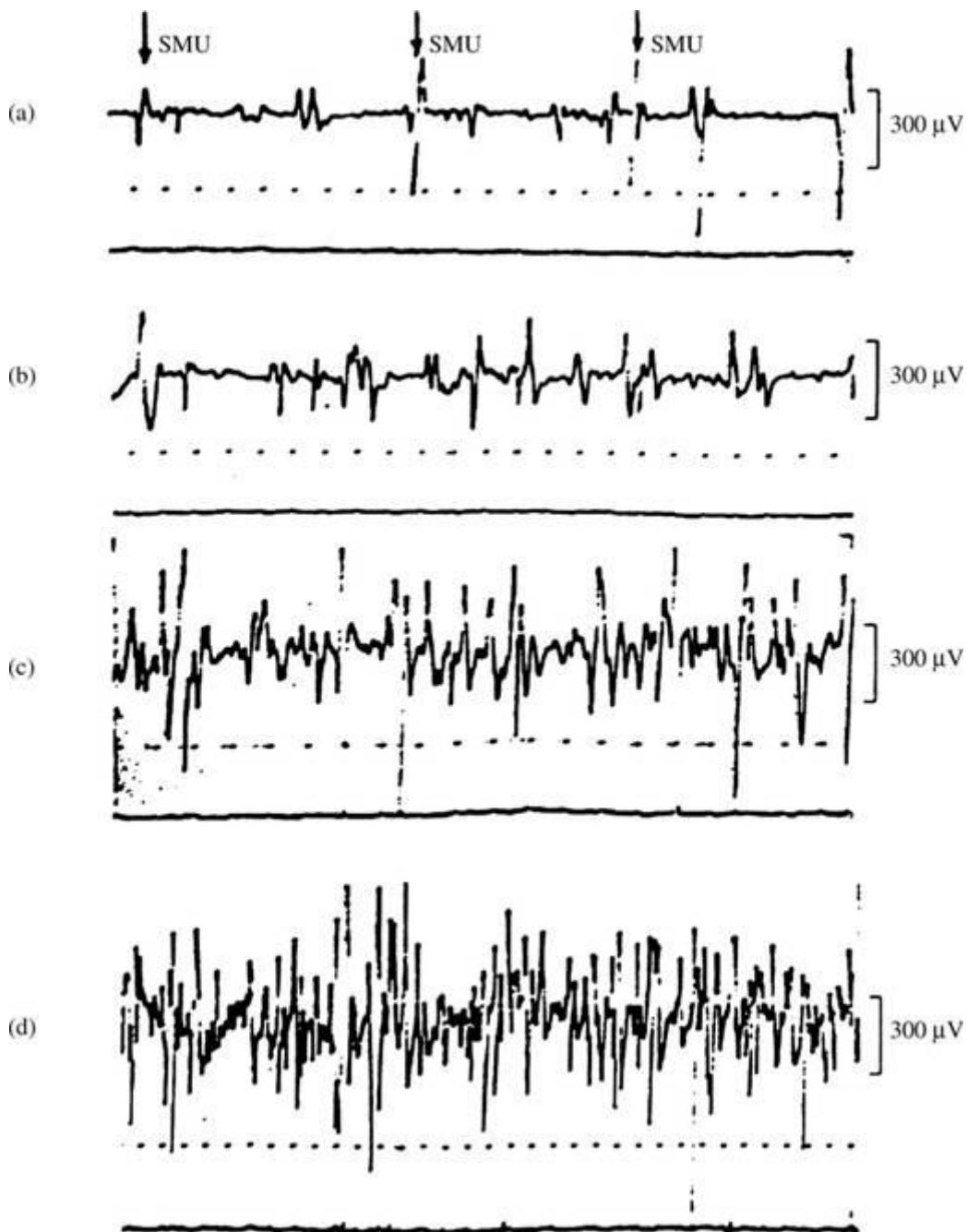


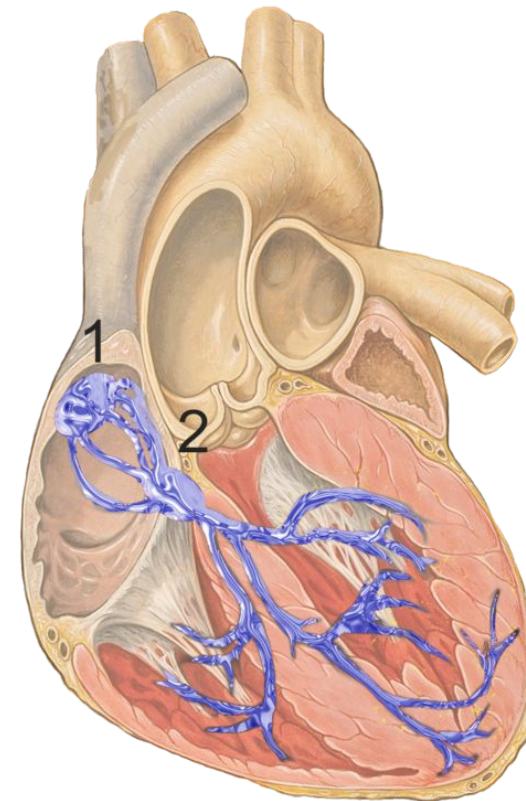
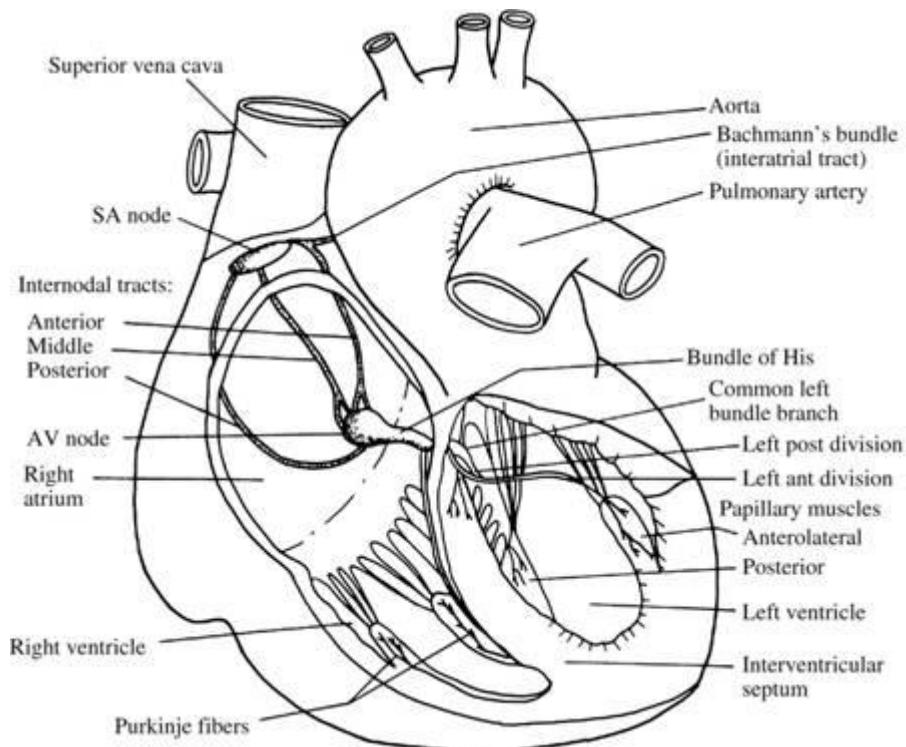
**Figure 4.8** Sensory nerve action potentials evoked from median nerve of a healthy subject at elbow and wrist after stimulation of index finger with ring electrodes. The potential at the wrist is triphasic and of much larger magnitude than the delayed potential recorded at the elbow. Considering the median nerve to be of the same size and shape at the elbow as at the wrist, we find that the difference in magnitude and waveshape of the potentials is due to the size of the volume conductor at each location and the radial distance of the measurement point from the neural source. (From J. A. R. Lenman and A. E. Ritchie, *Clinical Electromyography*, 2nd ed., Philadelphia: Lippincott, 1977; reproduced by permission of the authors.)



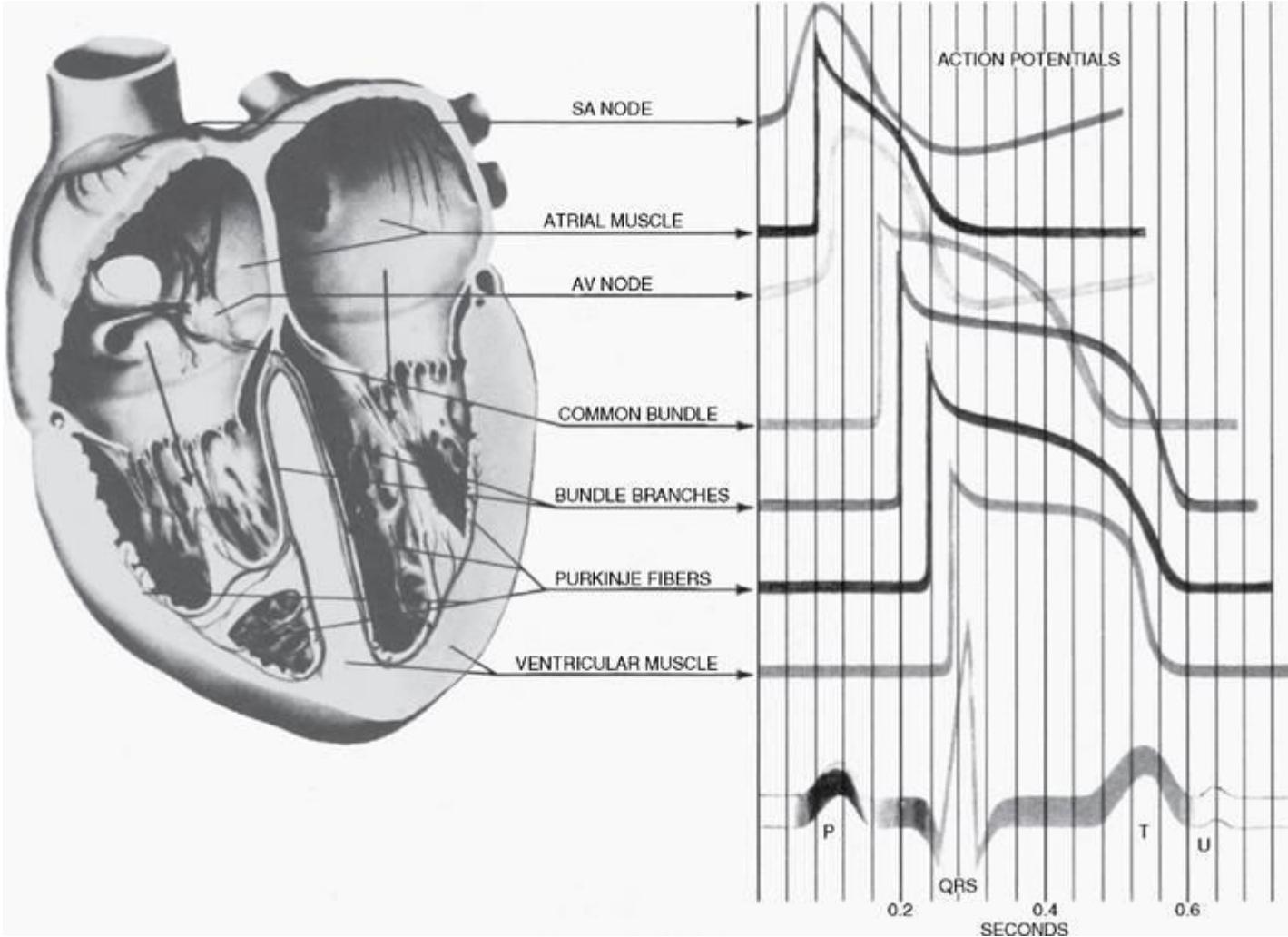
**Figure 4.10** Diagram of a single motor unit (SMU), which consists of a single motoneuron and the group of skeletal muscle fibers that it innervates. Length transducers [muscle spindles, Figure 4.6(a)] in the muscle activate sensory nerve fibers whose cell bodies are located in the dorsal root ganglion. These bipolar neurons send axonal projections to the spinal cord that divide into a descending and an ascending branch. The descending branch enters into a simple reflex arc with the motor neuron, whereas the ascending branch conveys information regarding current muscle length to higher centers in the CNS via ascending nerve fiber tracts in the spinal cord and brain stem. These ascending pathways are discussed in Section 4.8.

**Figure 4.11 Motor unit action potentials from normal dorsal interosseus muscle during progressively more powerful contractions. In the interference pattern (c), individual units can no longer be clearly distinguished, (d) Interference pattern during very strong muscular contraction. Time scale is 10 ms per dot. (From J. A. R. Lenman and A. E. Ritchie, *Clinical Electromyography*, 2nd ed., Philadelphia: Lippincott, 1977; reproduced by permission of the authors.)**

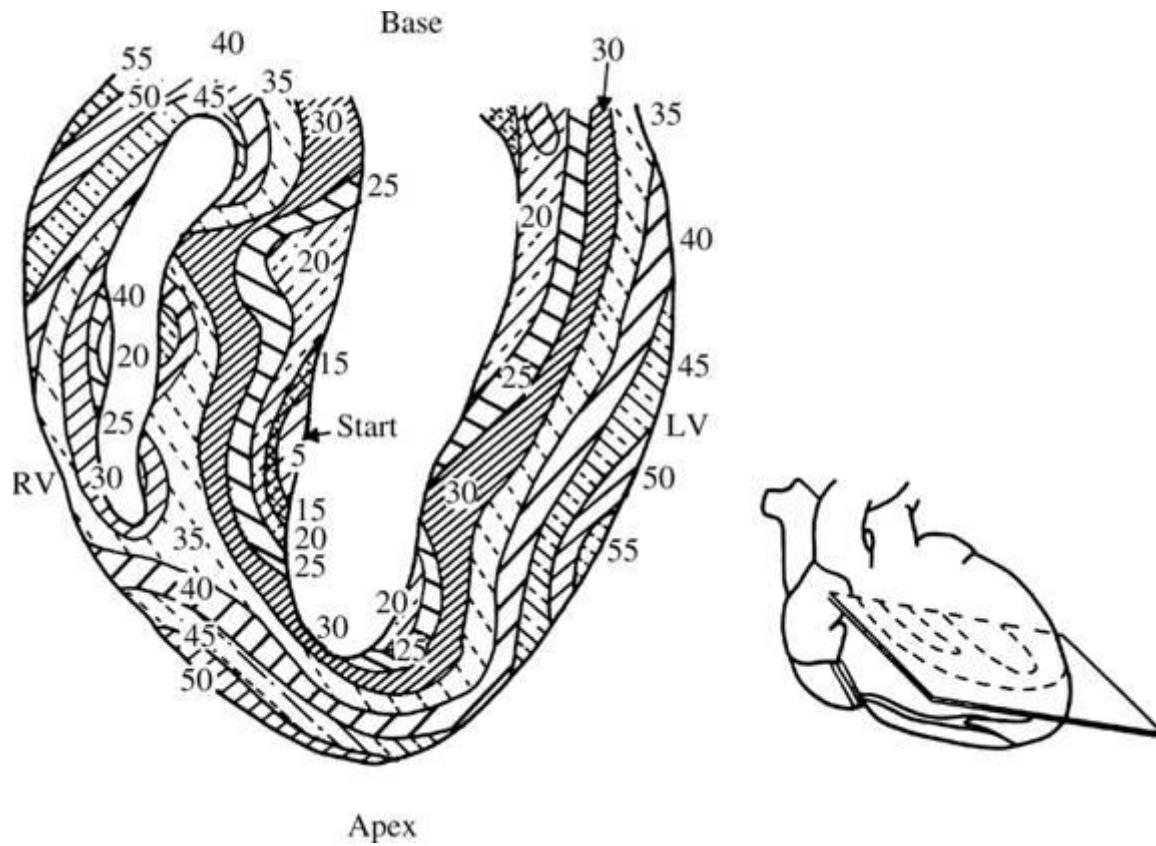




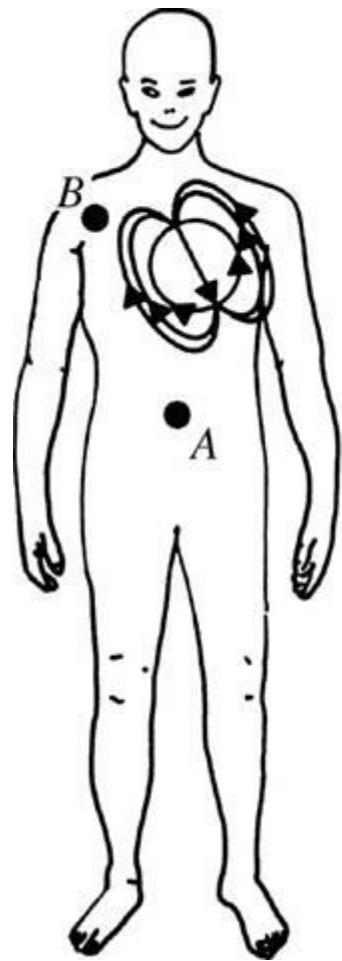
**Figure 4.12 Distribution of specialized conductive tissues in the atria and ventricles, showing the impulse-forming and conduction system of the heart. The rhythmic cardiac impulse originates in pacemaking cells in the sinoatrial (SA) node, located at the junction of the superior vena cava and the right atrium. Note the three specialized pathways (anterior, middle, and posterior internodal tracts) between the SA and atrioventricular (AV) nodes. Bachmann's bundle (interatrial tract) comes off the anterior internodal tract leading to the left atrium. The impulse passes from the SA node in an organized manner through specialized conducting tracts in the atria to activate first the right and then the left atrium. Passage of the impulse is delayed at the AV node before it continues into the bundle of His, the right bundle branch, the common left bundle branch, the anterior and posterior divisions of the left bundle branch, and the Purkinje network. The right bundle branch runs along the right side of the interventricular septum to the apex of the right ventricle before it gives off significant branches. The left common bundle crosses to the left side of the septum and splits into the anterior division (which is thin and long and goes under the aortic valve in the outflow tract to the anterolateral papillary muscle) and the posterior division (which is wide and short and goes to the posterior papillary muscle lying in the inflow tract). (From B. S. Lipman, E. Massie, and R. E. Kleiger, *Clinical Scalar Electrocardiography*. Copyright © 1972 by Yearbook Medical Publishers, Inc., Chicago. Used with permission.)**



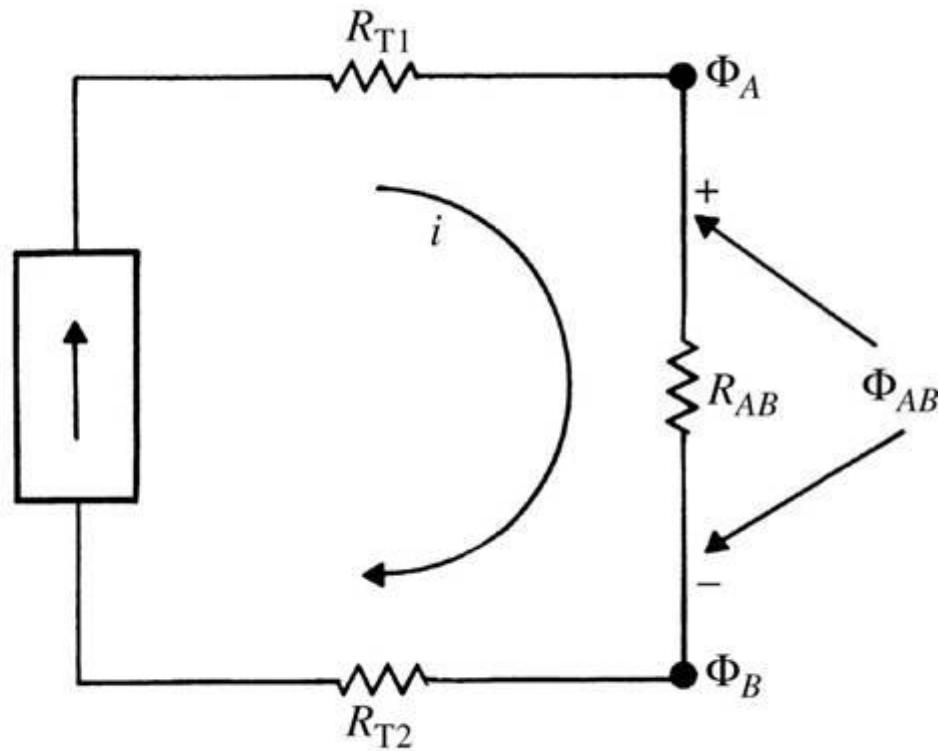
**Figure 4.13 Representative electric activity from various regions of the heart**  
The bottom trace is a scalar ECG, which has a typical QRS amplitude of 1 to 3 mV. (© Copyright 1969 CIBA Pharmaceutical Company, Division of CIBA-GEIGY Corp. Reproduced, with permission, from *The Ciba Collection of Medical Illustrations*, by Frank H. Netter, M.D. All rights reserved.)



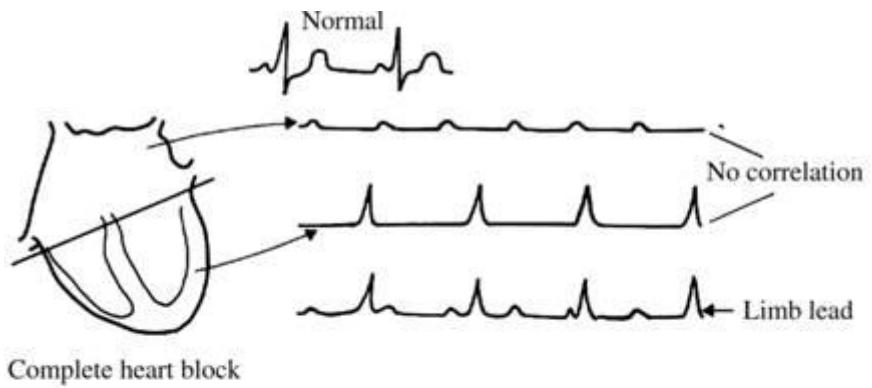
**Figure 4.15 Isochronous lines of ventricular activation of the human heart**  
 Note the nearly closed activation surface at 30 ms into the QRS complex.  
 (Modified from “The Biophysical Basis for Electrocardiography,” by R. Plonsey, in *CRC Critical Reviews in Bioengineering*, 1, 1, p. 5, 1971, © The Chemical Rubber Co., 1971. Used by permission of The Chemical Rubber Co. Based on data by D. Durrer et al., "Total Excitation of the Isolated Human Heart," 1970, *Circulation*, 41, 899–912, by permission of the American Heart Association, Inc.)



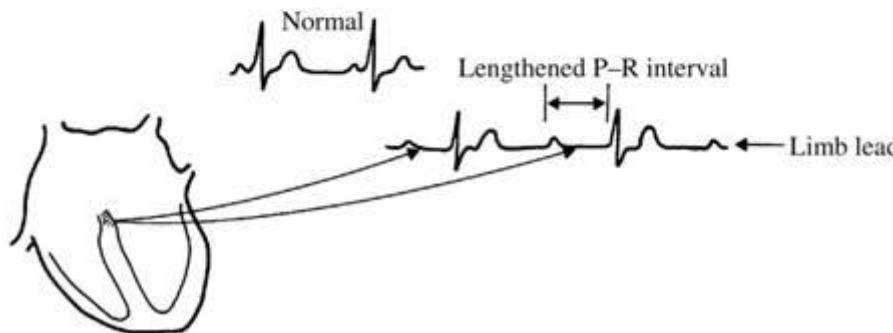
Equivalent cardiac generator



**Figure 4.16 The electrocardiographic problem** Points *A* and *B* are arbitrary observation points on the torso,  $R_{AB}$  is the resistance between them, and  $R_{T1}$ ,  $R_{T2}$  are lumped thoracic medium resistances. The bipolar ECG scalar lead voltage  $\Phi_{AB} = \Phi_A - \Phi_B$ , where these voltages are both measured with respect to an indifferent reference potential.

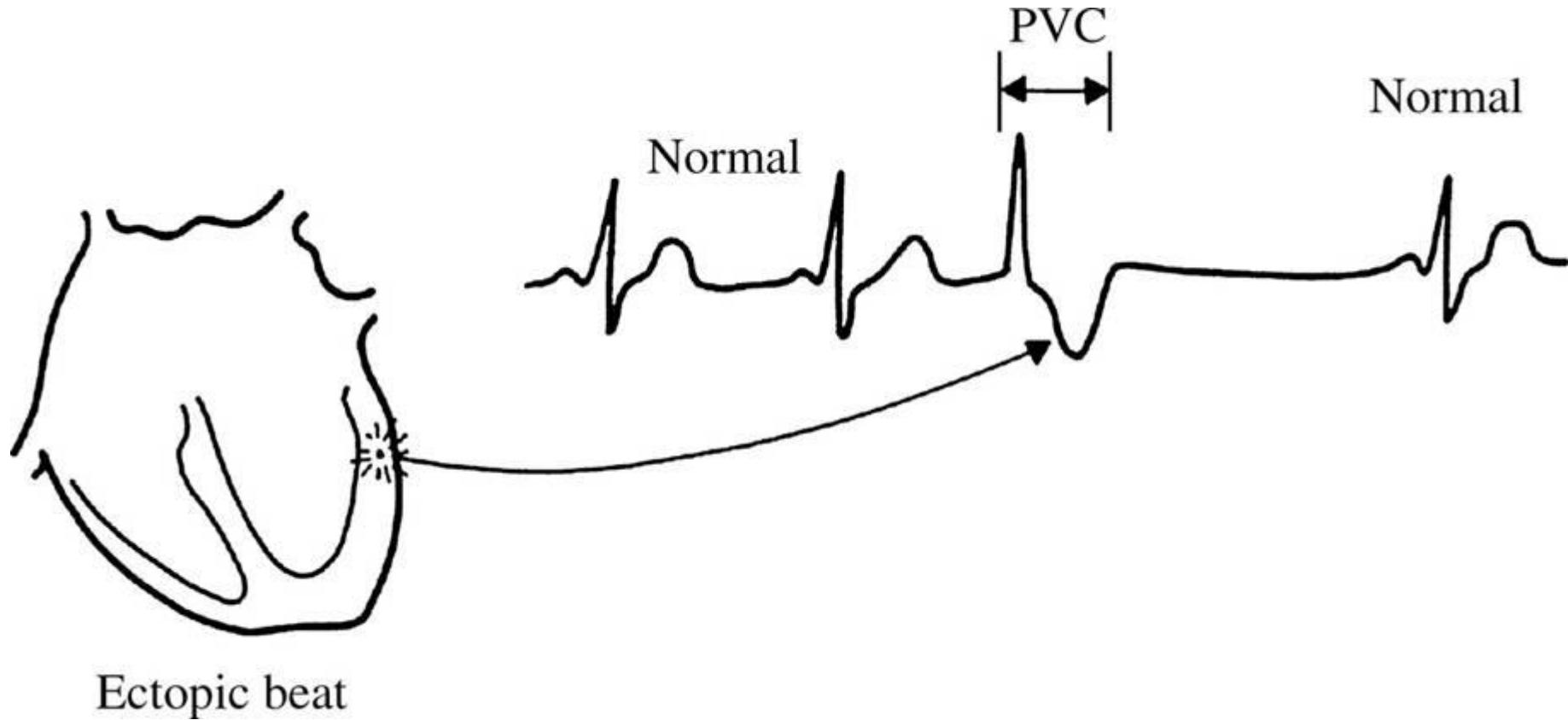


(a)

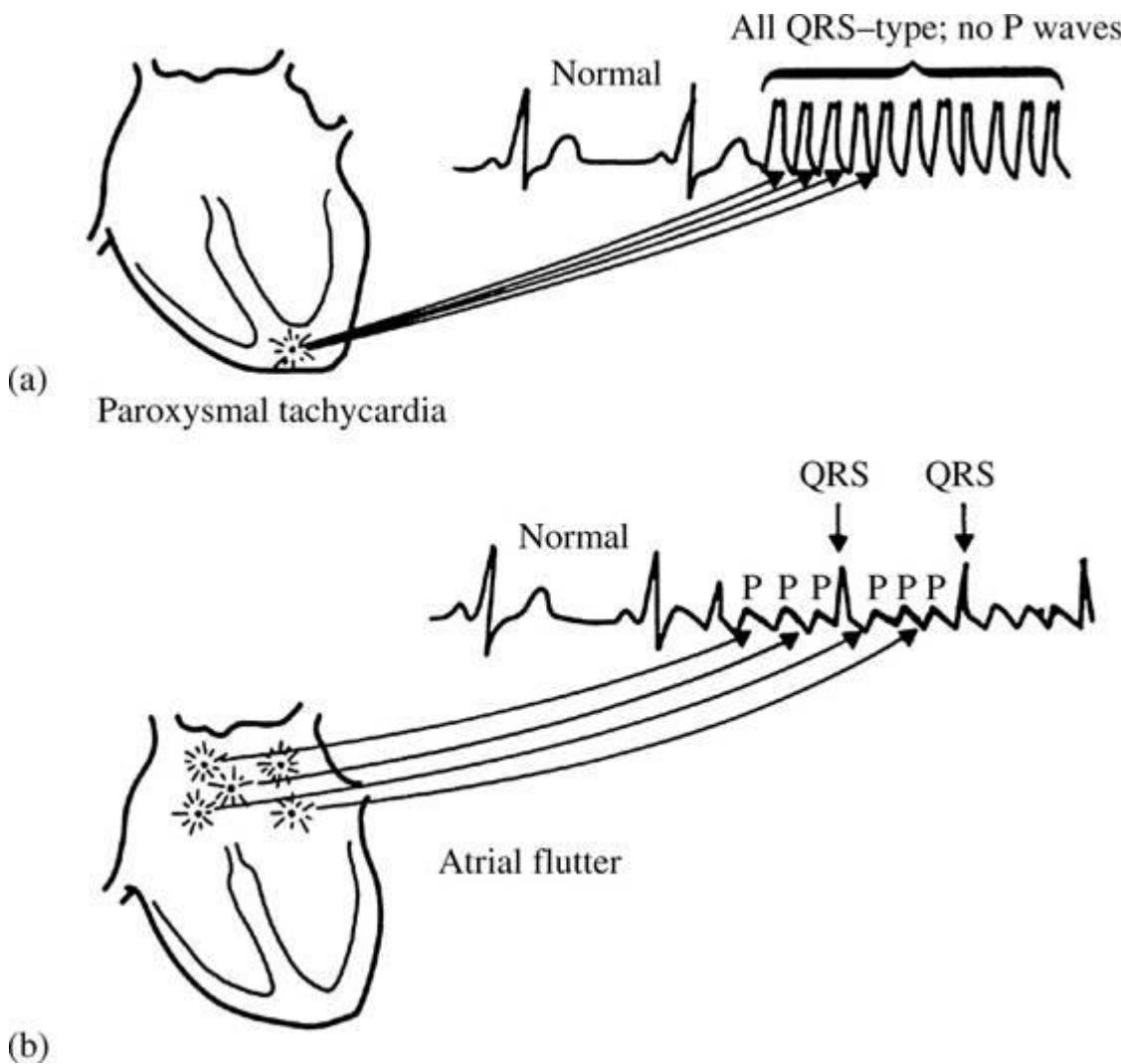


(b)

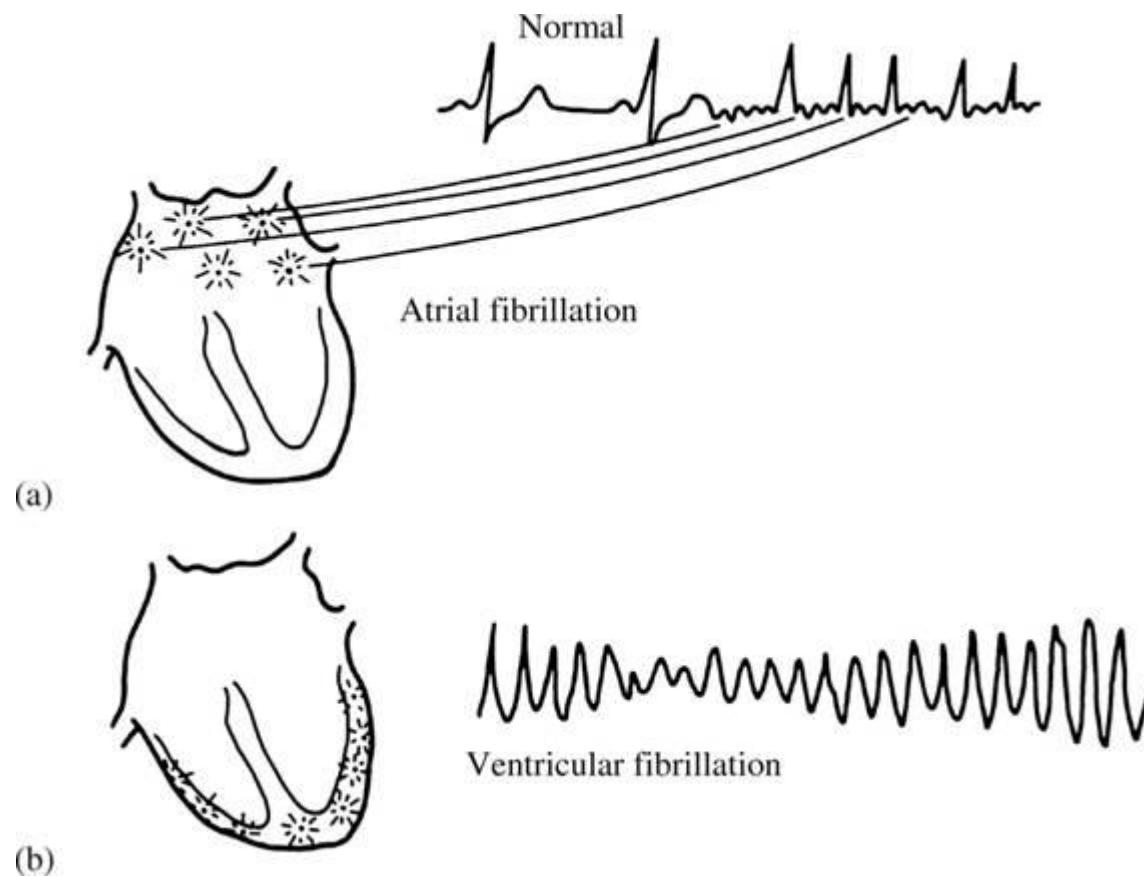
**Figure 4.17 Atrioventricular block (a) Complete heart block.** Cells in the AV node are dead and activity cannot pass from atria to ventricles. Atria and ventricles beat independently, ventricles being driven by an ectopic (other-than-normal) pacemaker, (b) AV block wherein the node is diseased (examples include rheumatic heart disease and viral infections of the heart). Although each wave from the atria reaches the ventricles, the AV nodal delay is greatly increased. This is first-degree heart block. (Adapted from Brendan Phibbs, *The Human Heart*, 3rd ed., St. Louis: The C.V. Mosby Company, 1975.)



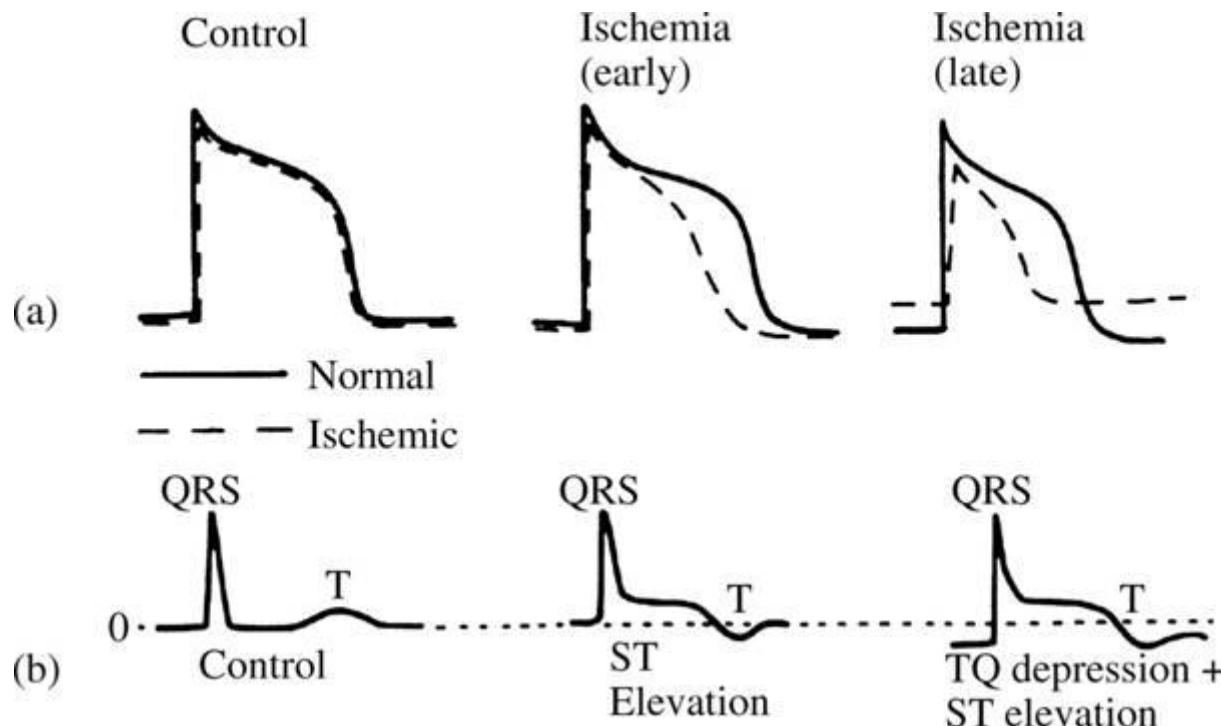
**Figure 4.18** Normal ECG followed by an ectopic beat An irritable focus, or ectopic pacemaker, within the ventricle or specialized conduction system may discharge, producing an extra beat, or extrasystole, that interrupts the normal rhythm. This extrasystole is also referred to as a premature ventricular contraction (PVC). (Adapted from Brendan Phibbs, *The Human Heart*, 3rd ed., St. Louis: The C.V. Mosby Company, 1975.)



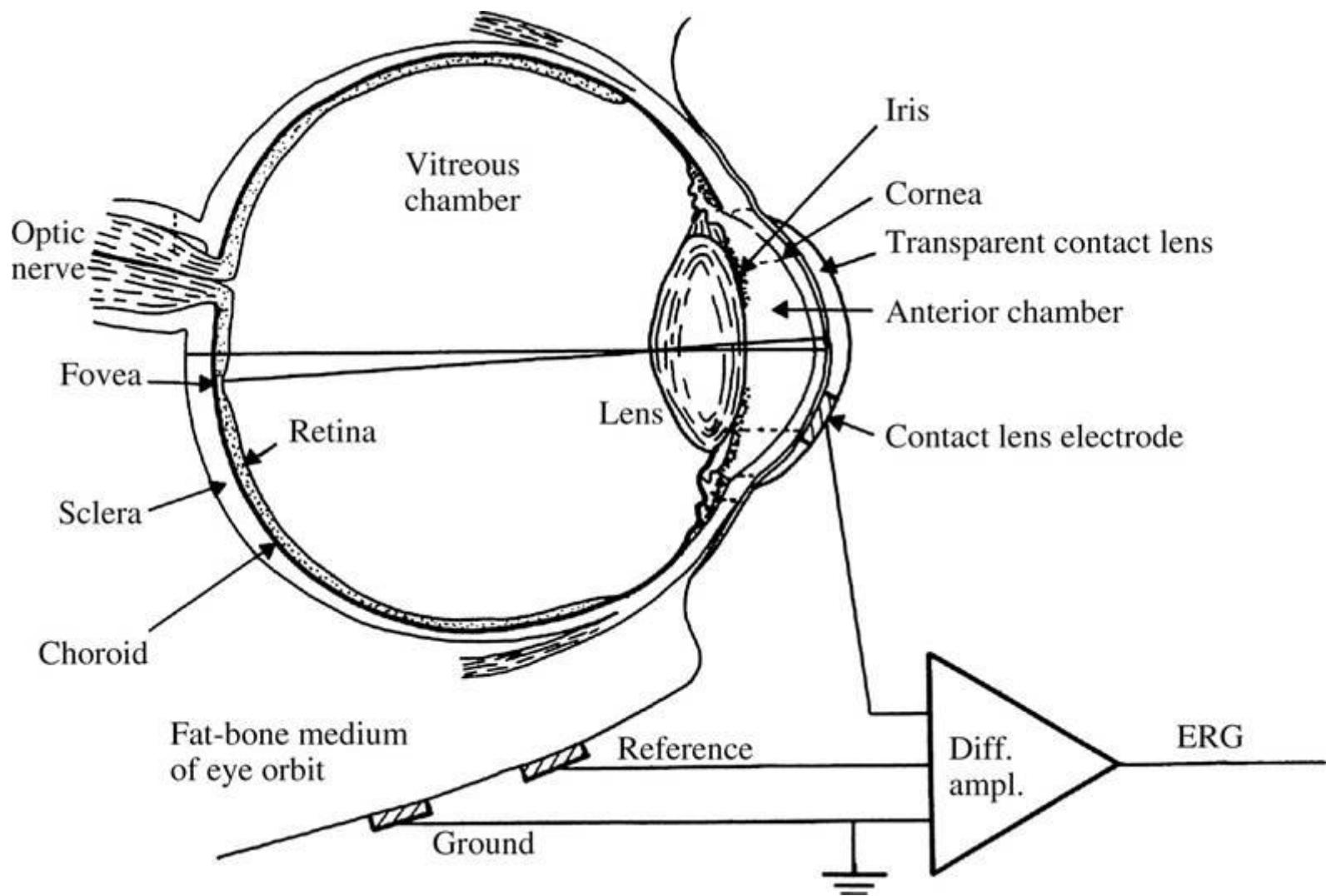
**Figure 4.19 (a) Paroxysmal tachycardia.** An ectopic focus may repetitively discharge at a rapid regular rate for minutes, hours, or even days, (b) **Atrial flutter.** The atria begin a very rapid, perfectly regular “flapping” movement, beating at rates of 200 to 300 beats/min. (Adapted from Brendan Phibbs, *The Human Heart*, 3rd ed., St. Louis: The C.V. Mosby Company, 1975.)



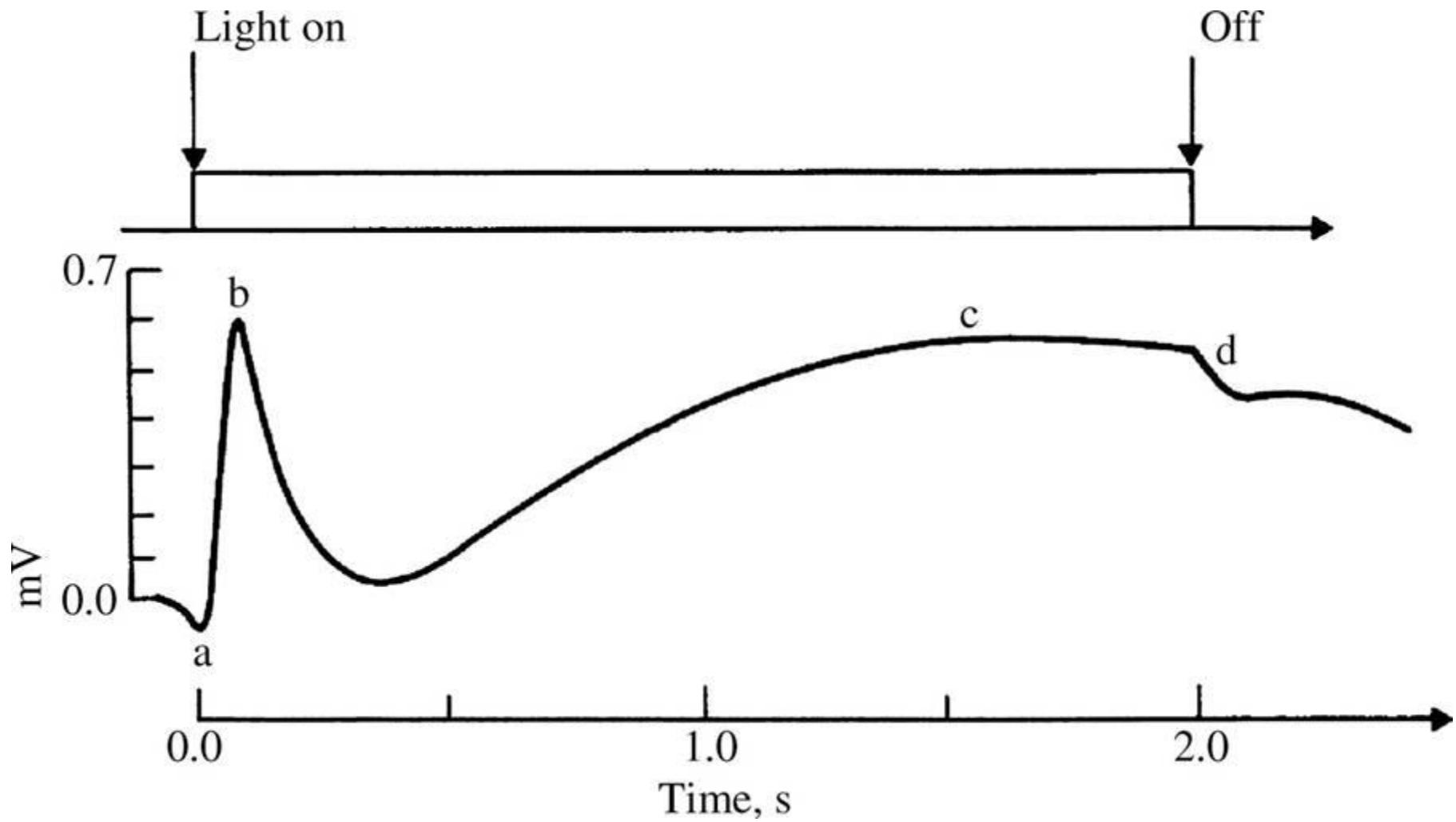
**Figure 4.20** (a) Atrial fibrillation. The atria stop their regular beat and begin a feeble, uncoordinated twitching. Concomitantly, low-amplitude, irregular waves appear in the ECG, as shown. This type of recording can be clearly distinguished from the very regular ECG waveform containing atrial flutter, (b) Ventricular fibrillation. Mechanically the ventricles twitch in a feeble, uncoordinated fashion with no blood being pumped from the heart. The ECG is likewise very uncoordinated, as shown. (Adapted from Brendan Phibbs, *The Human Heart*, 3rd ed., St. Louis: The C.V. Mosby Company, 1975.)



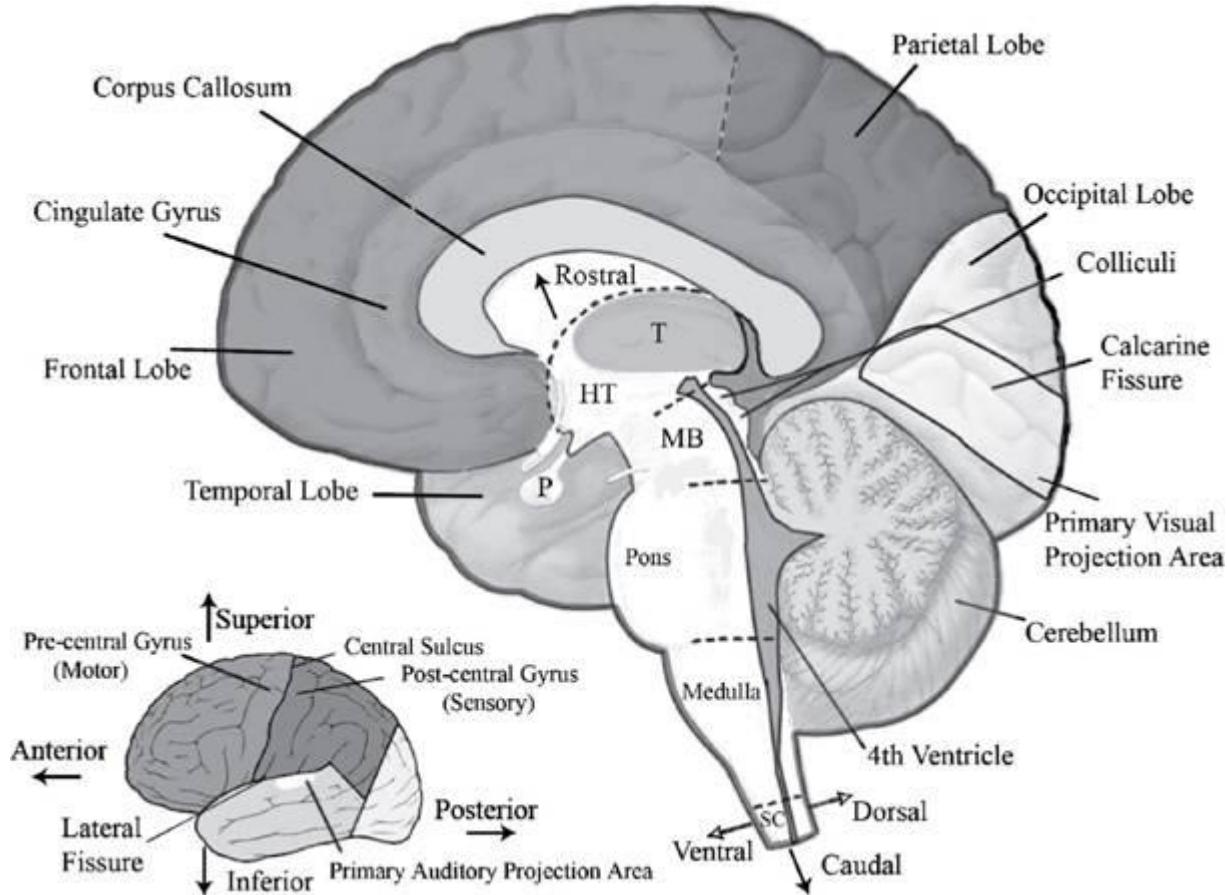
**Figure 4.21 (a)** Action potentials recorded from normal (solid lines) and ischemic (dashed lines) myocardium in a dog. Control is before coronary occlusion, (b) During the control period prior to coronary occlusion, there is no ECG S-T segment shift; after ischemia, there is such a shift. (From Andrew G. Wallace, “Electrophysiology of the Myocardium,” in Clinical Cardiopulmonary Physiology, 3rd ed. New York: Grune & Stratton, 1969; used with permission of Grune & Stratton. Based on data by W. E. Sampson and H. M. Scher, “Mechanism of S-T Segment Alteration During Acute Myocardial Injury,” 1960, Circulation Research, 8, by permission of The American Heart Association.)



**Figure 4.22** The transparent contact lens contains one electrode, shown here on horizontal section of the right eye. Reference electrode is placed on the right temple.



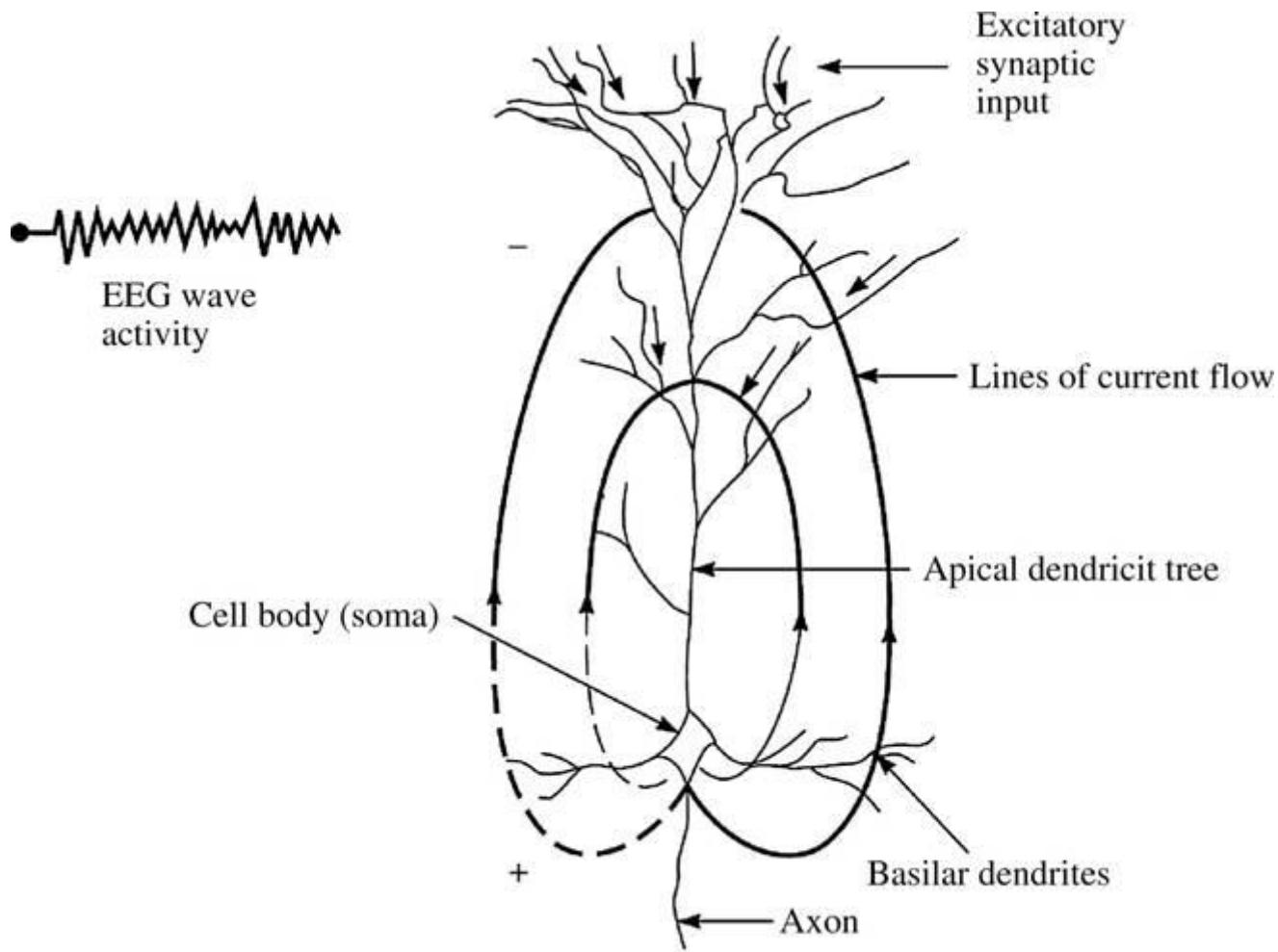
**Figure 4.23 Vertebrate electroretinogram**



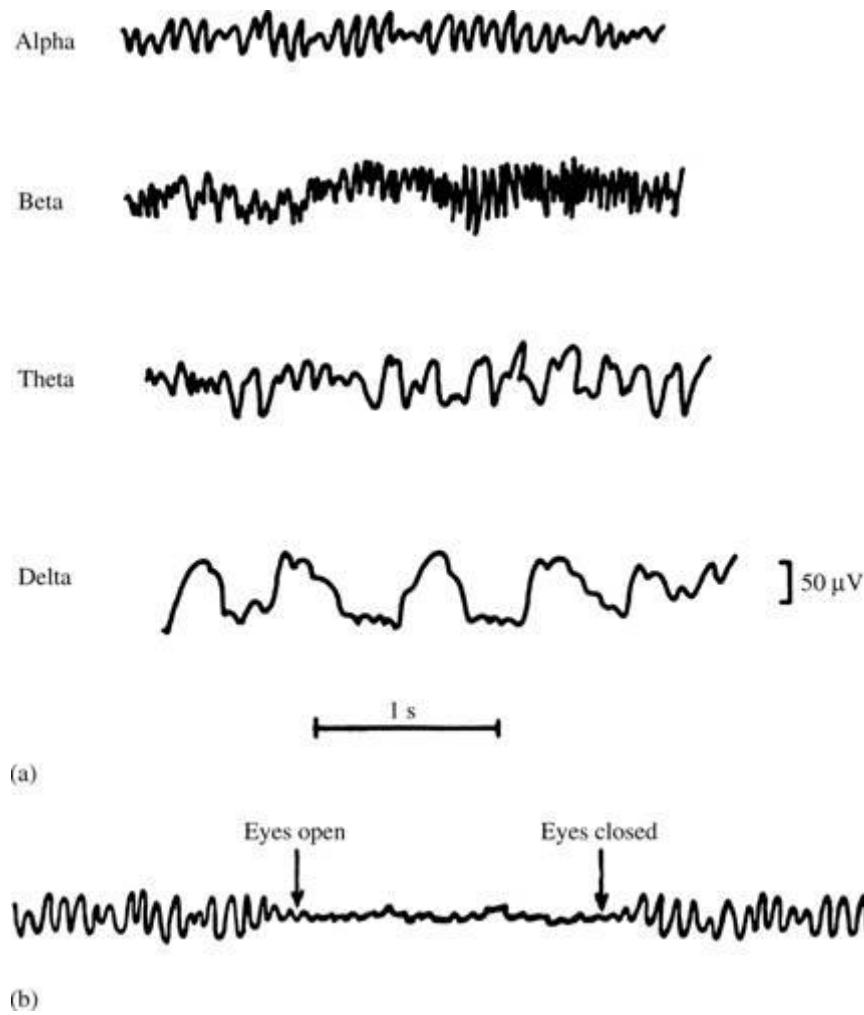
**Figure 4.24 Anatomical relationship of brainstem structures (medulla oblongata, pons, midbrain, and diencephalon (thalamus and hypothalamus)) to the cerebrum and cerebellum. General anatomic directions of orientation in the nervous system are superimposed on the diagrams. Here the terms *rostral* (toward head), *caudal* (toward tail), *dorsal* (back), and *ventral* (front) are associated with the brainstem; remaining terms are associated with the cerebrum. The terms *medial* and *lateral* imply nearness and remoteness, respectively, to or from the central midline axis of the brain.**

**Symbols:** T (thalamus); HT (hypothalamus); MB (midbrain); SC (spinal cord); P pituitary gland.

Adapted from John H. Martin, *Neuroanatomy: Text and Atlas* 2nd ed., 1996, pp 14–15, Appleton and Lange, a Simon and Schuster Company. Reproduced with permission of The McGraw-Hill Companies.



**Figure 4.26 Electrogenesis of cortical field potentials for a net excitatory input to the apical dendritic tree of a typical pyramidal cell. For the case of a net inhibitory input, polarity is reversed and the apical region becomes a source (+). Current flow to and from active fluctuating synaptic knobs on the dendrites produces wave-like activity.**



**Figure 4.27 (a) Different types of normal EEG waves, (b) Replacement of alpha rhythm by an asynchronous discharge when patient opens eyes, (c) Representative abnormal EEG waveforms in different types of epilepsy. (From A. C. Guyton, *Structure and Function of the Nervous System*, 2nd ed., Philadelphia: W.B. Saunders, 1972; used with permission.)**



Petit mal



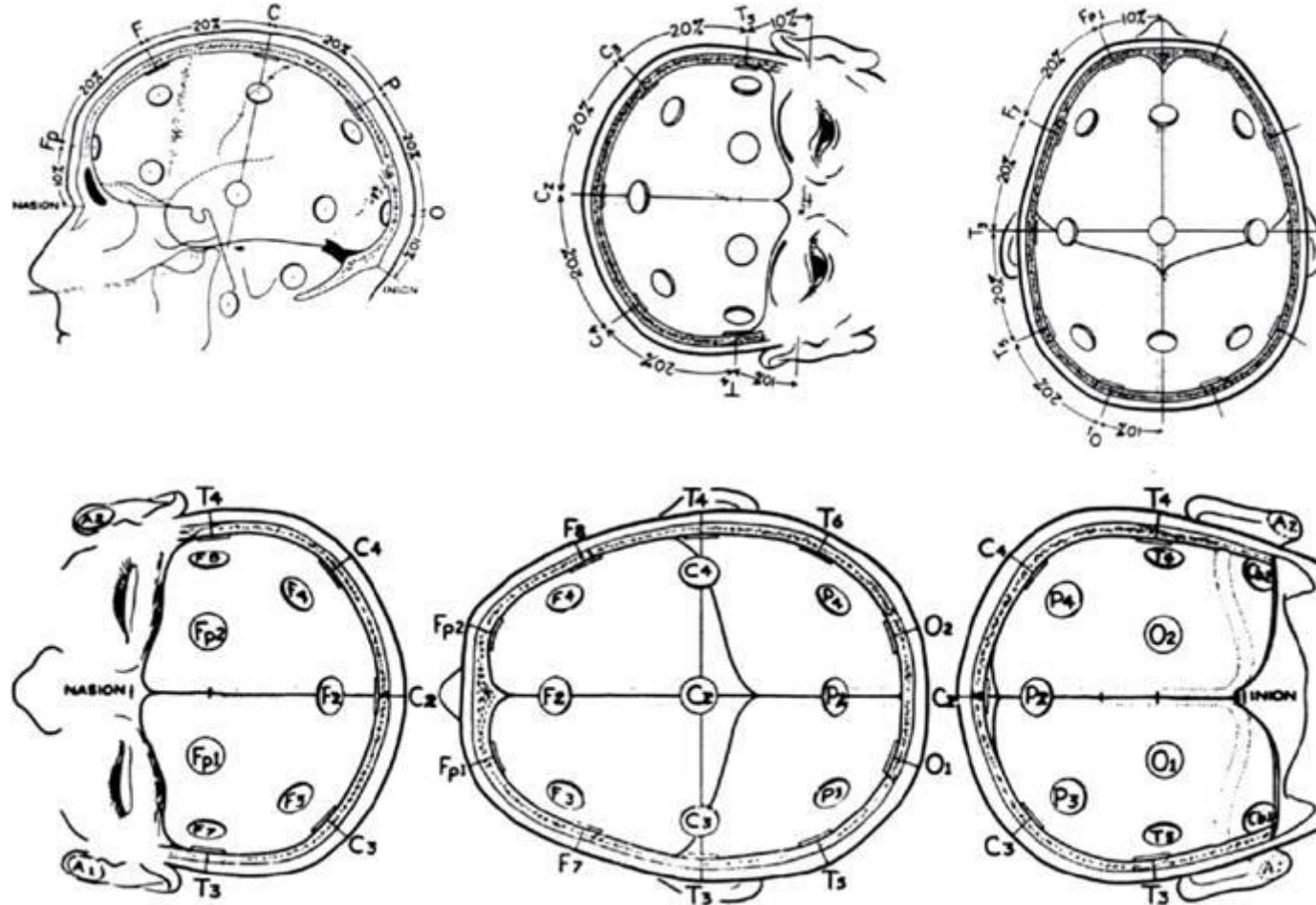
Grand mal epilepsy



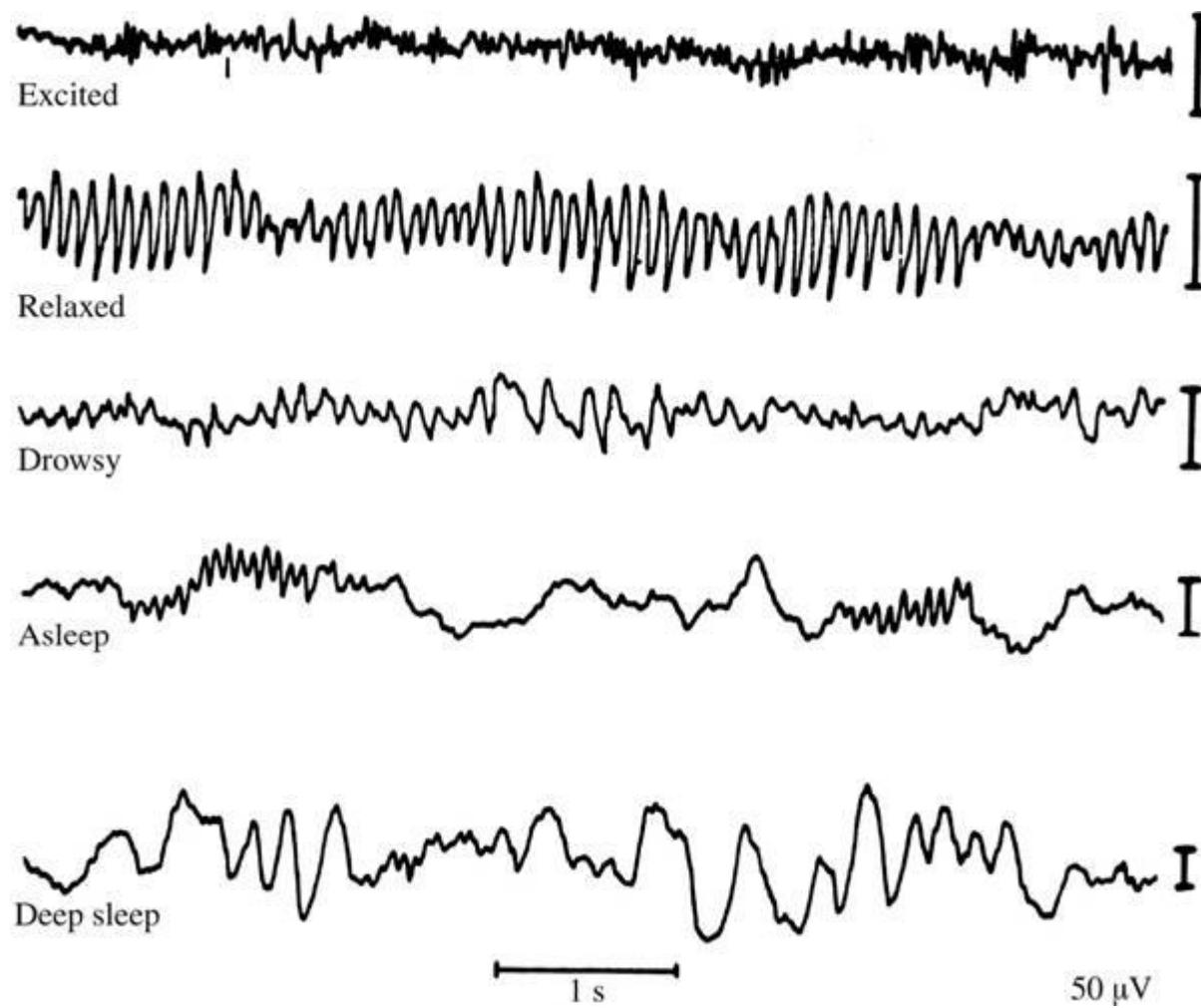
Psychomotor

(c)

**Figure 4.27 (a) Different types of normal EEG waves, (b) Replacement of alpha rhythm by an asynchronous discharge when patient opens eyes, (c) Representative abnormal EEG waveforms in different types of epilepsy.** (From A. C. Guyton, *Structure and Function of the Nervous System*, 2nd ed., Philadelphia: W.B. Saunders, 1972; used with permission.)



**Figure 4.28** The 10–20 electrode system This system is recommended by the International Federation of EEG Societies. (From H. H. Jasper, “The Ten–Twenty Electrode System of the International Federation in Electroencephalography and Clinical Neurophysiology,” *EEG Journal*, 1958, 10 (Appendix), 371–375.)



**Figure 4.29** The electroencephalographic changes that occur as a human subject goes to sleep. The calibration marks on the right represent 50 mV. (From H. H. Jasper, "Electrocephalography," in *Epilepsy and Cerebral Localization*, edited by W. G. Penfield and T. C. Erickson. Springfield, 111.: Charles C. Thomas, 1941.)

# EEG Source Imaging

# EEG Source Imaging

ESI es una técnica de **neuroimagenología multimodal** la cual integra información **espacial** desde Imágenes por Resonancia Magnética (MRIs) y **temporal** desde la electroencefalografía (EEG).

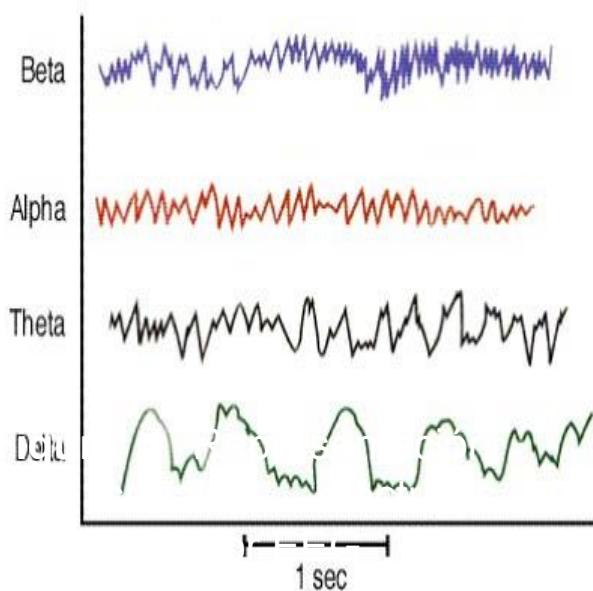
Para la aplicación de ESI se deben resolver dos problemas:

**El problema directo** del EEG (forward problem)

**El problema inverso** del EEG (inverse problem)

# Problema directo e inverso

- **Problema directo:** Cálculo de la distribución de potencial eléctrico generado por una fuente conocida de actividad eléctrica del cerebro.
- **Problema inverso:** Estimación de parámetros de la fuente de actividad eléctrica a partir de mediciones de potencial eléctrico en EEG.

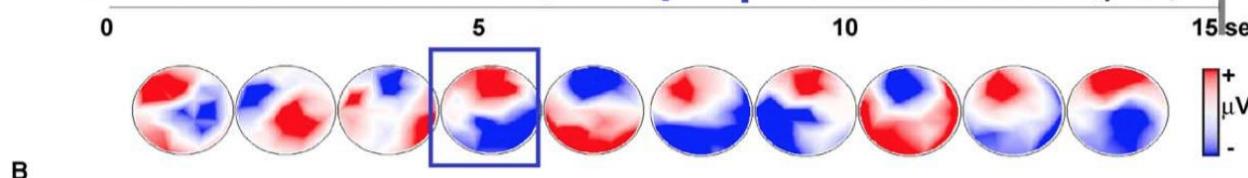
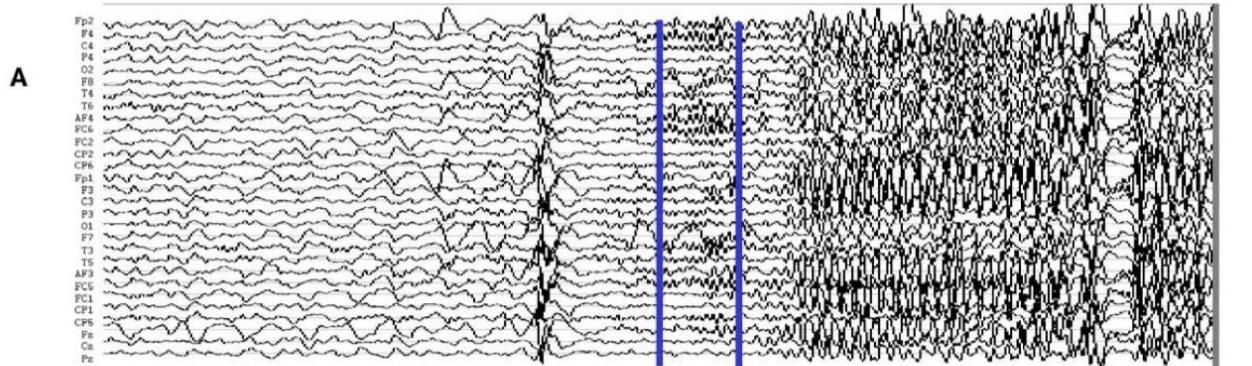


Problema inverso

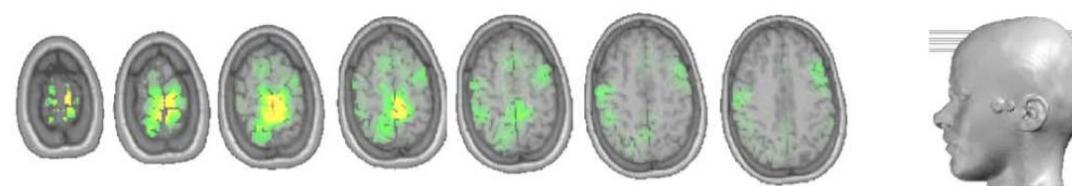


Problema directo



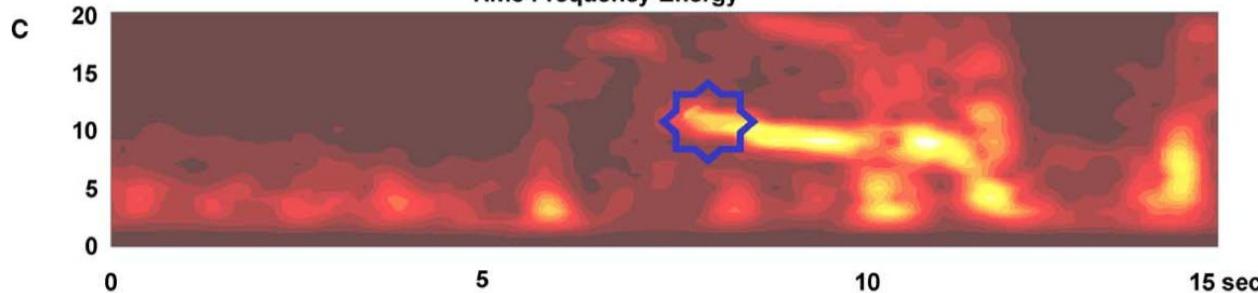


**B**

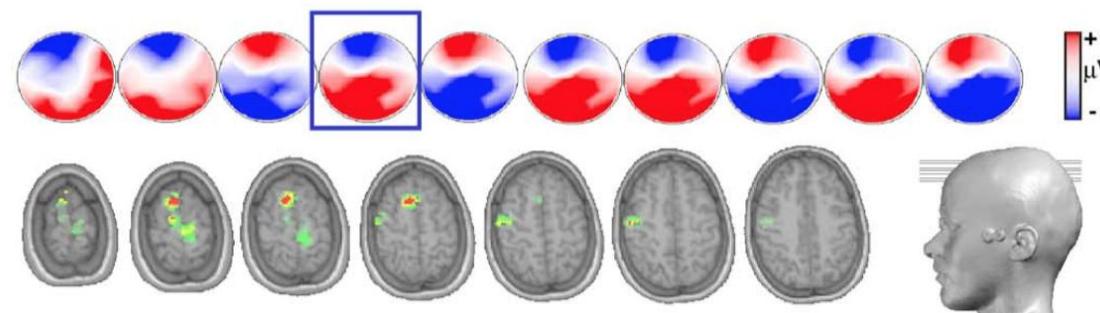


Hz

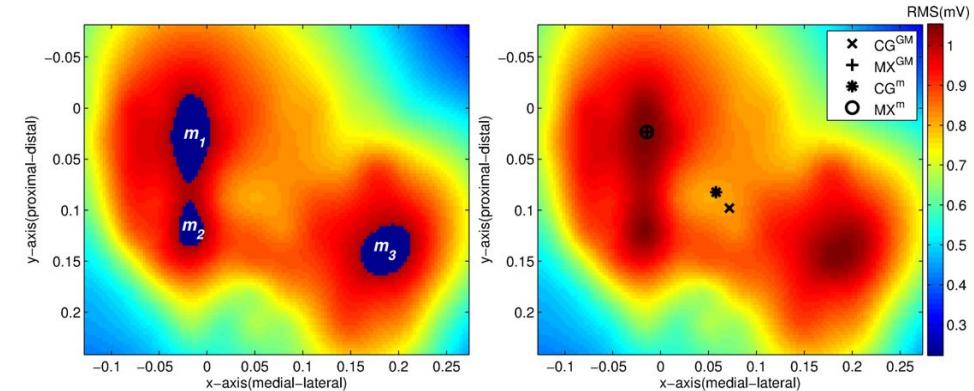
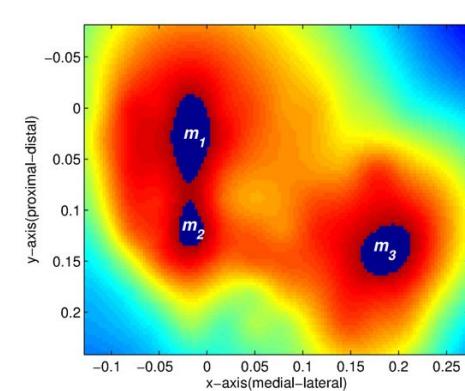
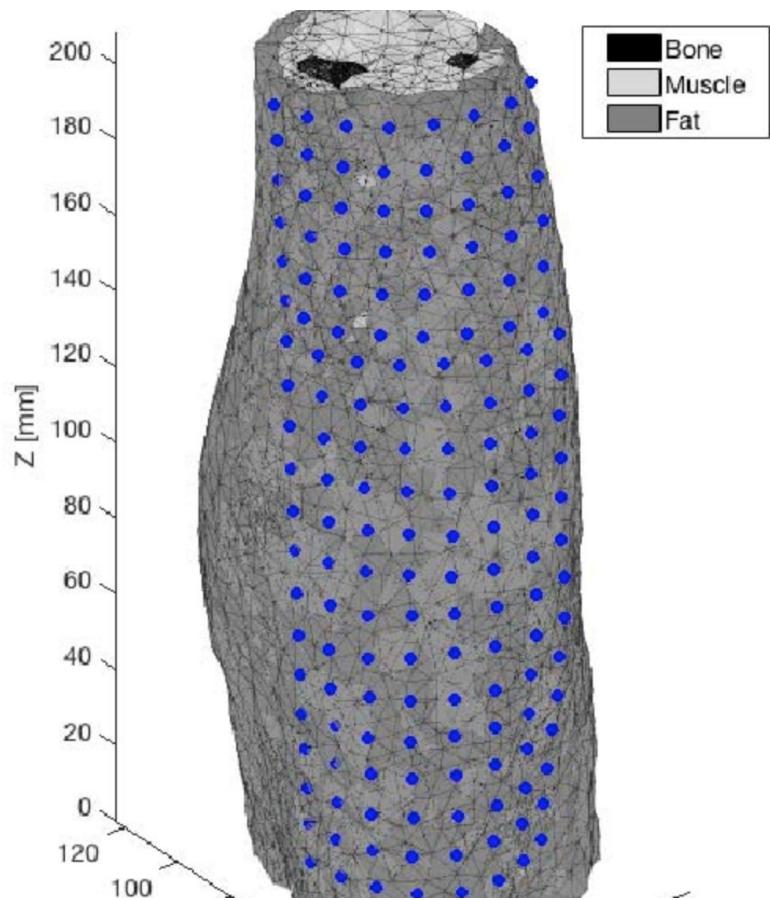
Time Frequency Energy



**D**



# En músculos



# **ICB314**

## **4. Biopotenciales, electrodos y amplificador de bioinstrumentación.**

### **Lectura complementaria:**

Capítulo 4, 5 y 6, J.G. Webster. Medical Instrumentation: Application and Design. 4th Edition, 2010.

Ákos Jobbágy, Sándor Varga (2014). Biomedical Instrumentation.

[http://www.tankonyvtar.hu/en/tartalom/tamop412A/2011\\_0079\\_jobbagy\\_biomedical/ch02.html](http://www.tankonyvtar.hu/en/tartalom/tamop412A/2011_0079_jobbagy_biomedical/ch02.html)

# Contenidos

Los potenciales bioeléctricos

Electrodos

Amplificador biológico

# **Electrodos**

# Electrodos

Los bioelectrodos son dispositivos que actúan como interface entre un proceso bioquímico y un dispositivo electrónico.

Se hace uso del hecho de que las soluciones biológicas contienen iones ( $\text{Na}^+$  y  $\text{Cl}^-$  son los mayormente involucrados en la medición de biopotenciales).

La función de un bioelectrodo entonces es transferir carga entre soluciones iónicas y conductores metálicos.

# Electrodos

---

Bioelectric Signal	Abbreviation	Biologic Source
Electrocardiogram	ECG	Heart—as seen from body surface
Cardiac electrogram	—	Heart—as seen from within
Electromyogram	EMG	Muscle
Electroencephalogram	EEG	Brain
Electrooptogram	EOG	Eye dipole field
Electroretinogram	ERG	Eye retina
Action potential	—	Nerve or muscle
Electrogastrogram	EGG	Stomach
Galvanic skin reflex	GSR	Skin

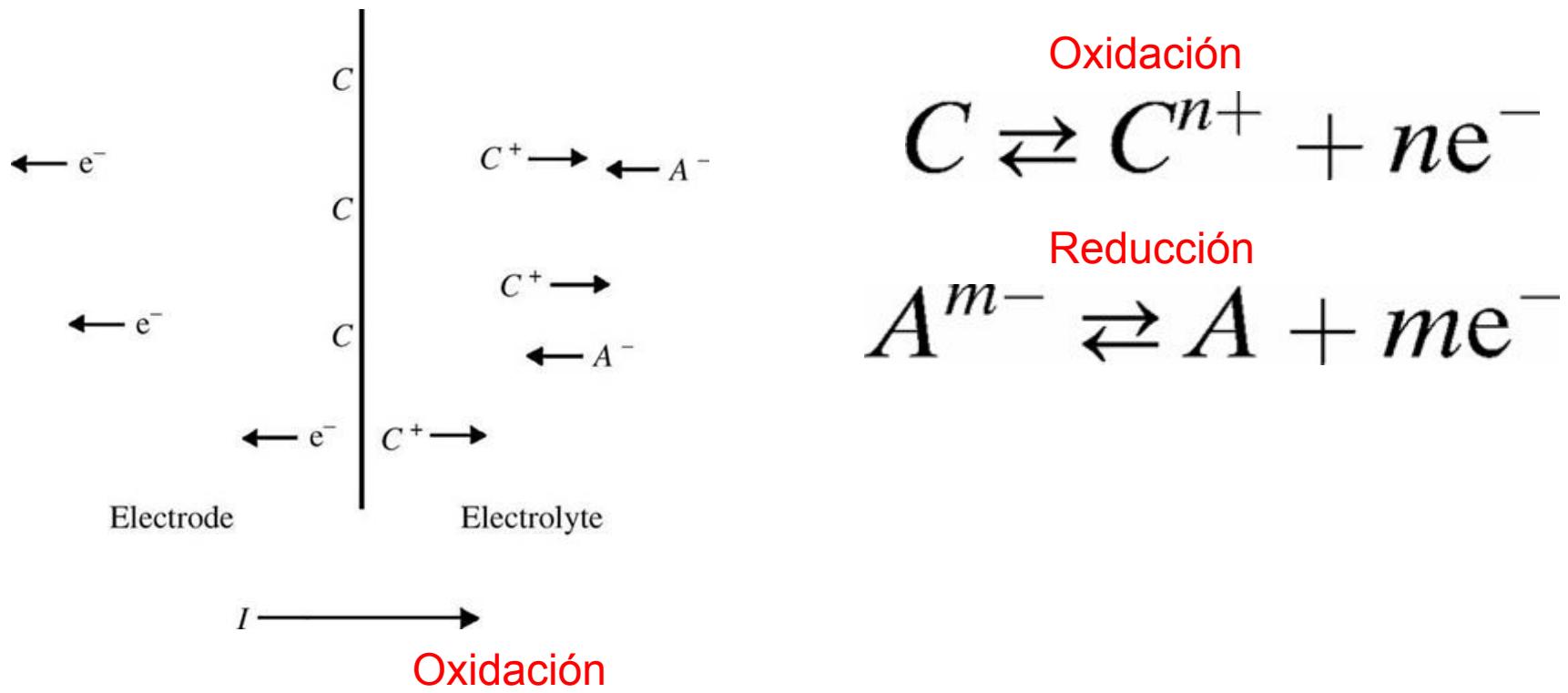
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# Electrodos

**TABLE 74.1** Biopotentials, Specifications, and Applications

Source	Amplitude (mV)	Bandwidth (Hz)	Sensor (Electrodes)	Measurement Error Source	Selected Applications
ECG	1–5	0.05–100	Ag–AgCl disposable	Motion artifact, 50/60 Hz powerline interference	Diagnosis of ischemia, arrhythmia, conduction defects
EEG	0.001–0.01	0.5–40	Gold-plated or Ag–AgCl reusable	Thermal (Johnson) RF noise, 50/60 Hz	Sleep studies, seizure detection, cortical mapping
EMG	1–10	20–2000	Ag or carbon, stainless steel, needle	50/60 Hz, RF	Muscle function, neuromuscular disease, prosthesis
EOG	0.01–0.1	dc–10	Ag–AgCl	Skin potential motion	Eye position, sleep state, vestibulo-ocular reflex

# Interface electrodo-electrolito



**Figure 5.1 Electrode–electrolyte interface. The current crosses it from left to right. The electrode consists of metallic atoms C. The electrolyte is an aqueous solution containing cations of the electrode metal  $C^+$  and anions  $A^-$ .**

**Table 5.1** Half-cell Potentials for Common Electrode Materials at 25 °C

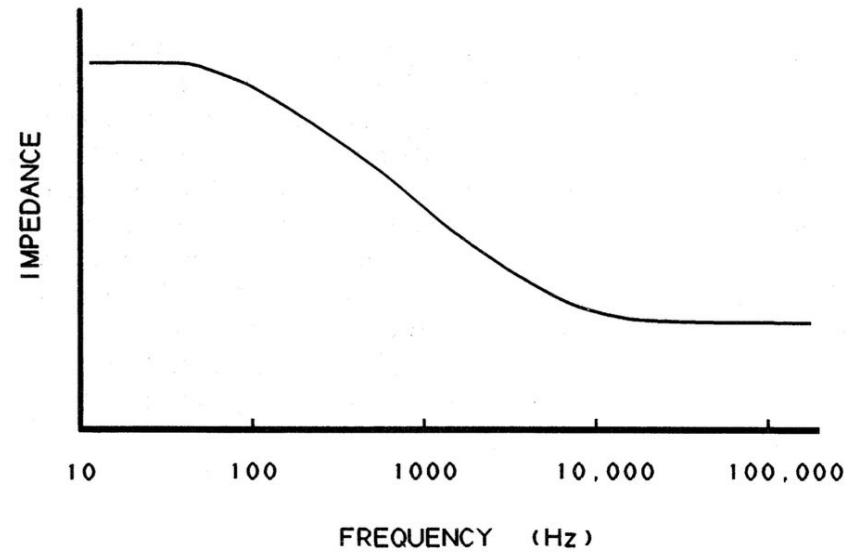
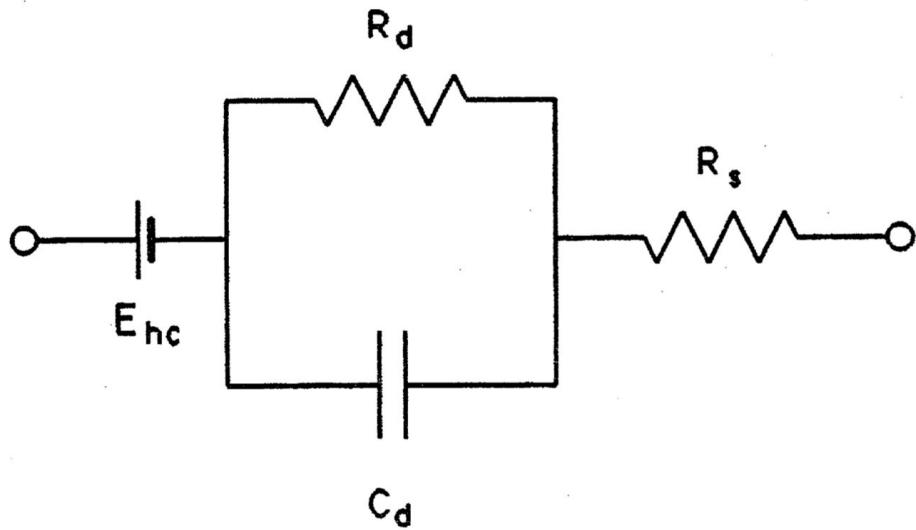
The metal undergoing the reaction shown has the sign and potential  $E^0$  when referenced to the hydrogen electrode

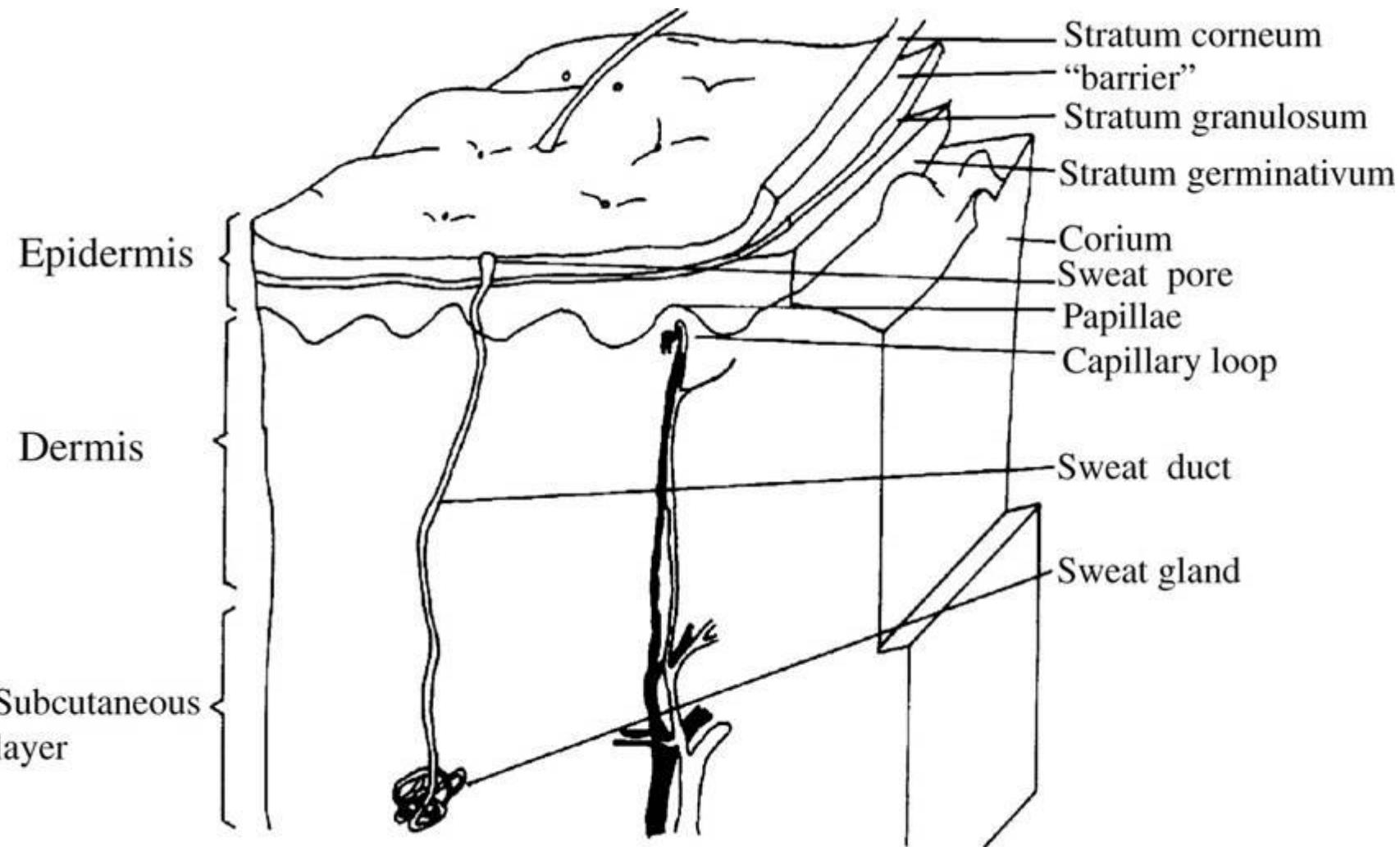
Metal and Reaction	Potential $E^0$ (V)
$\text{Al} \rightarrow \text{Al}^{3+} + 3\text{e}^-$	-1.706
$\text{Zn} \rightarrow \text{Zn}^{2+} + 2\text{e}^-$	-0.763
$\text{Cr} \rightarrow \text{Cr}^{3+} + 3\text{e}^-$	-0.744
$\text{Fe} \rightarrow \text{Fe}^{2+} + 2\text{e}^-$	-0.409
$\text{Cd} \rightarrow \text{Cd}^{2+} + 2\text{e}^-$	-0.401
$\text{Ni} \rightarrow \text{Ni}^{2+} + 2\text{e}^-$	-0.230
$\text{Pb} \rightarrow \text{Pb}^{2+} + 2\text{e}^-$	-0.126
$\text{H}_2 \rightarrow 2\text{H}^+ + 2\text{e}^-$	0.000 by definition
$\text{Ag} + \text{Cl}^- \rightarrow \text{AgCl} + \text{e}^-$	+0.223
$2\text{Hg} + 2\text{Cl}^- \rightarrow \text{Hg}_2\text{Cl}_2 + 2\text{e}^-$	+0.268
$\text{Cu} \rightarrow \text{Cu}^{2+} + 2\text{e}^-$	+0.340
$\text{Cu} \rightarrow \text{Cu}^+ + \text{e}^-$	+0.522
$\text{Ag} \rightarrow \text{Ag}^+ + \text{e}^-$	+0.799
$\text{Au} \rightarrow \text{Au}^{3+} + 3\text{e}^-$	+1.420
$\text{Au} \rightarrow \text{Au}^+ + \text{e}^-$	+1.680

SOURCE: Data from *Handbook of Chemistry and Physics*, 55th ed., Cleveland, OH: CRC Press, 1974–1975, with permission.

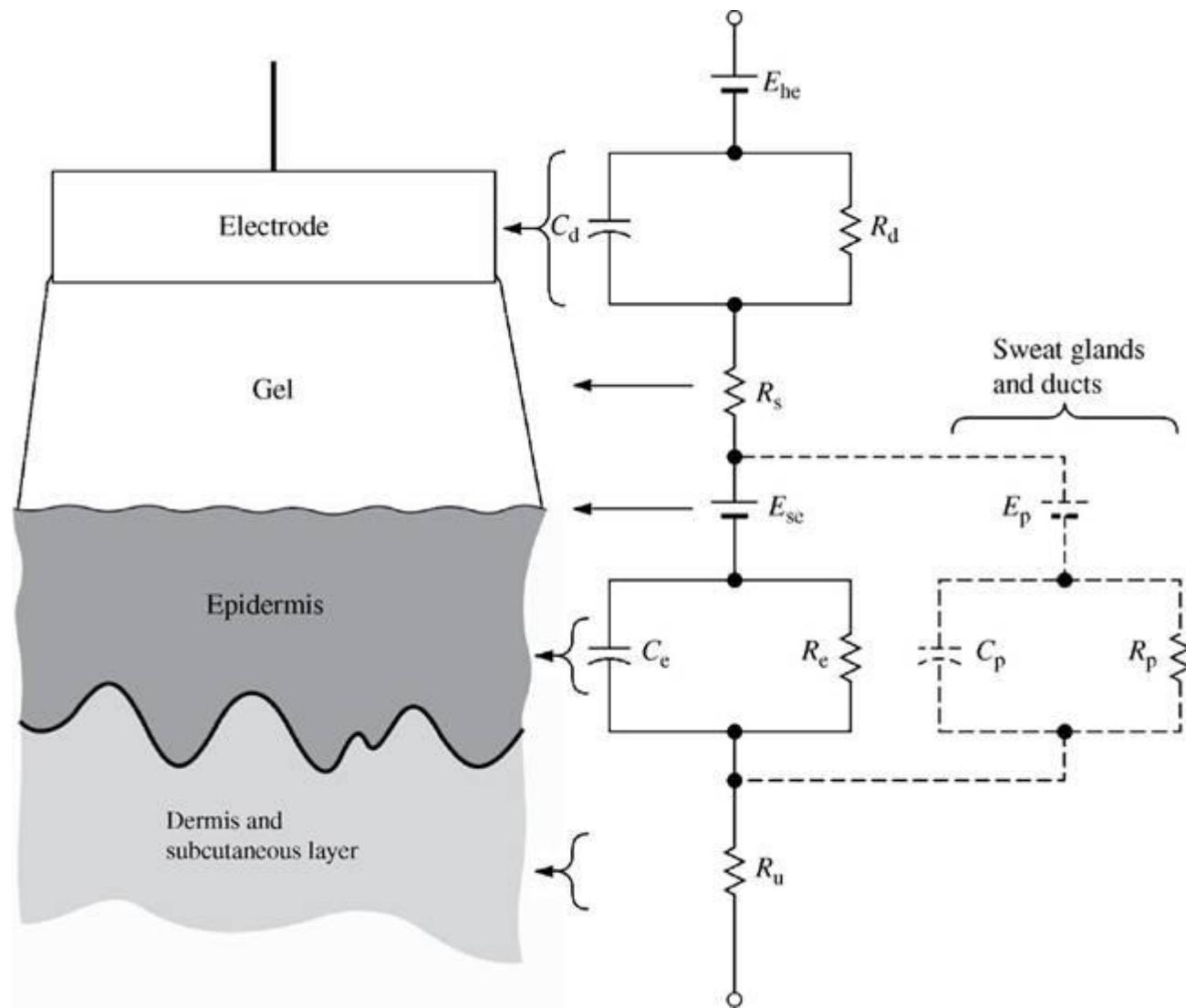
# Características eléctricas

Círculo equivalente de un electrodo.





**Figure 5.7** Magnified section of skin, showing the various layers (Copyright © 1977 by The Institute of Electrical and Electronics Engineers. Reprinted, with permission, from *IEEE Trans. Biomed. Eng.*, March 1977, vol. BME-24, no. 2, pp. 134–139.)



**Figure 5.8 A body-surface electrode is placed against skin, showing the total electrical equivalent circuit obtained in this situation. Each circuit element on the right is at approximately the same level at which the physical process that it represents would be in the left-hand diagram.**

# **Tipos de electrodos**

Muchos tipos para muchos tipos de mediciones.  
Los más comunes son:

**Electrodos de superficie (body-surface biopotential electrodes).**

**Electrodos intracavitarios o intratejidos.**

**Microelectrodos.**

**Electrodo fabricados con tecnología microelectrónica.**

# Electrodos de superficie

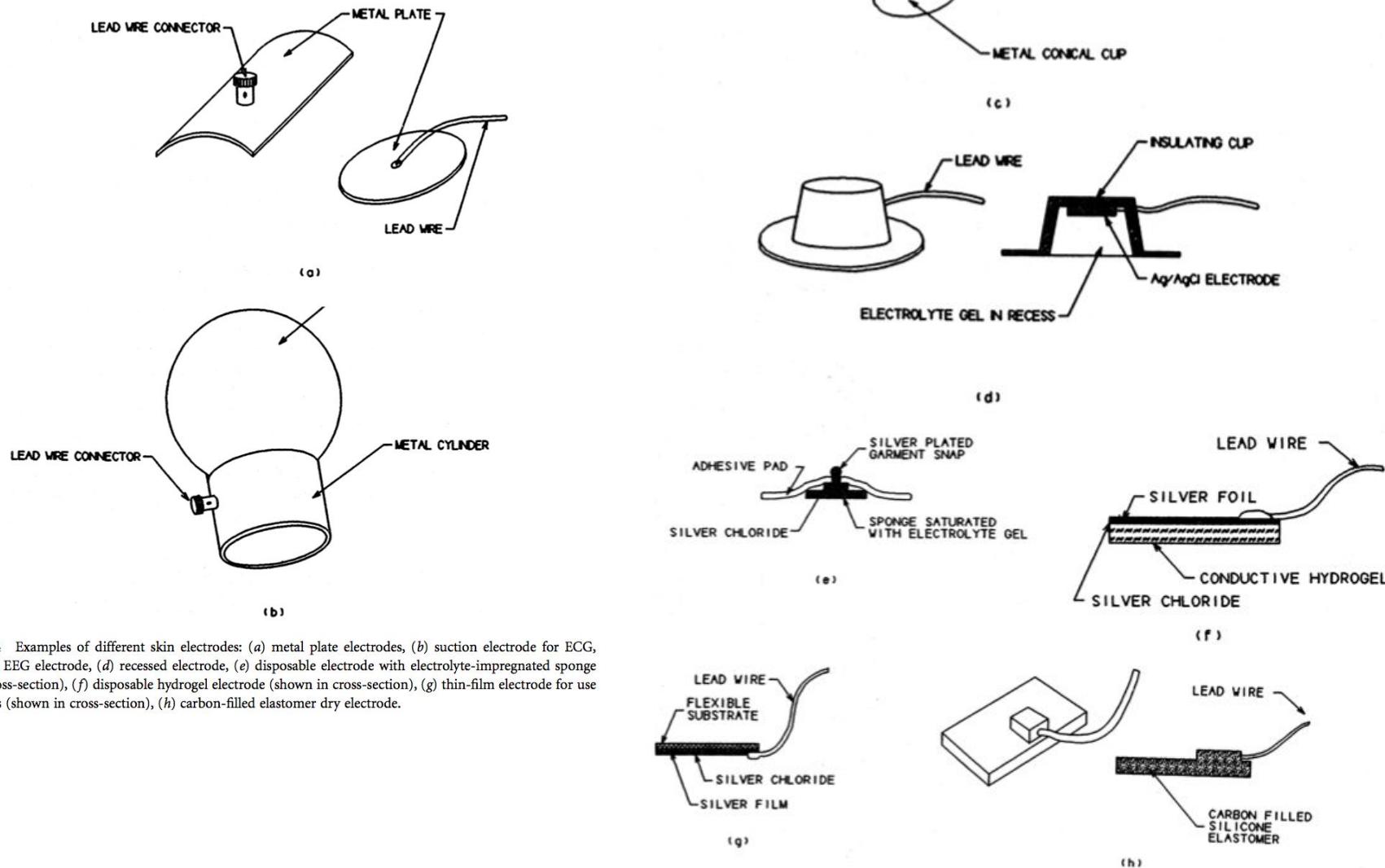
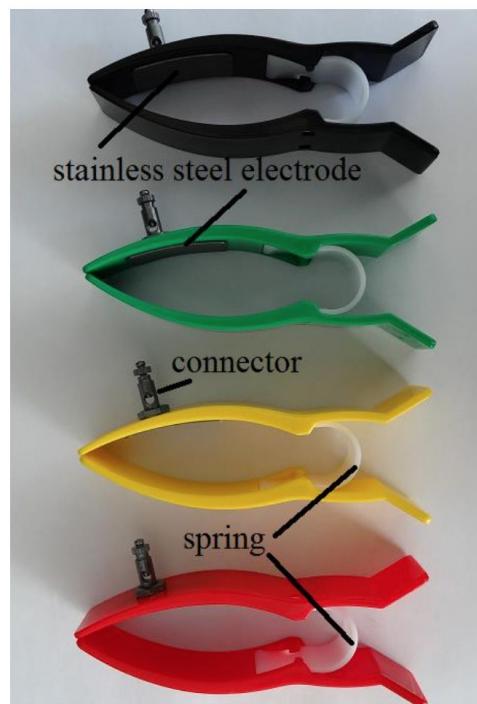


FIGURE 48.4 Examples of different skin electrodes: (a) metal plate electrodes, (b) suction electrode for ECG, (c) metal cup EEG electrode, (d) recessed electrode, (e) disposable electrode with electrolyte-impregnated sponge (shown in cross-section), (f) disposable hydrogel electrode (shown in cross-section), (g) thin-film electrode for use with neonates (shown in cross-section), (h) carbon-filled elastomer dry electrode.

FIGURE 48.4 (continued)



Figure 1.12. Disposable electrodes with adhesive ring





# Tecnología vestible y moda



<http://www.adafruit.com/blog/2014/04/16/sparkly-tank-top-made-with-adafruit-neopixels-wearablewednesday/>



63% algodón, 35% hilo de plata y 2% spandex  
1.5 ohm/cm en una dirección, 15 ohm/cm en la otra

Pedazo de 20x20cm ~ US\$10

<https://www.adafruit.com/products/1>

# Eletrodos electrotextiles

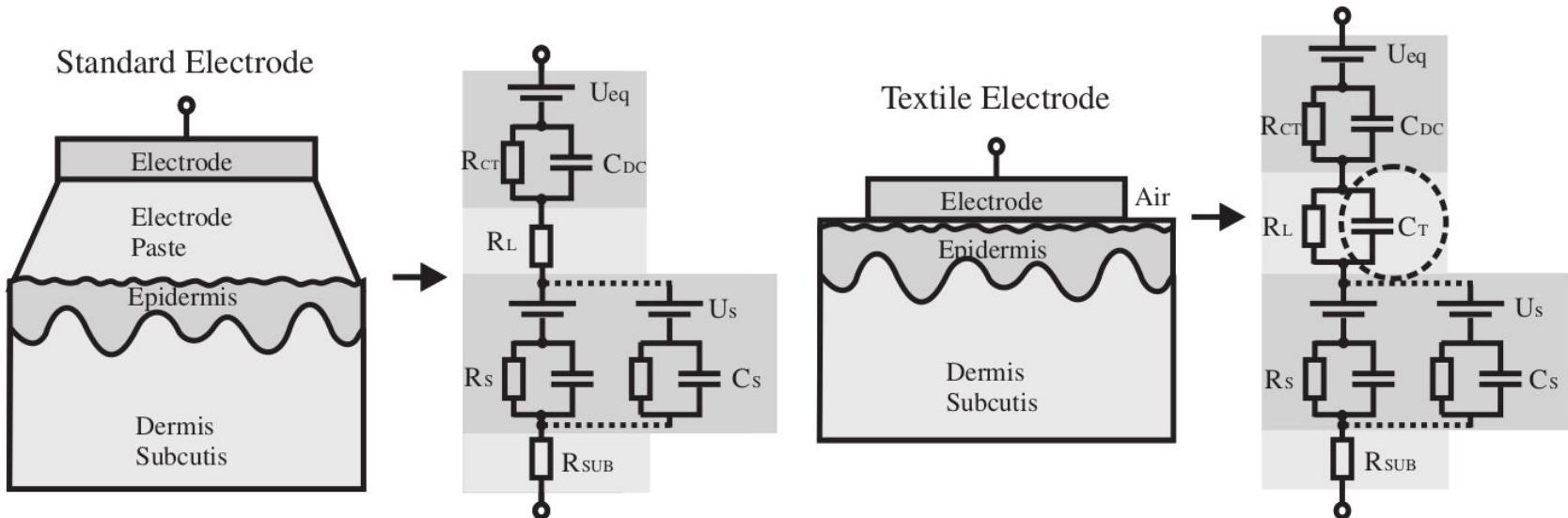


VivoMetrics' remote LifeShirt



WEALTHY Shirt

# Modelos de electrodo textil versus estándar



$$Z_{\text{Standard}} = \frac{R_C T}{1 + j\omega R_{CT} C_{DC}} + R_L + \frac{R_S}{1 + j\omega R_S C_S} + R_{\text{SUB}}$$

$$Z_{\text{Textile}} = \frac{R_C T}{1 + j\omega R_{CT} C_{DC}} + \frac{R_L}{1 + j\omega R_L C_T} + \frac{R_S}{1 + j\omega R_S C_S} + R_{\text{SUB}}$$

Characterization of textile electrodes and conductors using  
standardized  
measurement setups. Beckmann et al. 2010

# Electrodos intracavitarios o intratejido

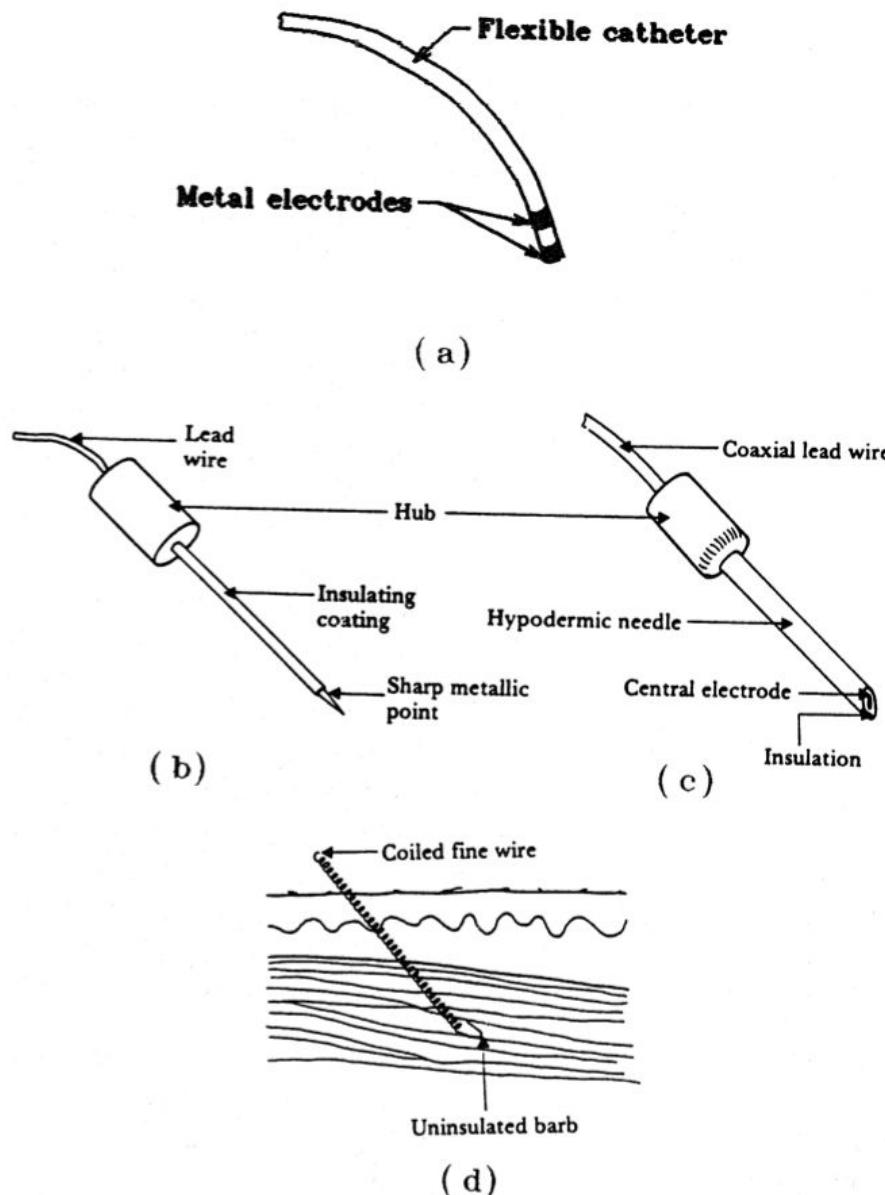
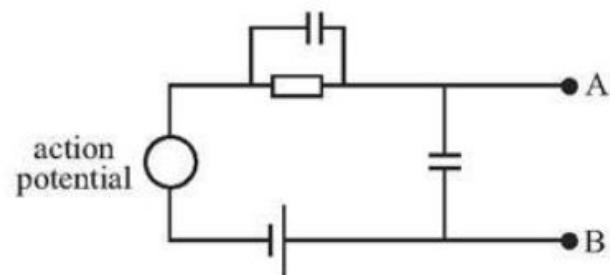
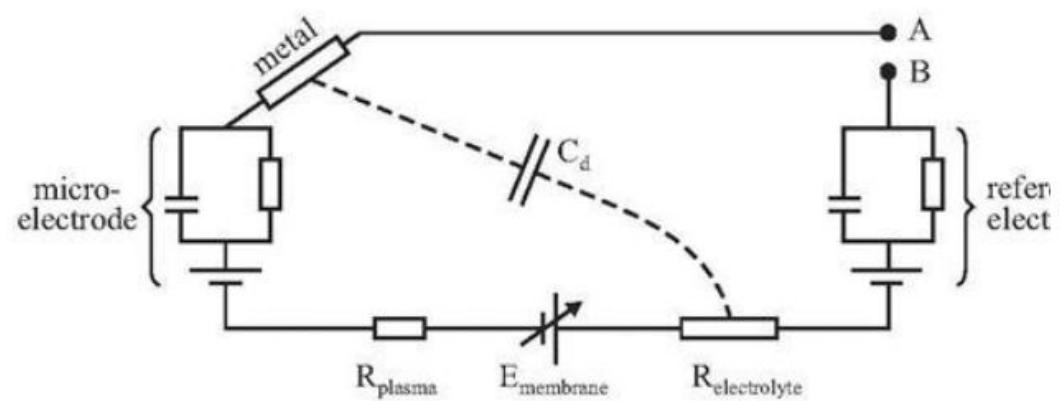
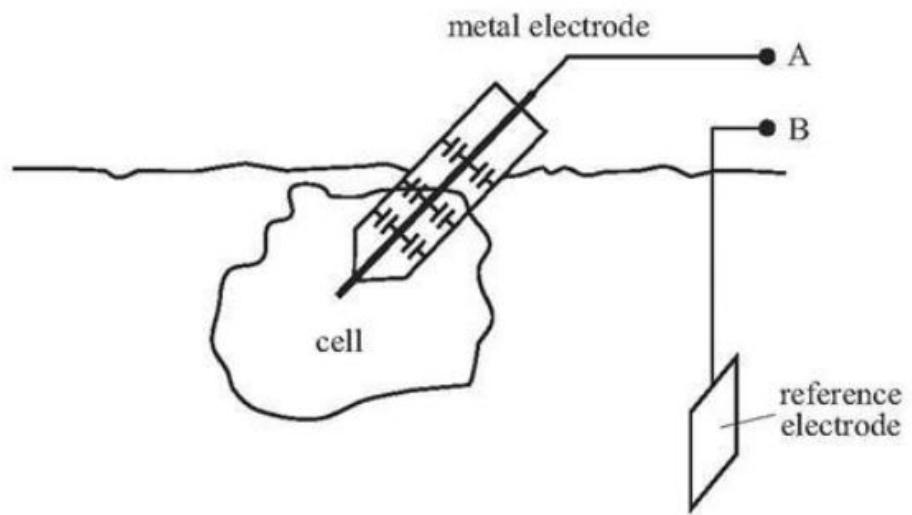
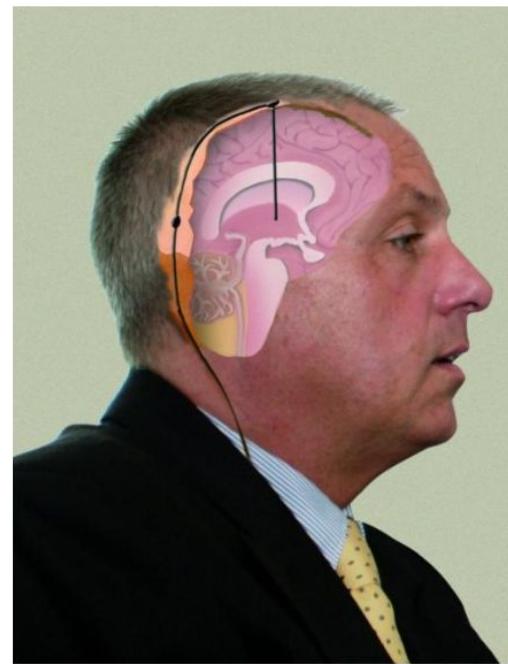
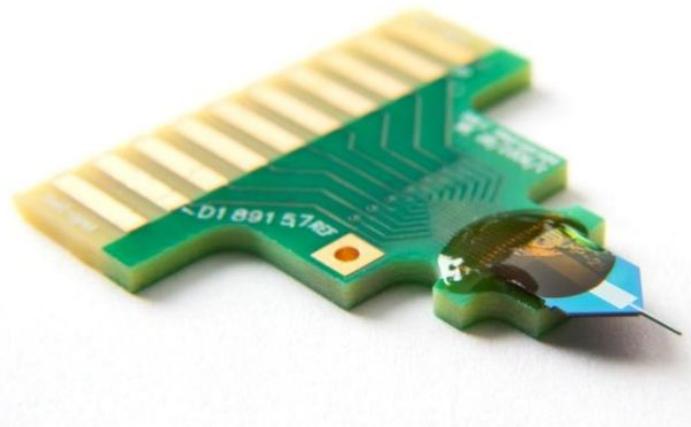
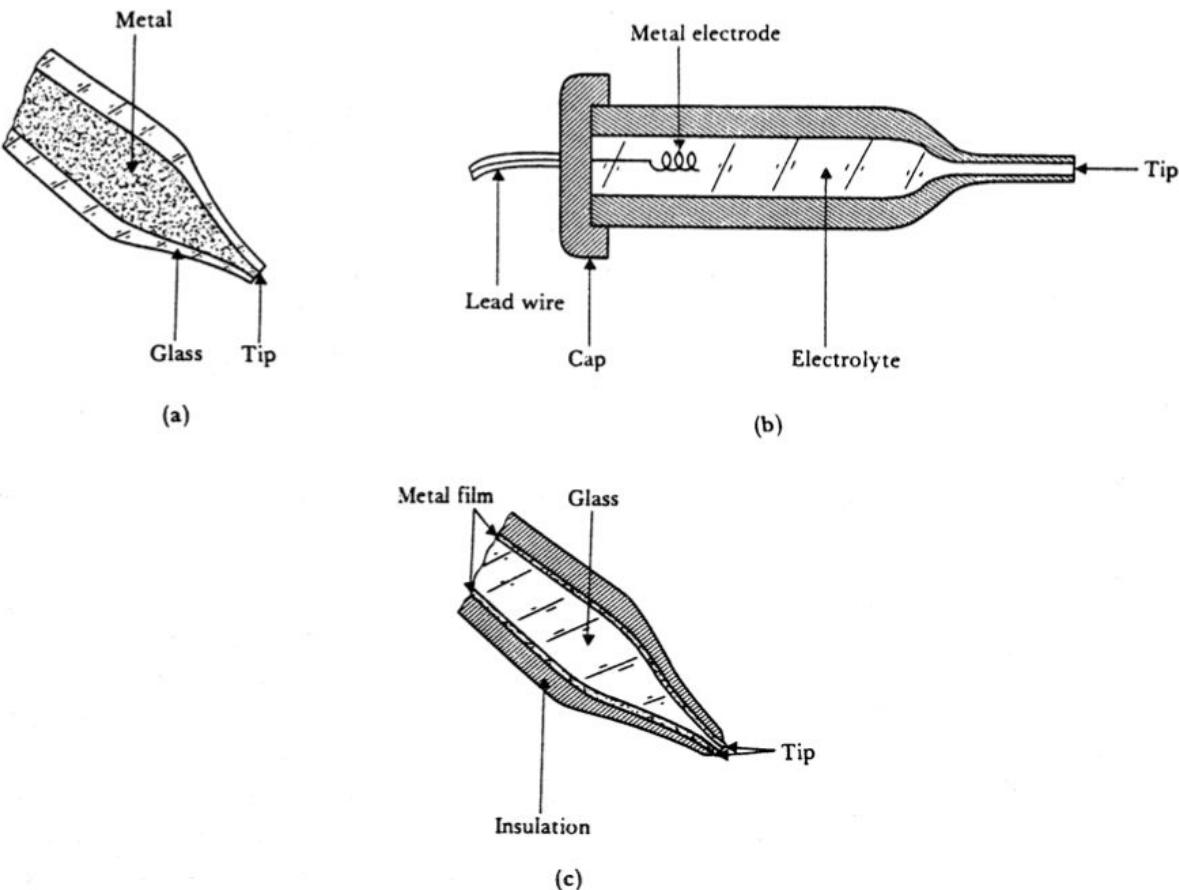


FIGURE 48.5 Examples of different internal electrodes: (a) catheter or probe electrode, (b) needle electrode, (c) coaxial needle electrode, (d) coiled wire electrode. (Reprinted with permission from Webster JG (ed). 1992. Medical Instrumentation: Application and Design, Houghton Mifflin, Boston.)





# Microelectrodos



**FIGURE 48.6** Microelectrodes: (a) metal, (b) micropipette, (c) thin metal film on micropipette. (Reprinted with permission from Webster JC (ed). 1992. Medical Instrumentation: Application and Design, Houghton Mifflin, Boston.)

# Tipos de electrodos - aplicaciones

Application	Biopotential	Type of Electrode
Cardiac monitoring	ECG	Ag/AgCl with sponge Ag/AgCl with hydrogel
Infant cardiopulmonary monitoring	ECG impedance	Ag/AgCl with sponge Ag/AgCl with hydrogel Thin-film Filled elastomer dry
Sleep encephalography	EEG	Gold cups Ag/AgCl cups Active electrodes
Diagnostic muscle activity	EMG	Needle
Cardiac electrograms	Electrogram	Intracardiac probe
Implanted telemetry of biopotentials	ECG EMG	Stainless steel wire loops Platinum disks
Eye movement	EOG	Ag/AgCl with hydrogel

# Ejemplo

Un par de electrodos son implantados en un animal para medir el ECG en un sistema de radiotelemetría.

Mediciones previas hechas en el par de electrodos muestran que la capacitancia de polarización es de 200 nF y que el half-cell potential para cada electrodo es 223 mV.

Se someten los electrodos a una excitación sinusoidal con las siguientes frecuencias y se mide la impedancia.

Reporte el circuito equivalente del electrodo.

Frequency	Impedance (Magnitude) ( $\Omega$ )
5 Hz	20,000
10 Hz	19,998
.	.
.	.
.	.
40 kHz	602
50 kHz	600
100 kHz	600

# **ICB314**

## **4. Biopotenciales, electrodos y amplificador de bioinstrumentación.**

### **Lectura complementaria:**

Capítulo 4, 5 y 6, J.G. Webster. Medical Instrumentation: Application and Design. 4th Edition, 2010.

Ákos Jobbágy, Sándor Varga (2014). Biomedical Instrumentation.

[http://www.tankonyvtar.hu/en/tartalom/tamop412A/2011\\_0079\\_jobbagy\\_biomedical/ch02.html](http://www.tankonyvtar.hu/en/tartalom/tamop412A/2011_0079_jobbagy_biomedical/ch02.html)

# Contenidos

Los potenciales bioeléctricos

Electrodos

Amplificador biológico

# **Amplificador biológico**

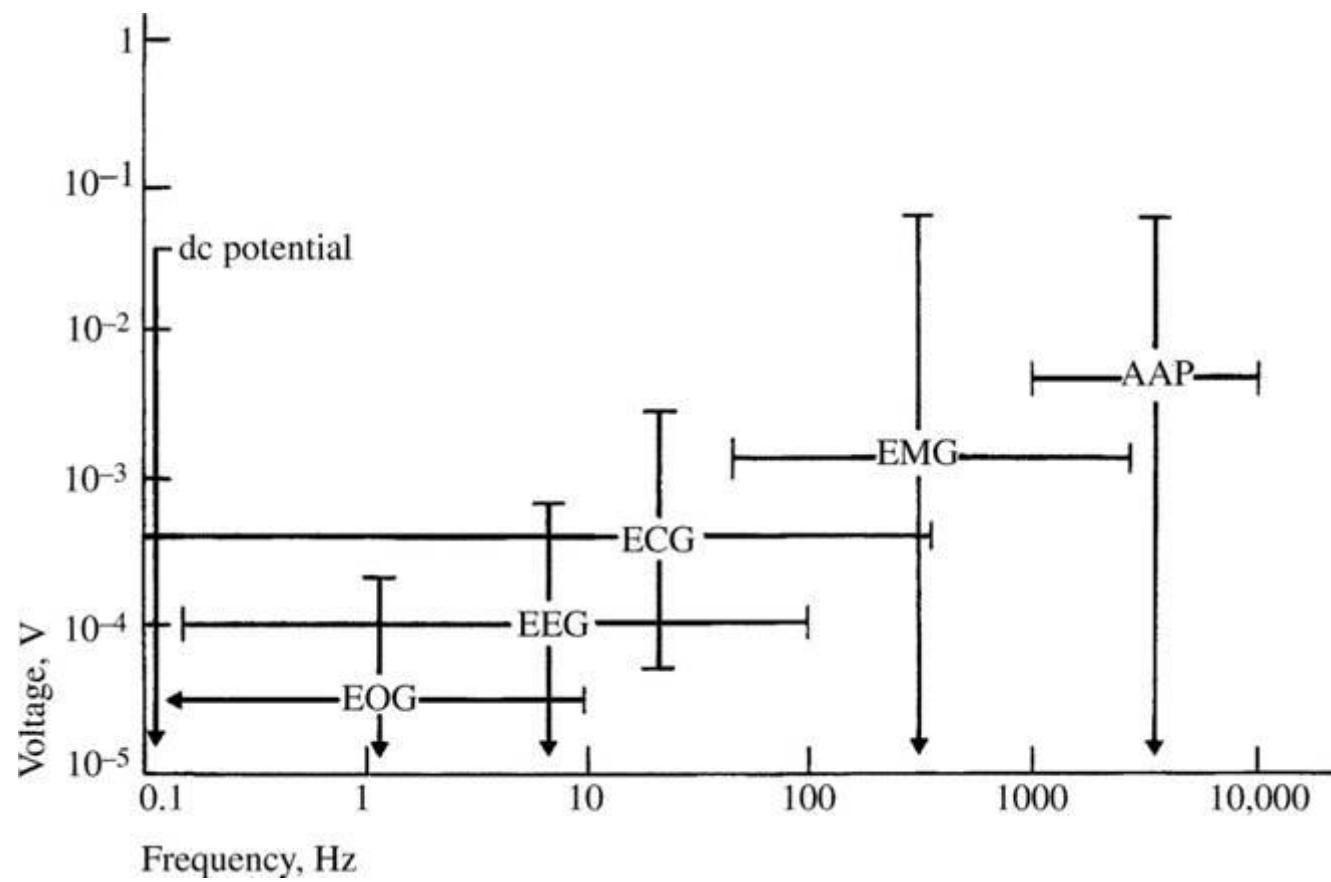
# Bioamplificador

**TABLE 64.2** Distinguishing Features and Design Consideration for Biopotentials

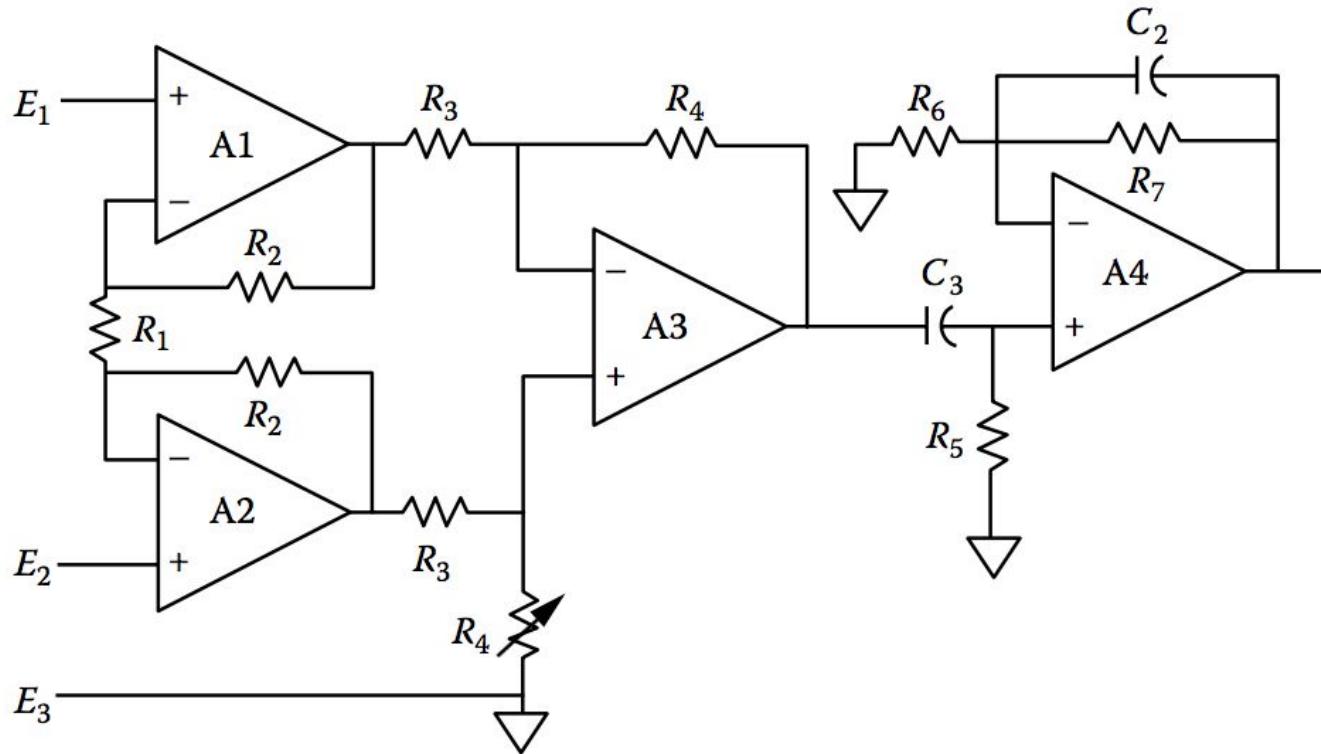
Biopotential	Distinguishing Feature	Exclusive Amplifier Design Consideration	Additional Features Desired
ECG <sup>a</sup>	1 mV signal, 0.05–100 Hz BW <sup>b</sup>	Moderate gain, BW, noise, CMRR, input $R$	Electrical safety, isolation, defibrillation protection
EEG	Very small signal (microvolts)	High gain, very low noise, filtering	Safety, isolation, low electrode–skin resistance
EMG	Higher BW	Gain and BW of op amps	Post-acquisition data processing
EOG	Lower frequencies, small signal	dc and low drift	Electrode–skin junction potential, artifact reduction

<sup>a</sup> The ECG signal acquisition is considered as the standard against which the other acquisitions are compared.

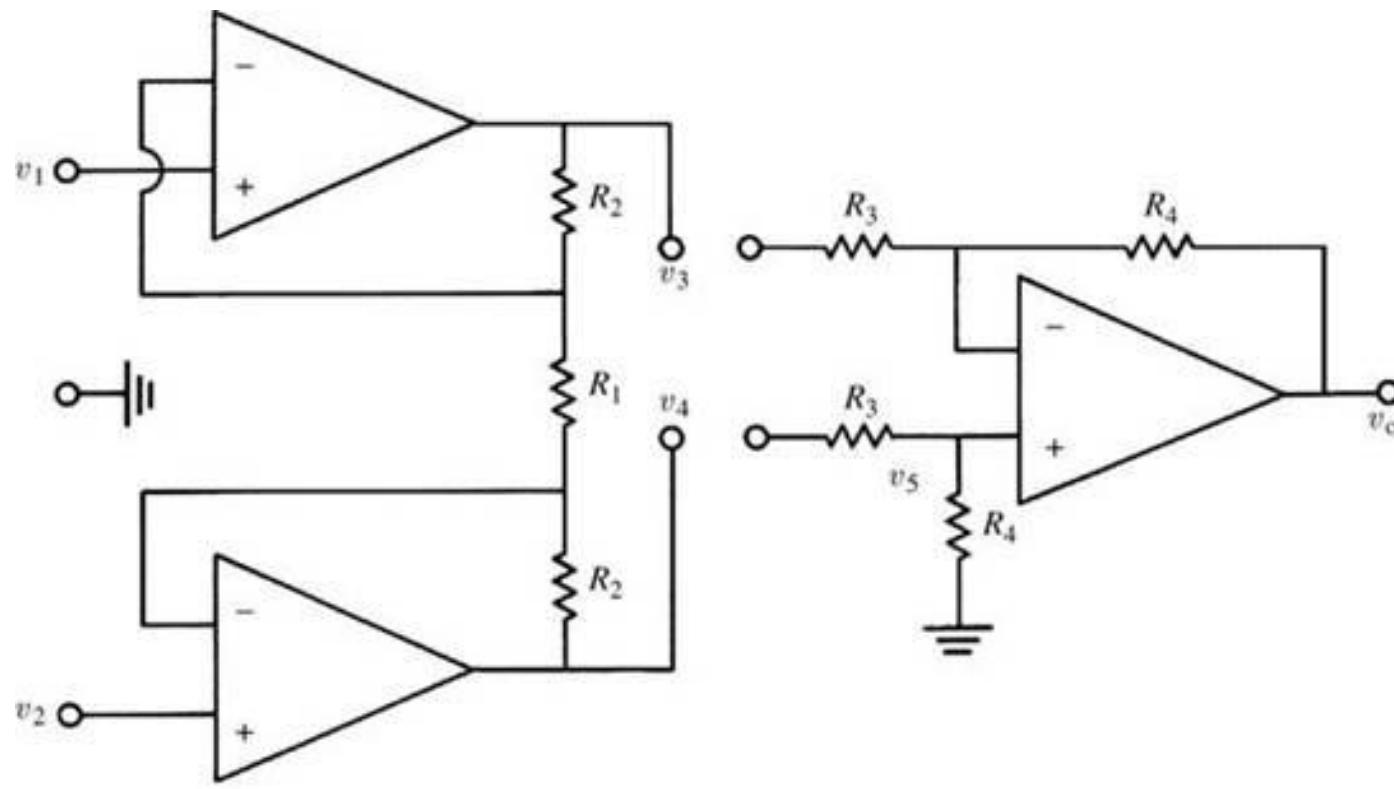
<sup>b</sup> BW, bandwidth.



# Bioamplificador



**FIGURE 64.5** The instrumentation amplifier. This amplifier has a very high input impedance, high CMRR, and a differential gain set by the resistors in the two amplifier stages. The gain of the first stage (amplifiers A1 and A2) is  $1 + 2R_2/R_1$ , the second stage (amplifier A3) is  $R_4/R_3$ , and the third stage (amplifier A4) is  $1 + R_7/R_6$ . The lower corner frequency is  $1/(2\pi R_5 C_1)$  and the upper corner frequency is  $1/(2\pi R_7 C_2)$ . The variable resistor  $R$  is adjusted to maximize the CMRR. Electrodes  $E_1$  and  $E_2$  are the recording electrodes, while  $E_3$  is the reference or the ground electrode.

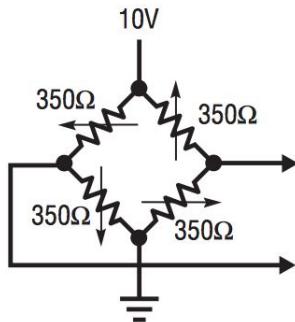


$$G_d = \frac{v_3 - v_4}{v_1 - v_2} = \frac{2R_2 + R_1}{R_1}$$

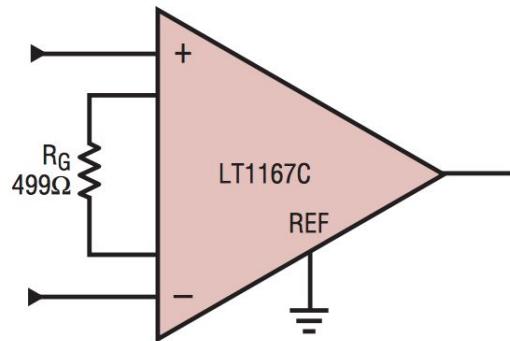
$$v_o = \frac{(v_4 - v_3)R_4}{R_3}$$

$$\text{CMRR} = \frac{G_d}{G_c}$$

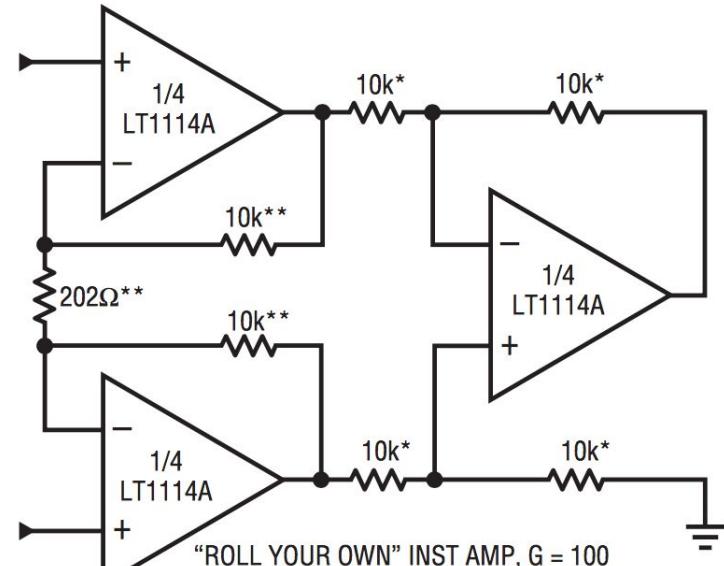
# Bioamplificador



PRECISION BRIDGE TRANSDUCER



LT1167 MONOLITHIC  
INSTRUMENTATION AMPLIFIER  
 $G = 100$ ,  $R_G = \pm 10\text{ppm}$  TC  
SUPPLY CURRENT = 1.3mA MAX



"ROLL YOUR OWN" INST AMP,  $G = 100$   
\* 0.02% RESISTOR MATCH, 3ppm/ $^{\circ}\text{C}$  TRACKING  
\*\* DISCRETE 1% RESISTOR,  $\pm 100\text{ppm}/^{\circ}\text{C}$  TC  
SUPPLY CURRENT = 1.35mA FOR 3 AMPLIFIERS

1167 F06

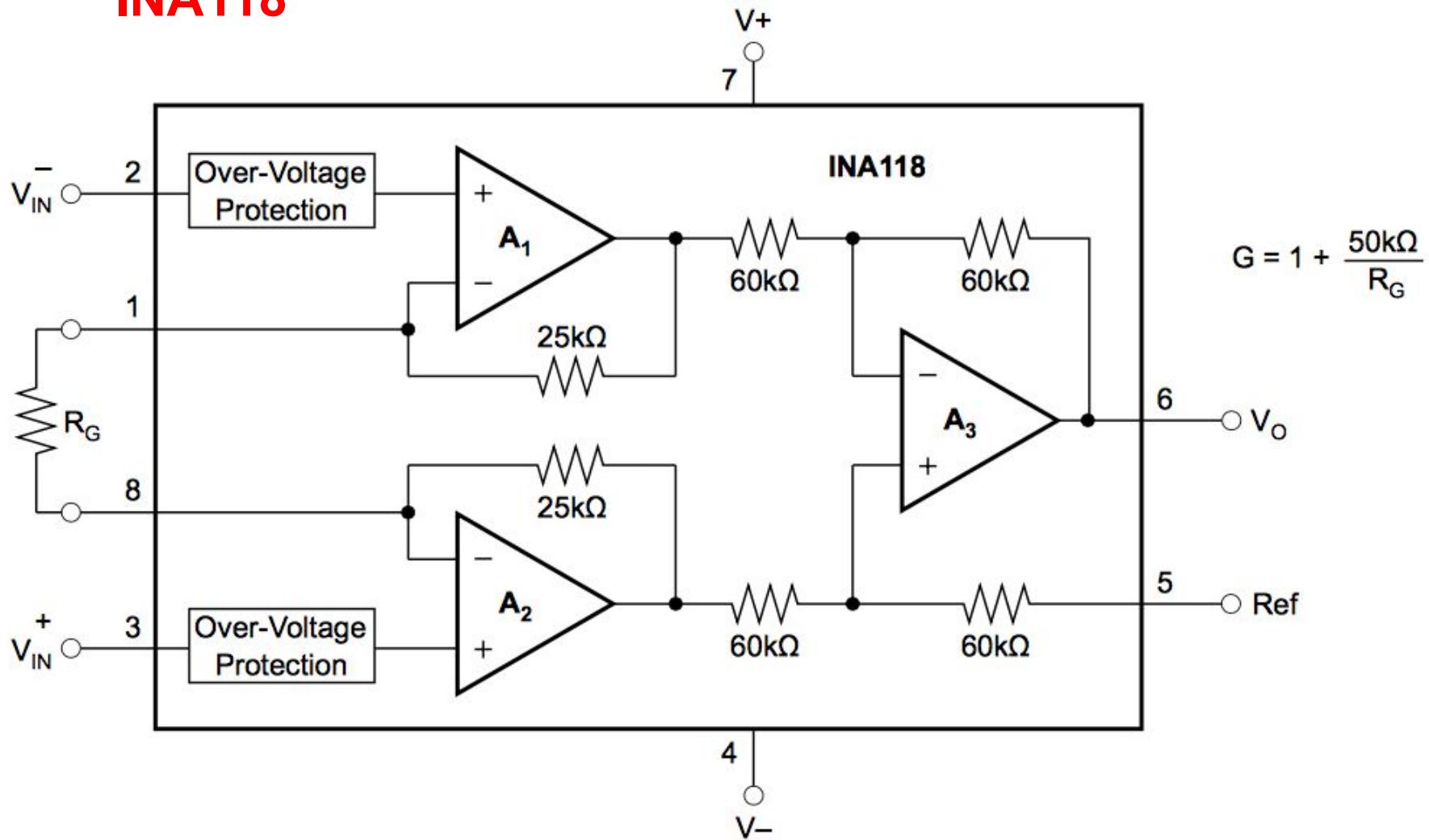
Figure 6. "Roll Your Own" vs LT1167

\* AD8232 – Amplificador ECG

# Bioamplificador

INA118

## Simplified Schematic



# Bioamplificador - mejoras

Reducción de la interferencia eléctrica.

- Aislando el sujeto, los cables e instrumento.
- Conectando a tierra sujeto e instrumentos.

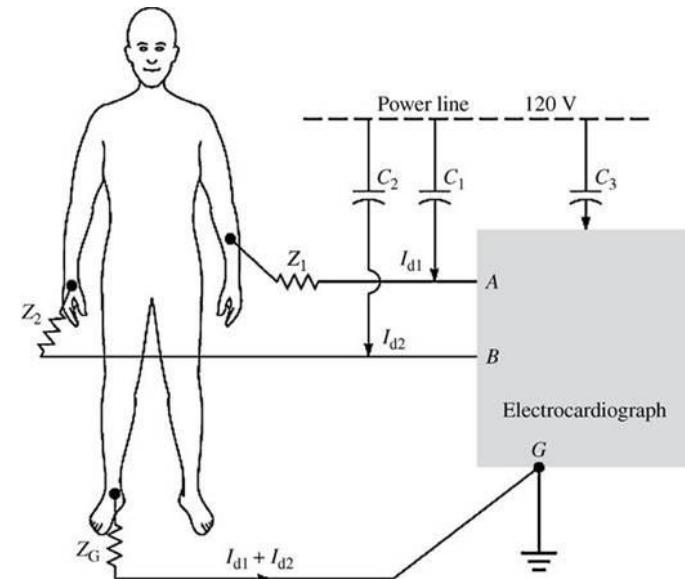
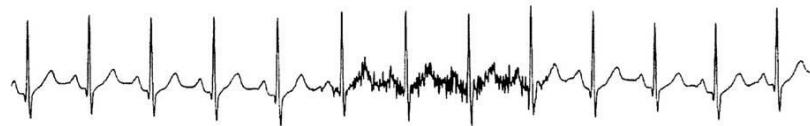
Fuentes de interferencia: líneas de alimentación, cables eléctricos, RF, motores eléctricos.

La interferencia que se induce y que es común en ambos electrodos de medición se denomina interferencia de modo común, en distinción a los biopotenciales que son diferenciales en ambos electrodos.

# Bioamplificador - mejoras

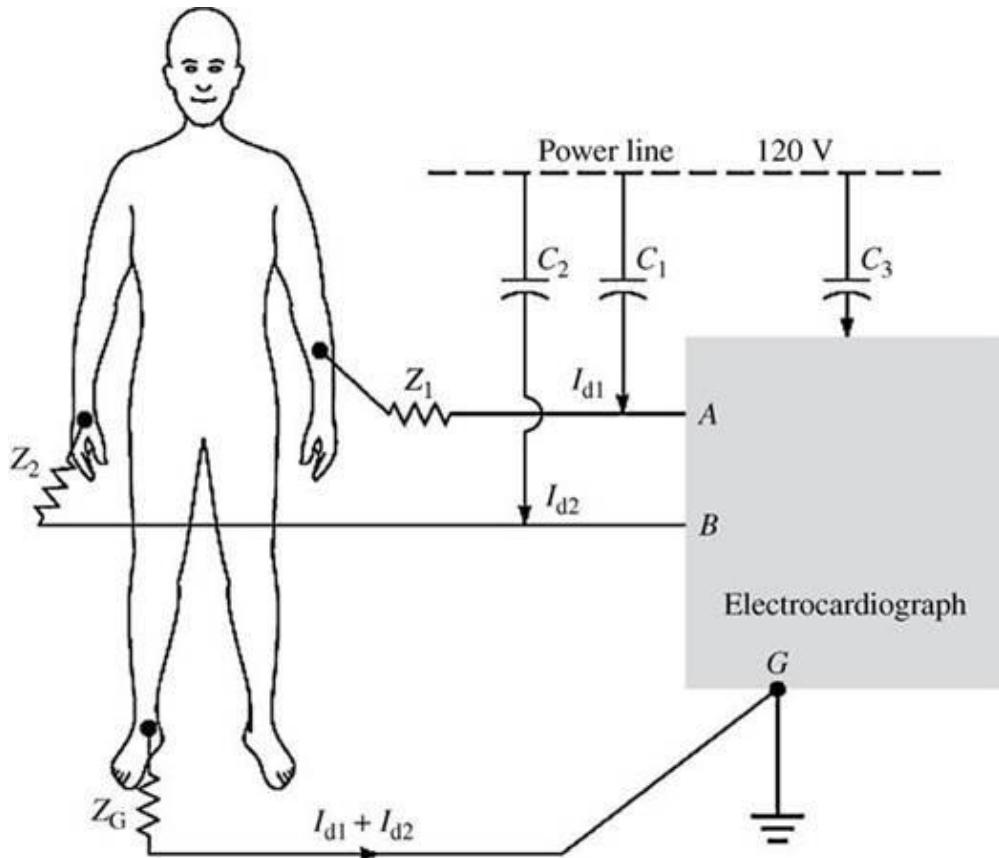
Interferencias de otros dispositivos.

Una fuente típica de interferencia es el sistema de alimentación.

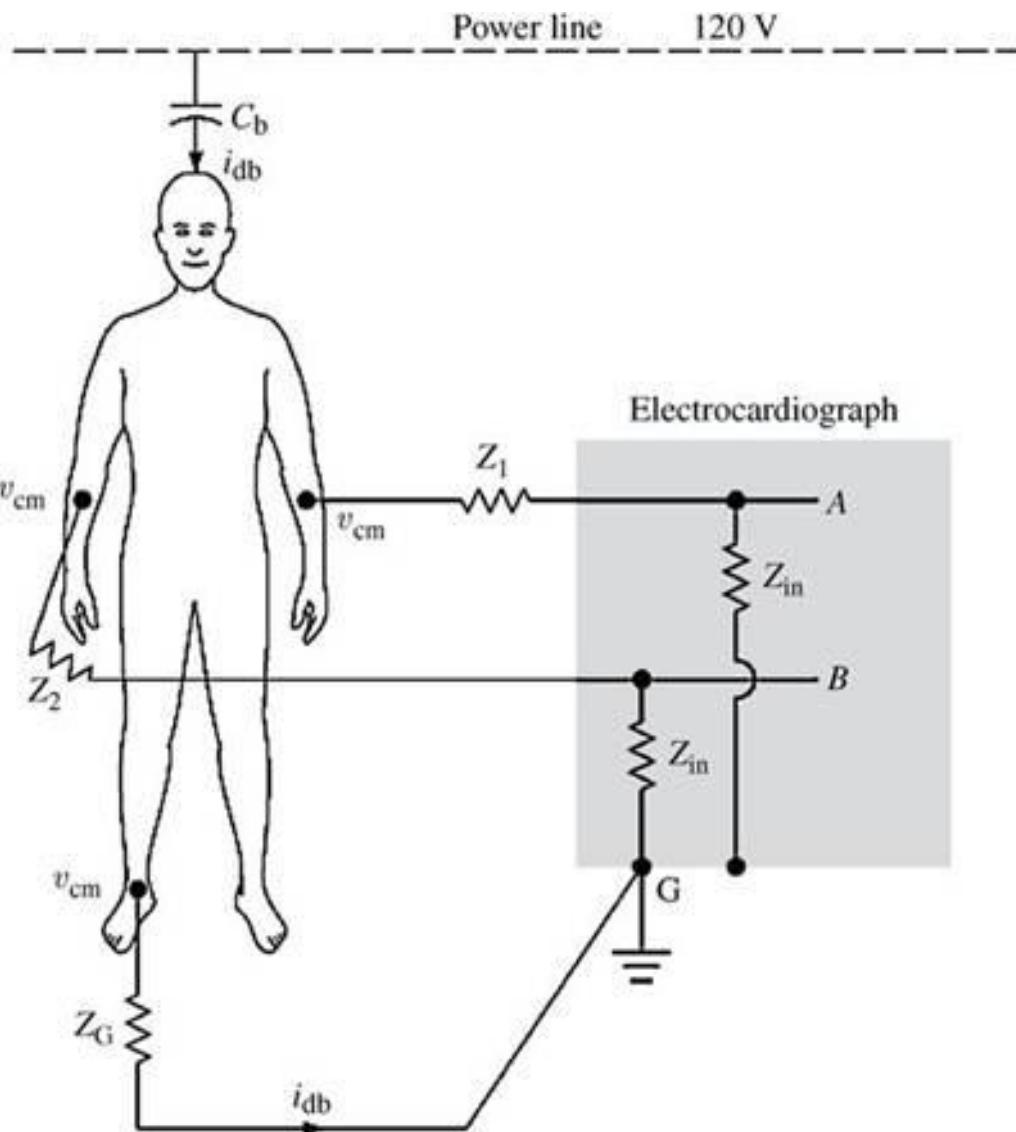


$$v_A - v_B = i_{d1}Z_1 - i_{d2}Z_2$$

$$v_A - v_B = i_{d1}(Z_1 - Z_2)$$



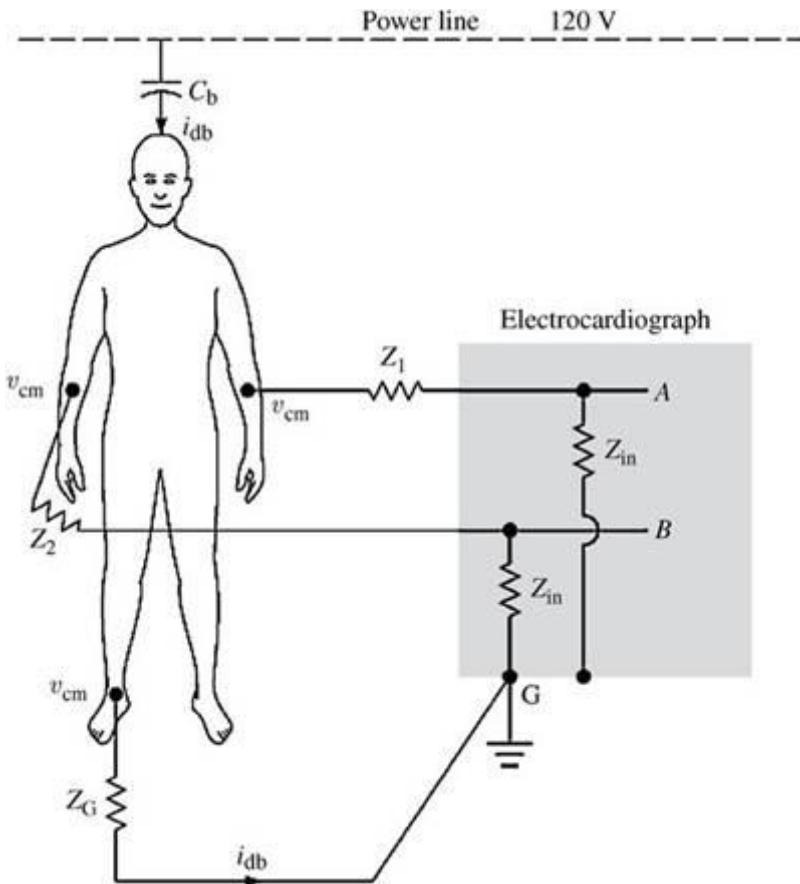
$$v_A - v_B = (6 \text{ nA})(20 \text{ k}\Omega) = 120 \mu\text{V}$$



$$v_{cm} = i_{db} Z_G$$

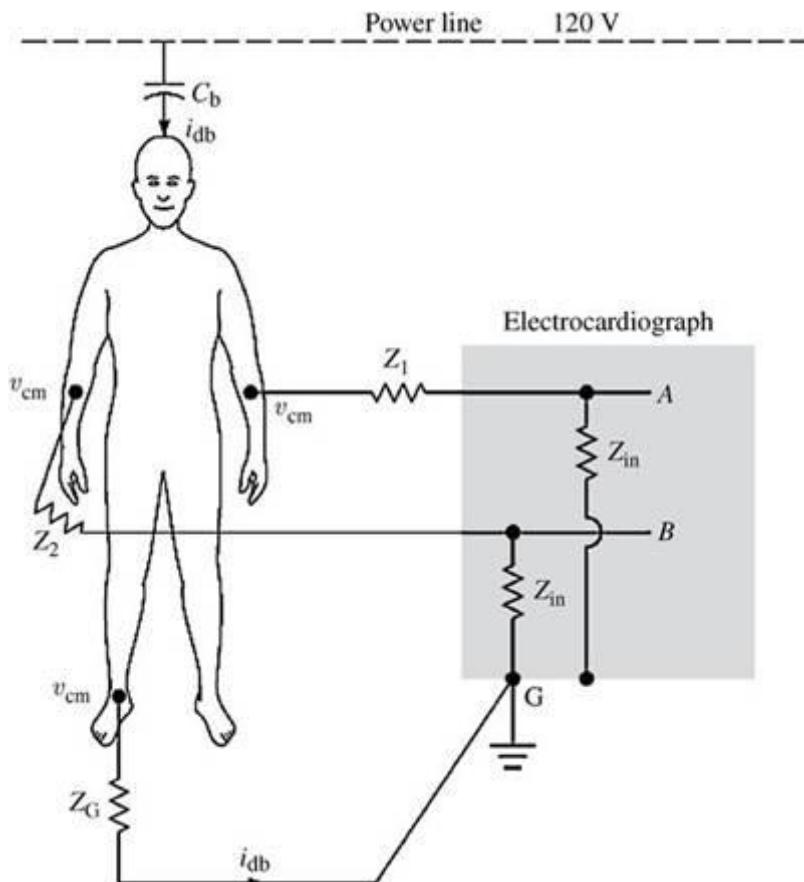
$$v_{\text{cm}} = i_{\text{db}} Z_G$$

$$v_{\text{cm}} = (0.2 \mu\text{A})(50 \text{k}\Omega) = 10 \text{ mV}$$



$$v_A - v_B = v_{cm} \left( \frac{Z_{in}}{Z_{in} + Z_1} - \frac{Z_{in}}{Z_{in} + Z_2} \right)$$

$$v_A - v_B = v_{cm} \left( \frac{Z_2 - Z_1}{Z_{in}} \right)$$



$$v_A - v_B = (10 \text{ mV})(20 \text{ k}\Omega / 5 \text{ M}\Omega) = 40 \mu\text{V}$$

Efecto en ECG y EEG?

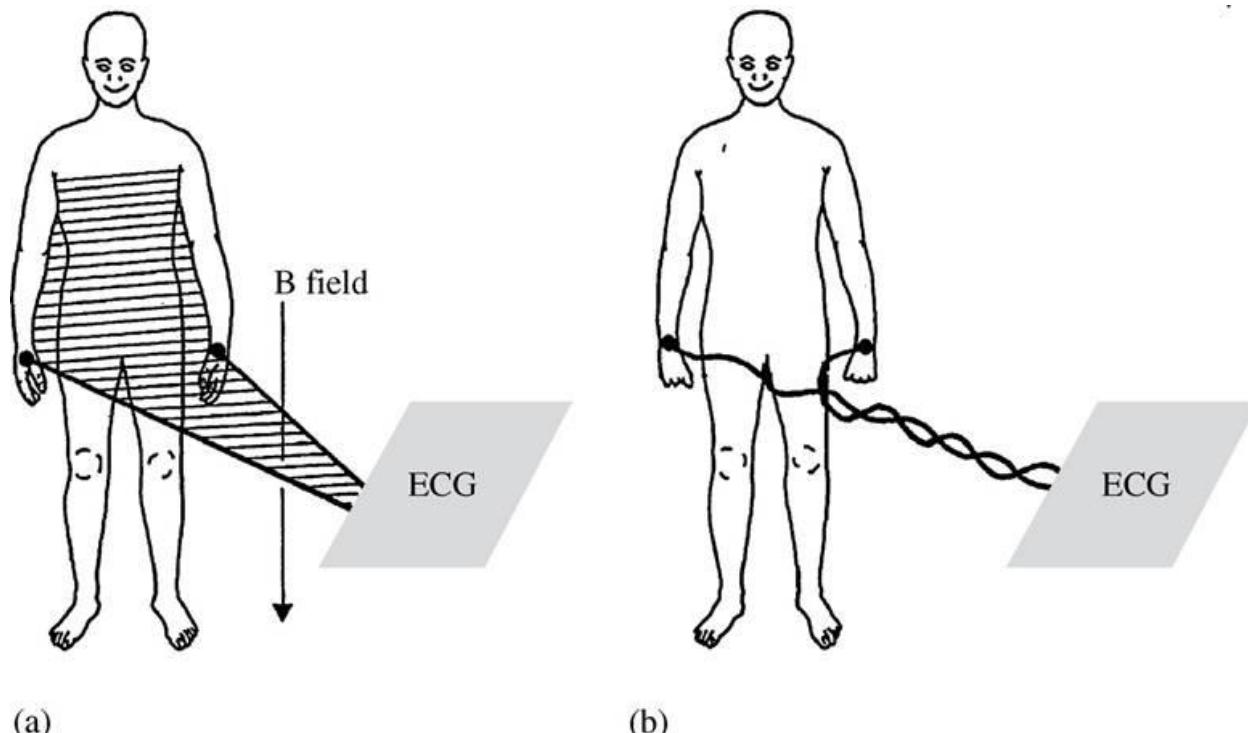
a.

b.



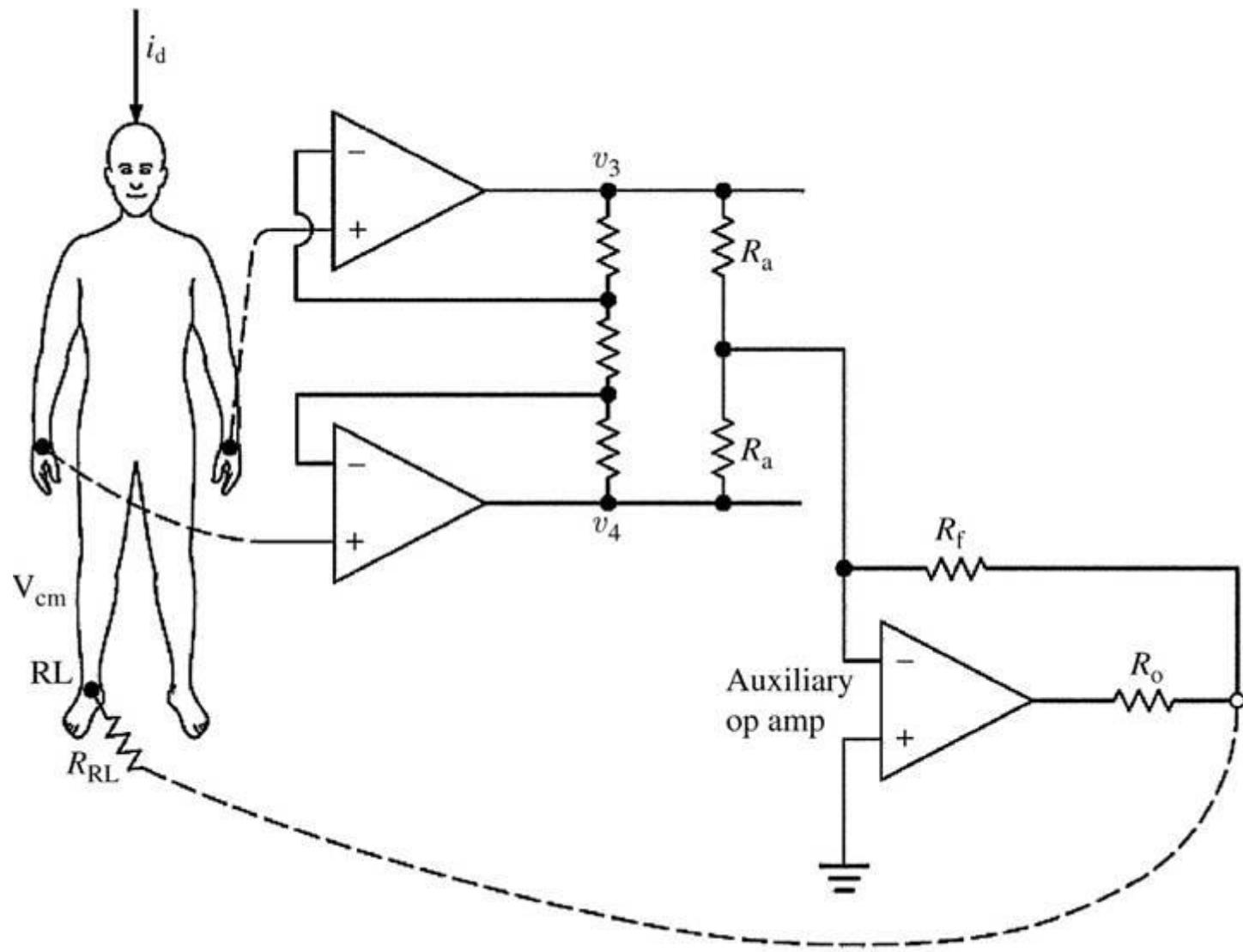
Otra fuente de interferencia de las líneas de alimentación es la inducción magnética

**Figure 6.12**  
**Magnetic-field pickup**  
**by the**  
**electrocardiograph (a)**  
**Lead wires for lead I**  
**make a closed loop**  
**(shaded area) when**  
**patient and**  
**electrocardiograph are**  
**considered in the**  
**circuit. The change in**  
**magnetic field passing**  
**through this area**  
**induces a current in the**  
**loop, (b) This effect can**  
**be minimized by**  
**twisting the lead wires**  
**together and keeping**  
**them close to the body**  
**in order to subtend a**  
**much smaller area.**



# Circuito DRL

**Figure 6.15**  
**Driven-right-leg**  
**circuit for**  
**minimizing**  
**common-mode**  
**interference.** The  
circuit derives  
common-mode  
voltage from a  
pair of averaging  
resistors  
connected to  $v_3$   
and  $v_4$  in Figure  
3.5. The right leg  
is not grounded  
but is connected  
to output of the  
auxiliary op amp.

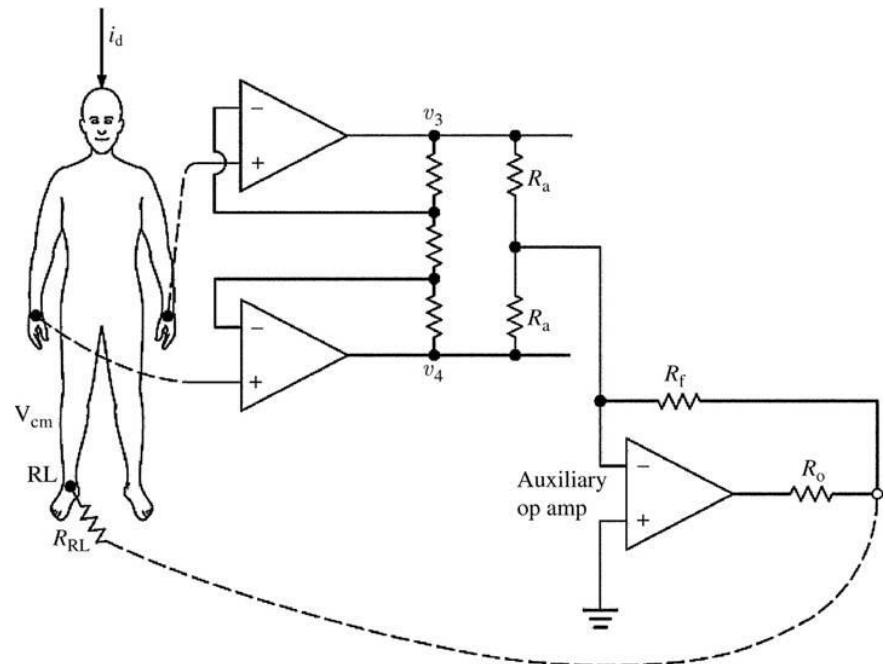


$$\frac{2v_{\text{cm}}}{R_a} + \frac{v_o}{R_f} = 0$$

$$v_o = -\frac{2R_f}{R_a} v_{\text{cm}}$$

$$v_{\text{cm}} = R_{\text{RL}} i_d + v_o$$

$$v_{\text{cm}} = \frac{R_{\text{RL}} i_d}{1 + 2R_f/R_a}$$



## Ejercicio:

En un hospital rural se quiere comprar un equipo de EEG, pero no se tiene el presupuesto para equipar una sala de adquisición con aislación electromagnética.

Un ingeniero clínico, en base a ciertos estudios, estima que puede tenerse ruido en modo común de amplitud 100mV.

¿Cuál es el CMRR mínimo del amplificador de EEG en estas condiciones, donde se esperan 25 $\mu$ V de amplitud del EEG y se desea que el ruido en modo común no supere el 1%?