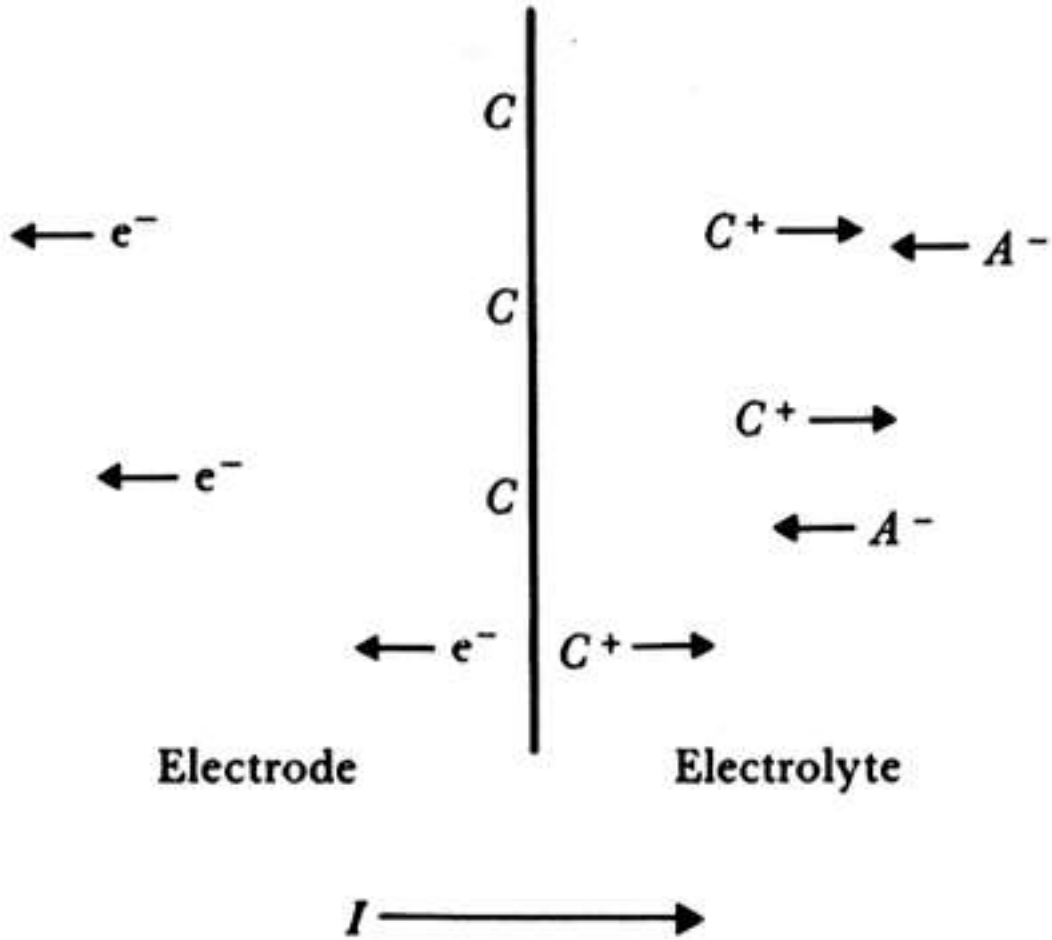


Figure 5.1 Electrode-electrolyte interface The current crosses it from left to right. The electrode consists of metallic atoms C. The electrolyte is an aqueous solution containing cations of the electrode metal C^+ and anions A^-.

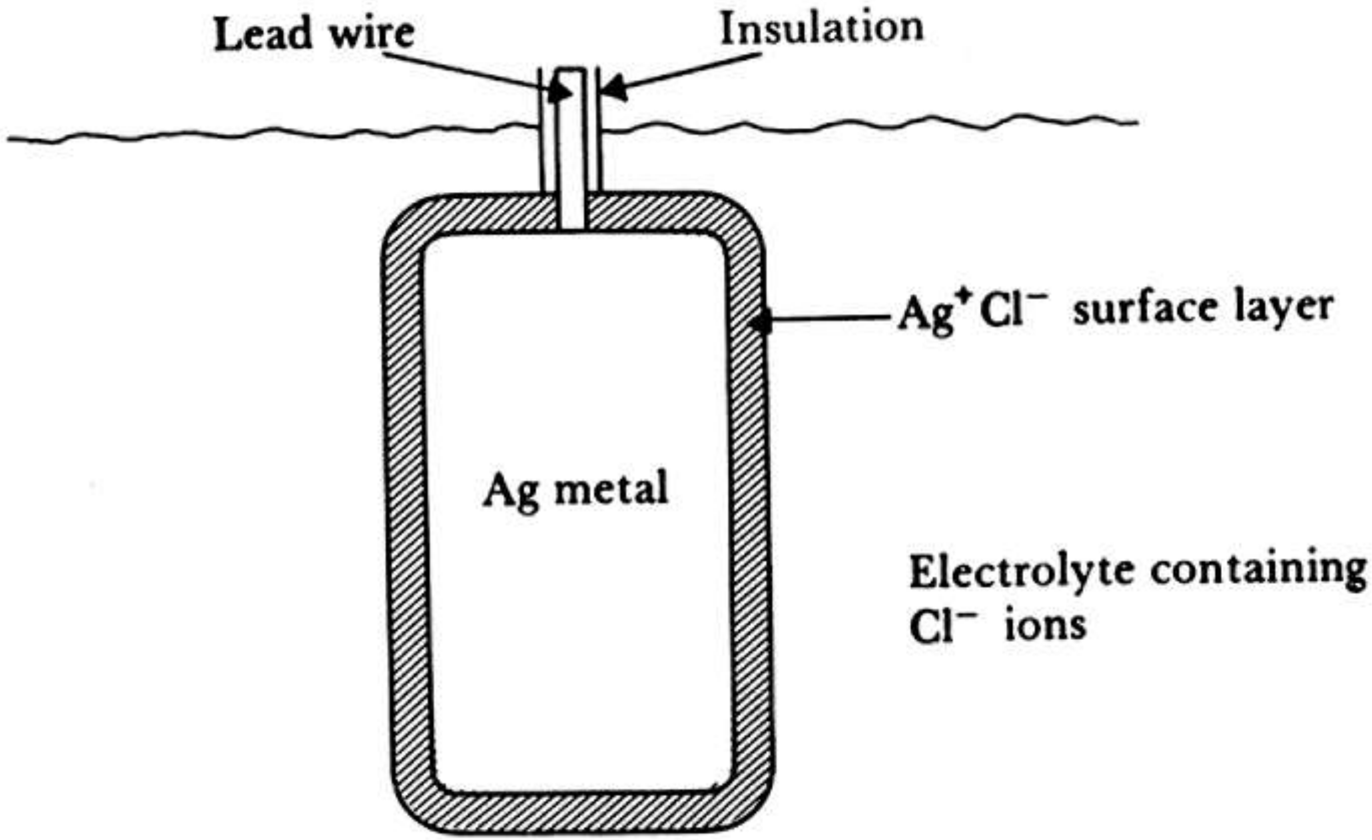


Figure 5.2 A silver/silver chloride electrode, shown in cross section.

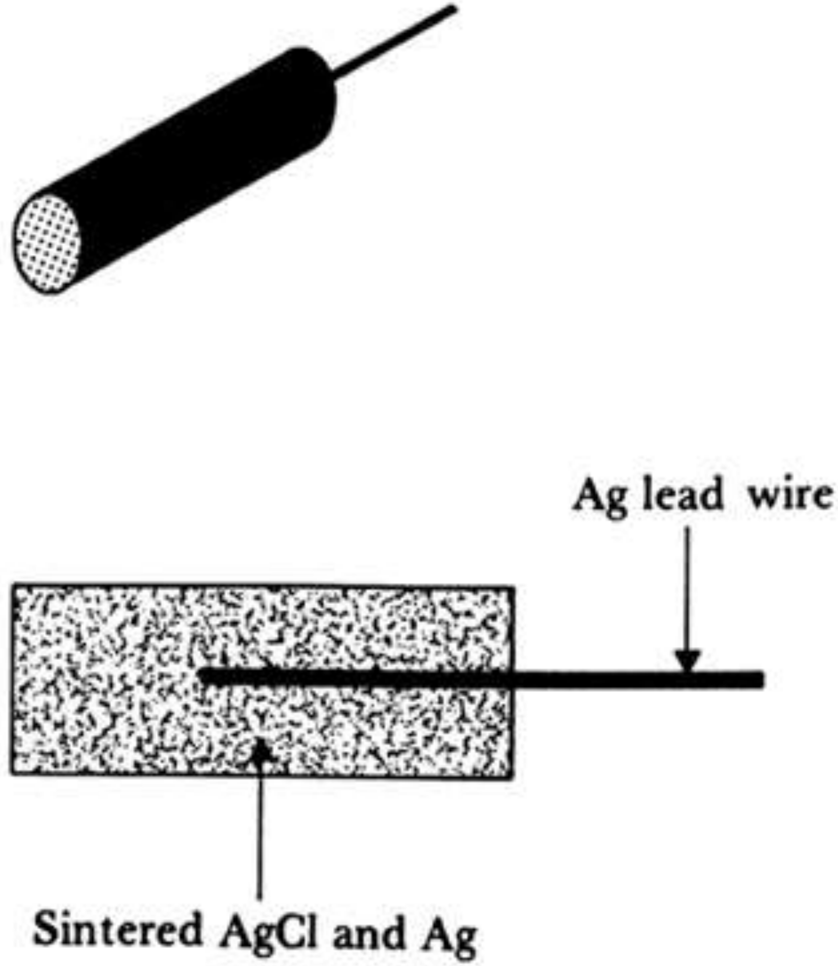


Figure 5.3 Sintered Ag/AgCl electrode.

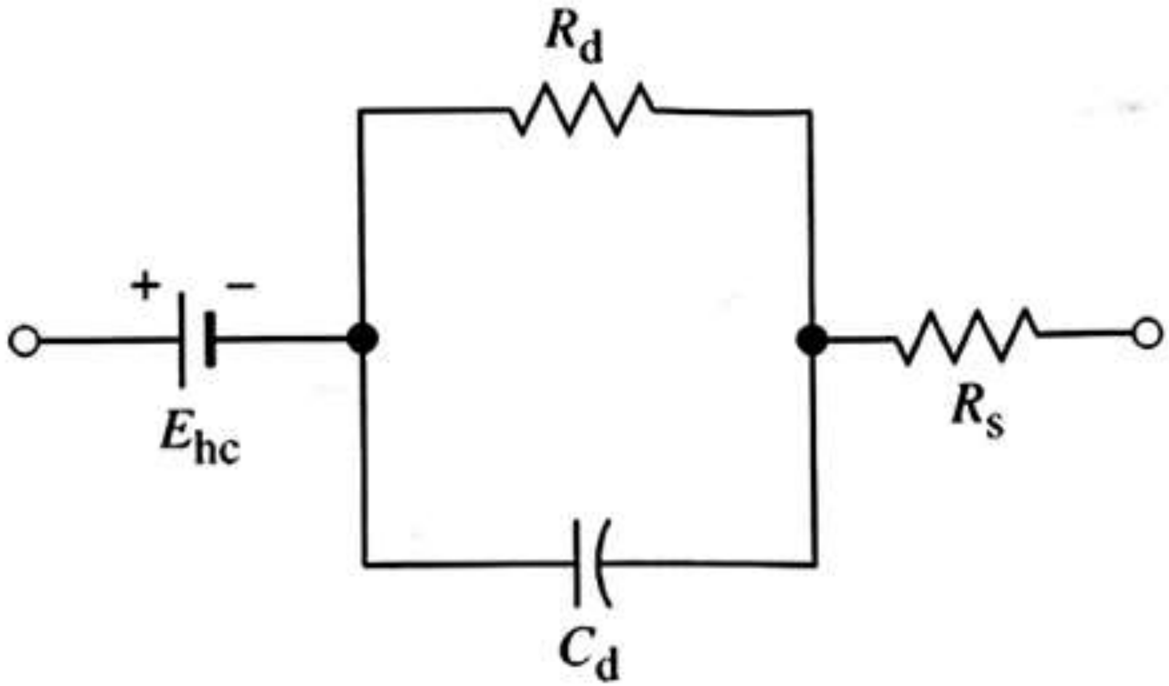


Figure 5.4 Equivalent circuit for a biopotential electrode in contact with an electrolyte
E_{hc} is the half-cell potential, R_d and C_d make up the impedance associated with the electrode-electrolyte interface and polarization effects, and R_s is the series resistance associated with interface effects and due to resistance in the electrolyte.

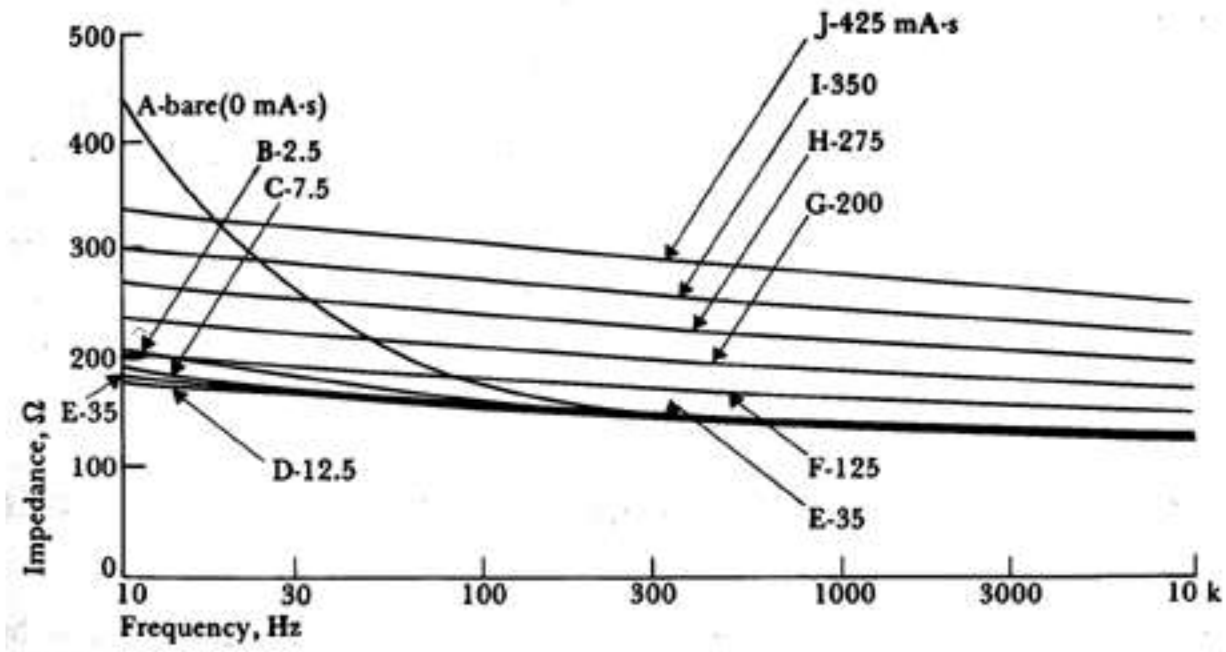


Figure 5.5 Impedance as a function of frequency for Ag electrodes coated with an electrolytically deposited AgCl layer. The electrode area is 0.25 cm^2. Numbers attached to curves indicate the number of mA·s for each deposit. (From L. A. Gedders, L. E. Baker, and A. G. Moore, "Optimum Electrolytic Chloriding of Silver Electrodes," *Medical and Biological Engineering*, 1969, 7, pp.49-56.)

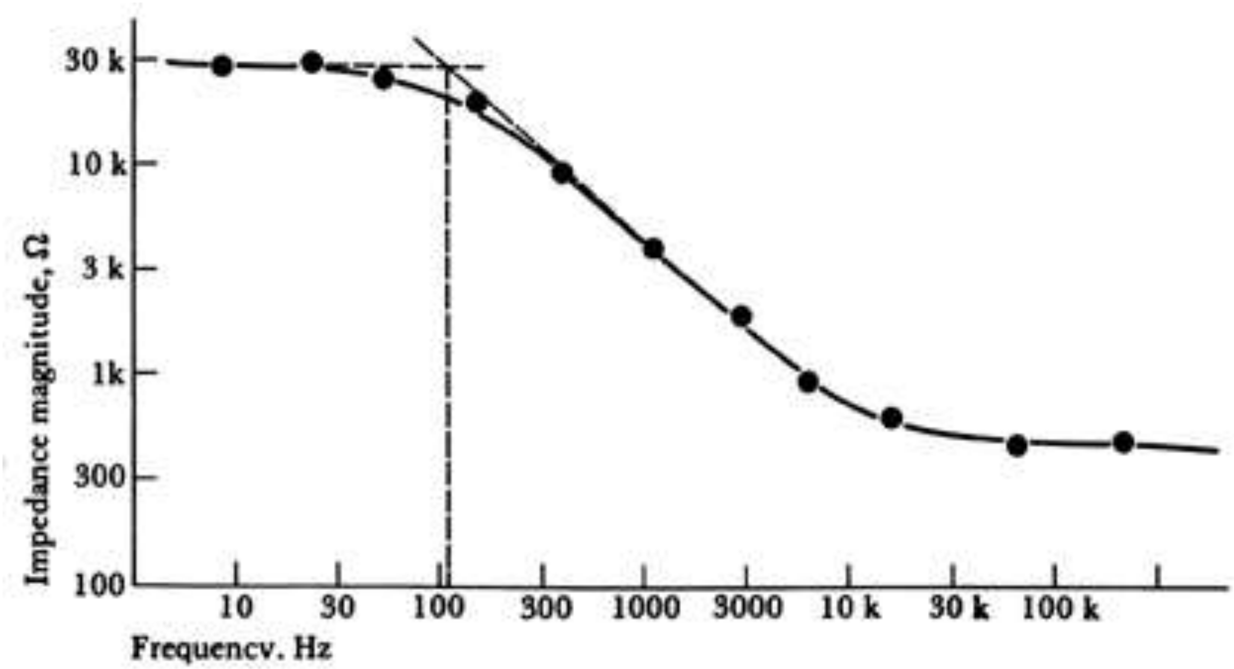


Figure 5.6 Experimentally determined magnitude of impedance as a function of frequency for electrodes.

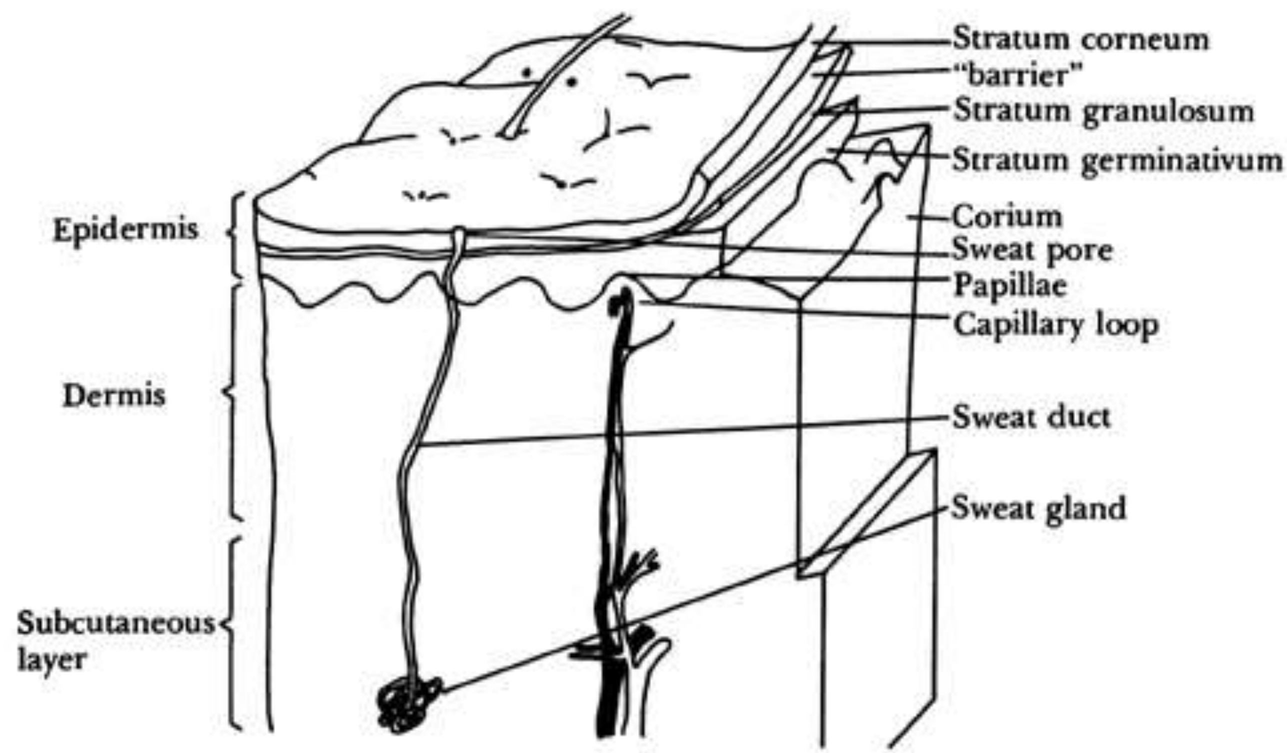


Figure 5.7 Magnified section of skin, showing the various layers (Copyright © 1977 by The Institute of Electrical and Electronics Engineers. Reprinted with permission, from *IEEE Trans. Biomed. Eng.*, March 1977, vol. BME-24, no. 2, pp. 134-139.)

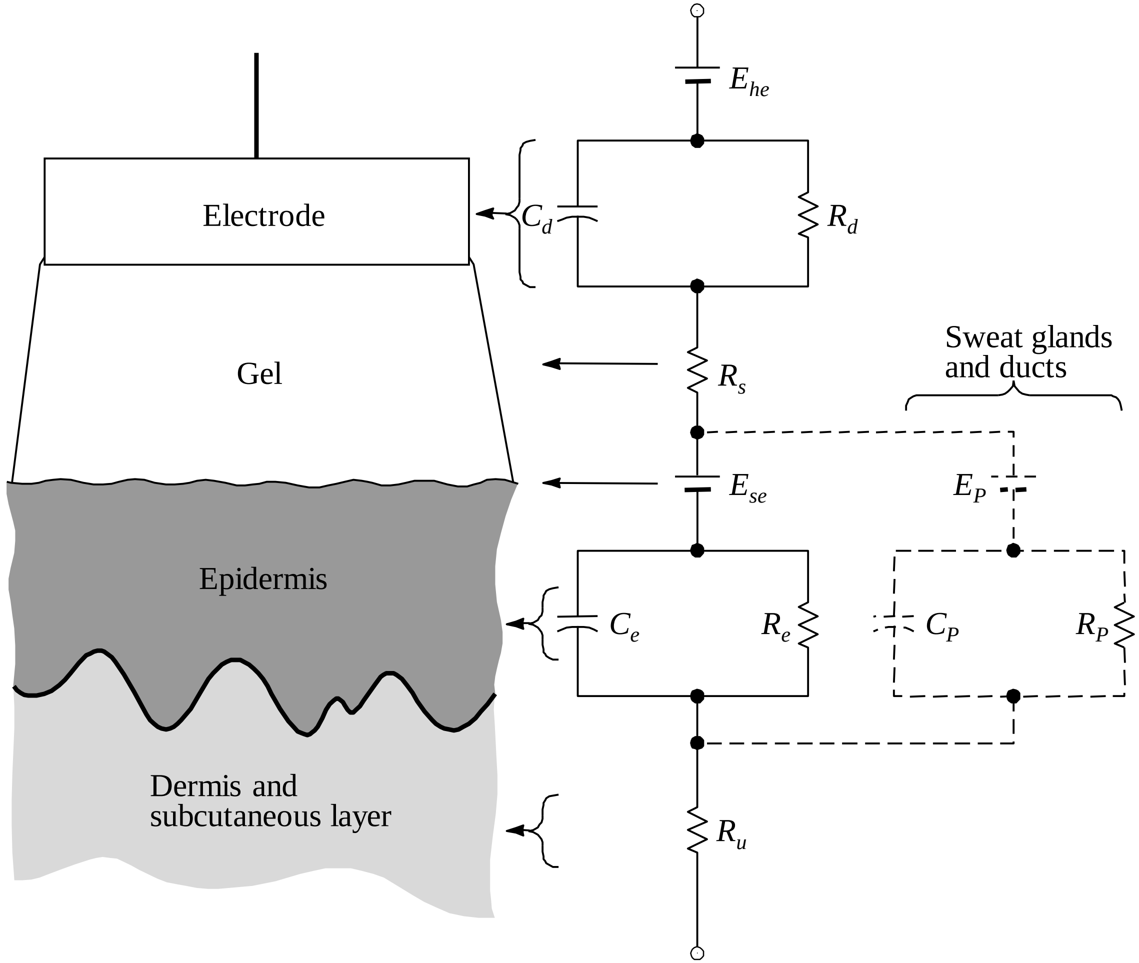


Figure 5.8 A body-surface electrode is placed against skin, showing the total electrical equivalent circuit obtained in this situation. Each circuit element on the right is at approximately the same level at which the physical process that it represents would be in the left-hand diagram.

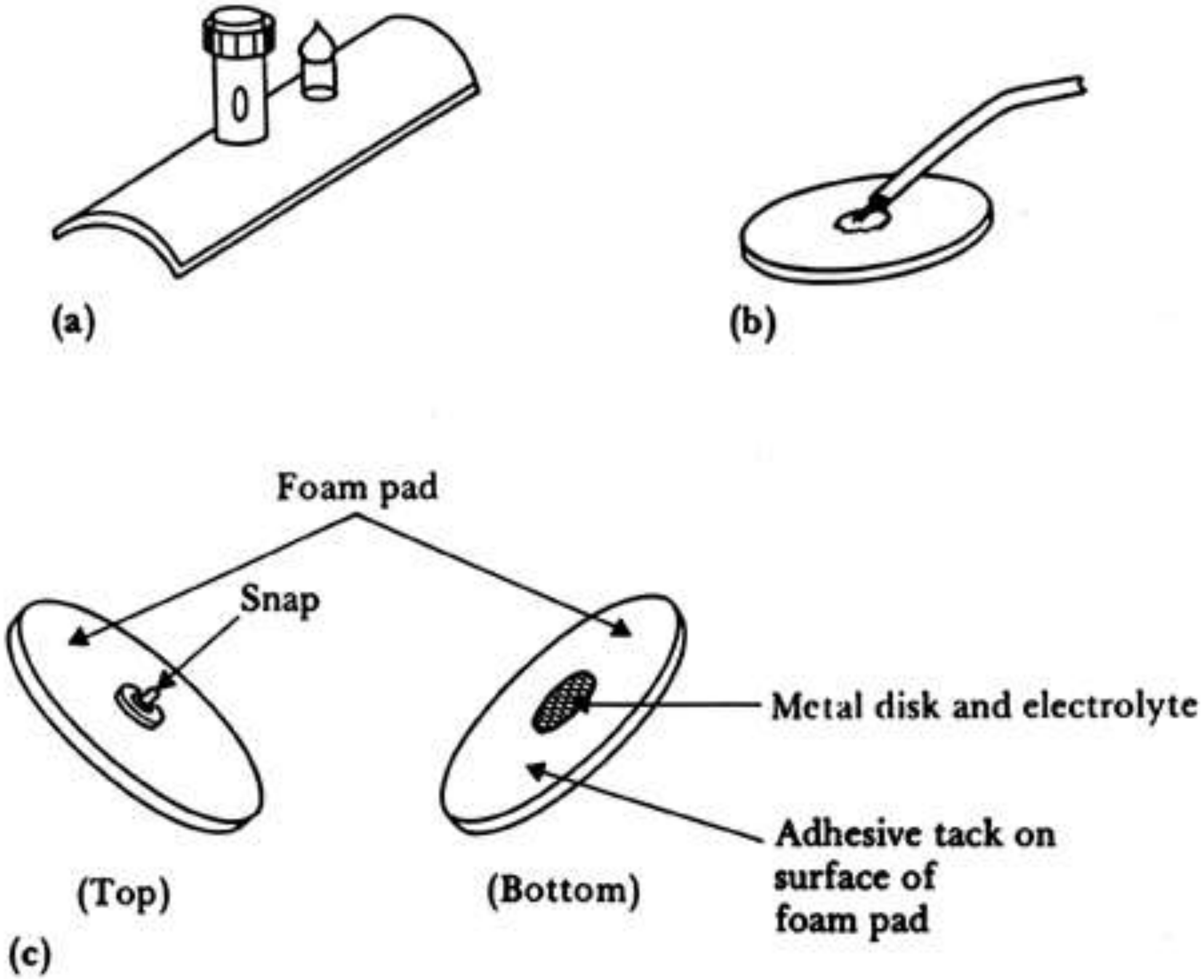


Figure 5.9 Body-surface biopotential electrodes (a) Metal-plate electrode used for application to limbs. (b) Metal-disk electrode applied with surgical tape. (c) Disposable foam-pad electrodes, often used with electrocardiograph monitoring apparatus.

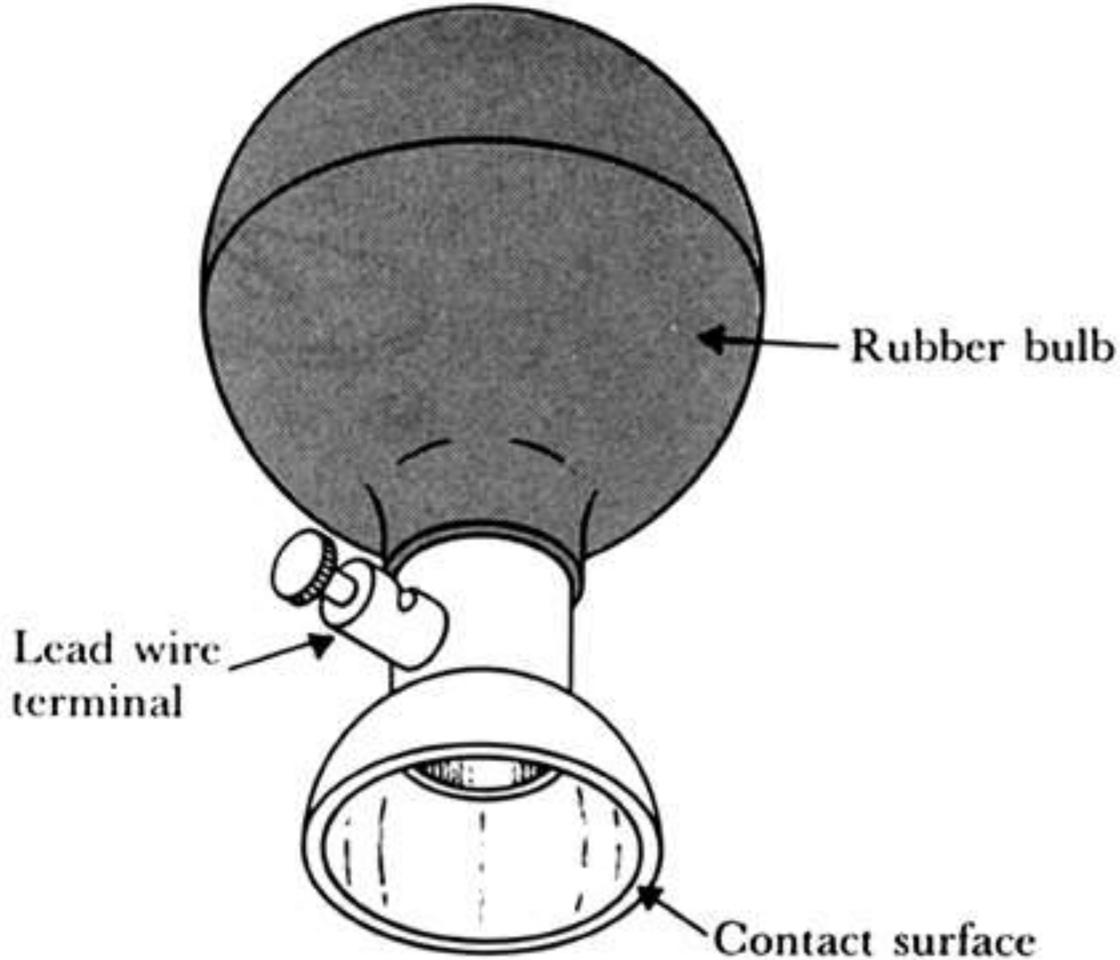


Figure 5.10 A metallic suction electrode is often used as a precordial electrode on clinical electrocardiographs.

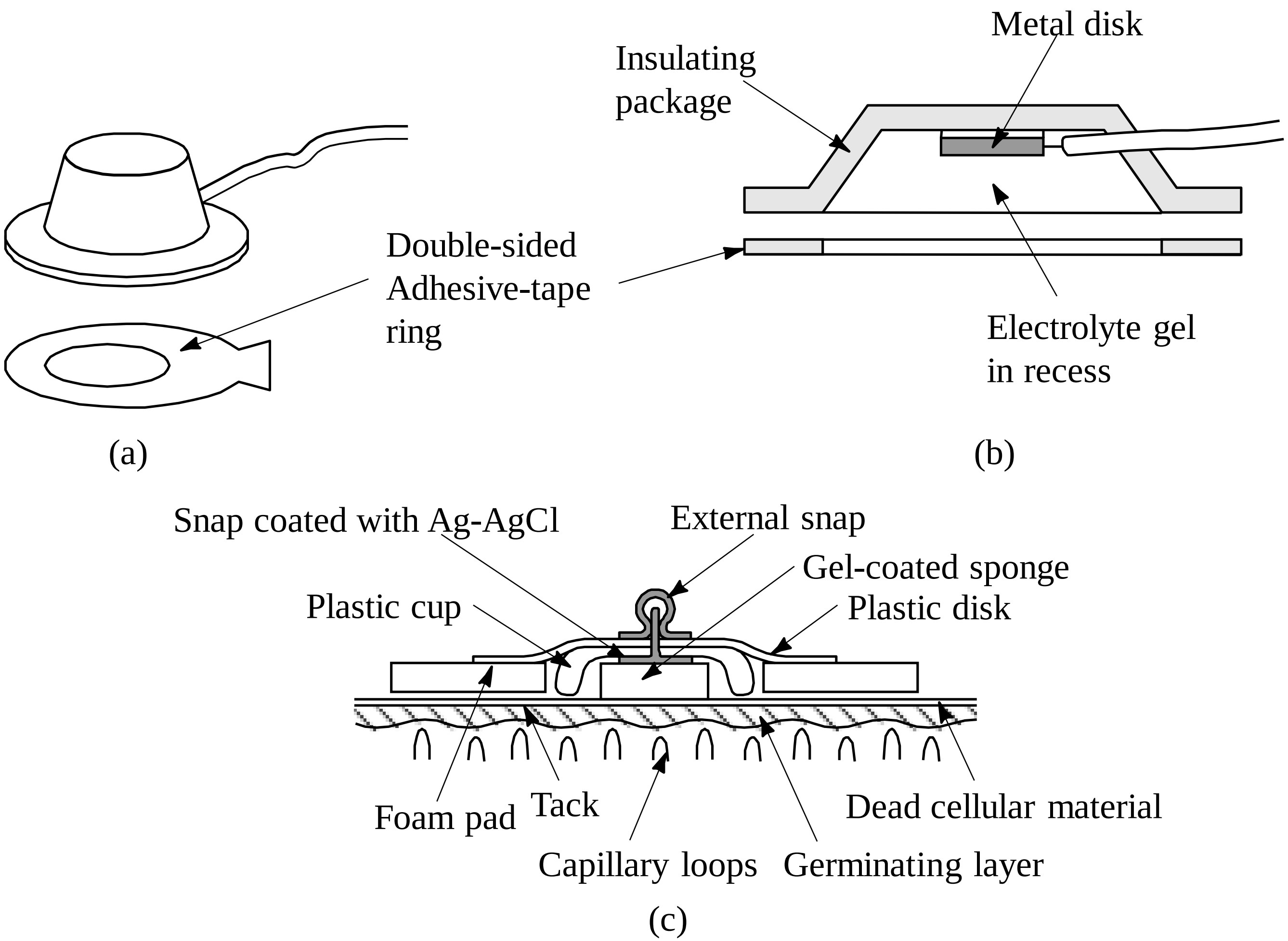


Figure 5.11 Examples of floating metal body-surface electrodes (a) Recessed electrode with top-hat structure. (b) Cross-sectional view of the electrode in (a). (c) Cross-sectional view of a disposable recessed electrode of the same general structure shown in Figure 5.9(c). The recess in this electrode is formed from an open foam disk, saturated with electrolyte gel and placed over the metal electrode.

Figure 5.12 Flexible body-surface electrodes (a) Carbon-filled silicone rubber electrode. (b) Flexible thin-film neonatal electrode (after Neuman, 1973). (c) Cross-sectional view of the thin-film electrode in (b). [Parts (b) and (c) are from International Federation for Medical and Biological Engineering. *Digest of the 10th ICMBE*, 1973.]

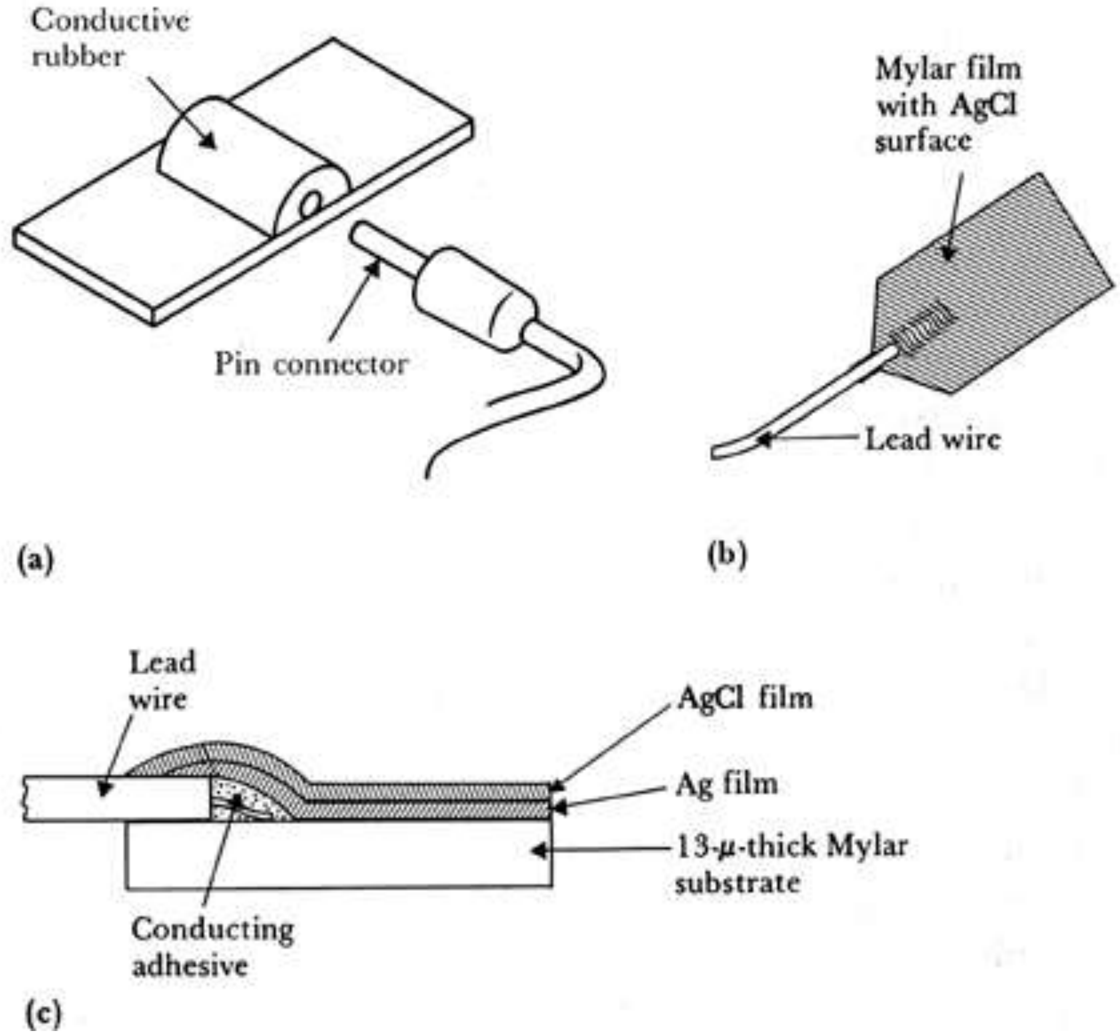
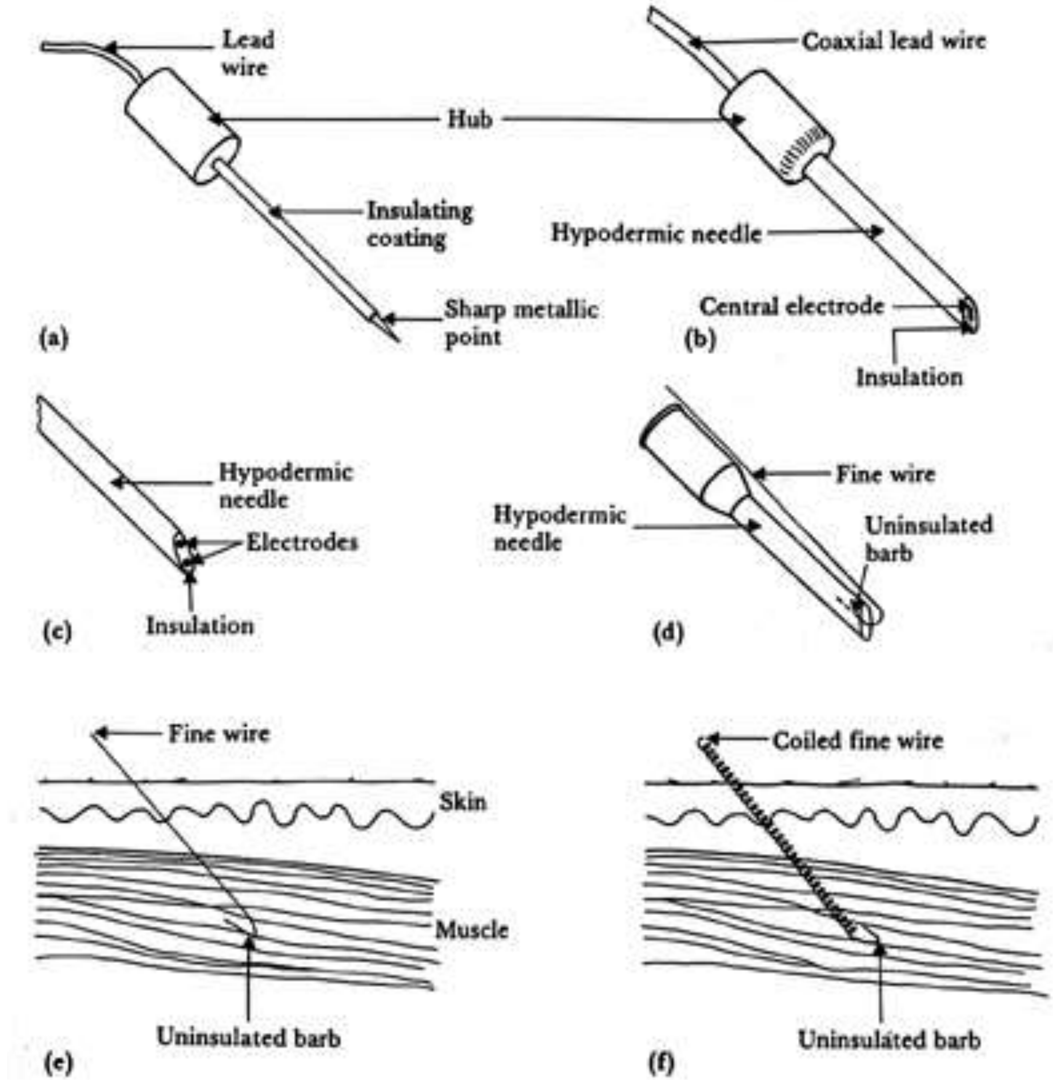


Figure 5.13 Needle and wire electrodes for percutaneous measurement of biopotentials (a) Insulated needle electrode. (b) Coaxial needle electrode. (c) Bipolar coaxial electrode. (d) Fine-wire electrode connected to hypodermic needle, before being inserted. (e) Cross-sectional view of skin and muscle, showing coiled fine-wire electrode in place.



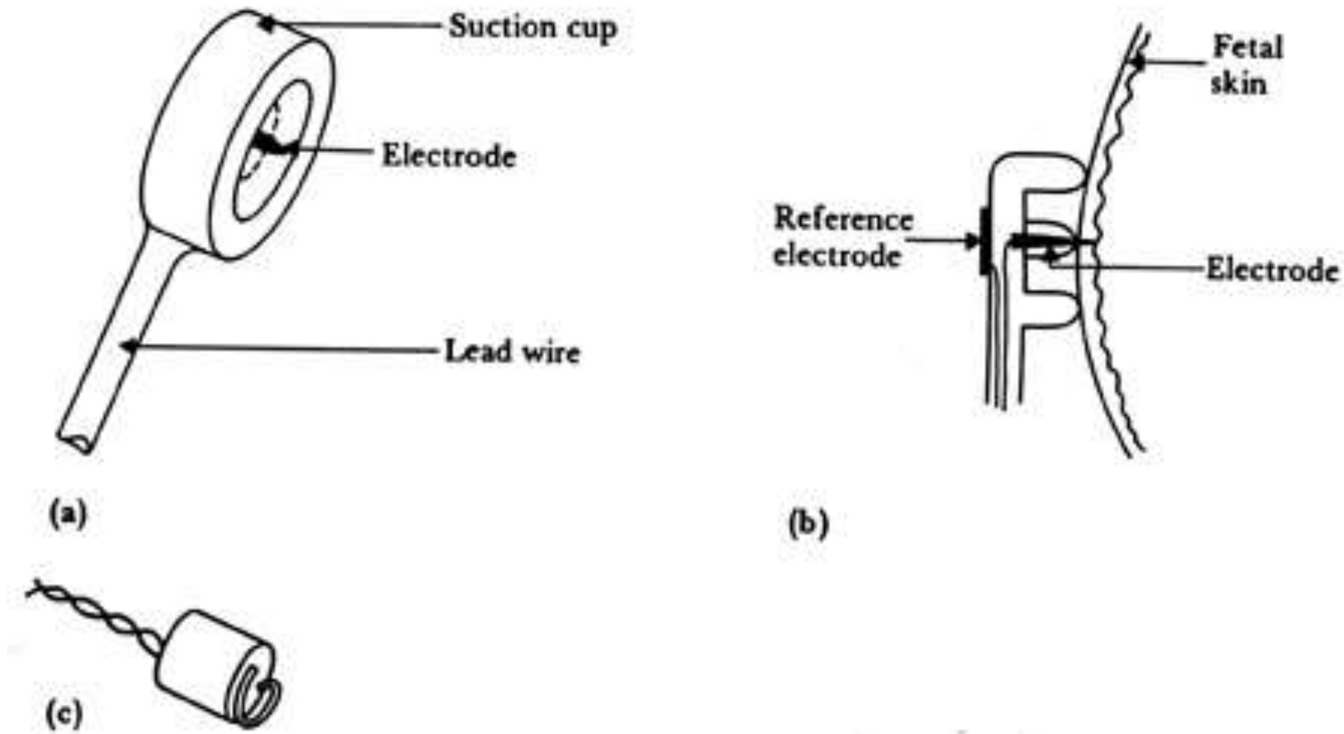


Figure 5.14 Electrodes for detecting fetal electrocardiogram during labor, by means of intracutaneous needles (a) Suction electrode. (b) Cross-sectional view of suction electrode in place, showing penetration of probe through epidermis. (c) Helical electrode, which is attached to fetal skin by corkscrew type action.

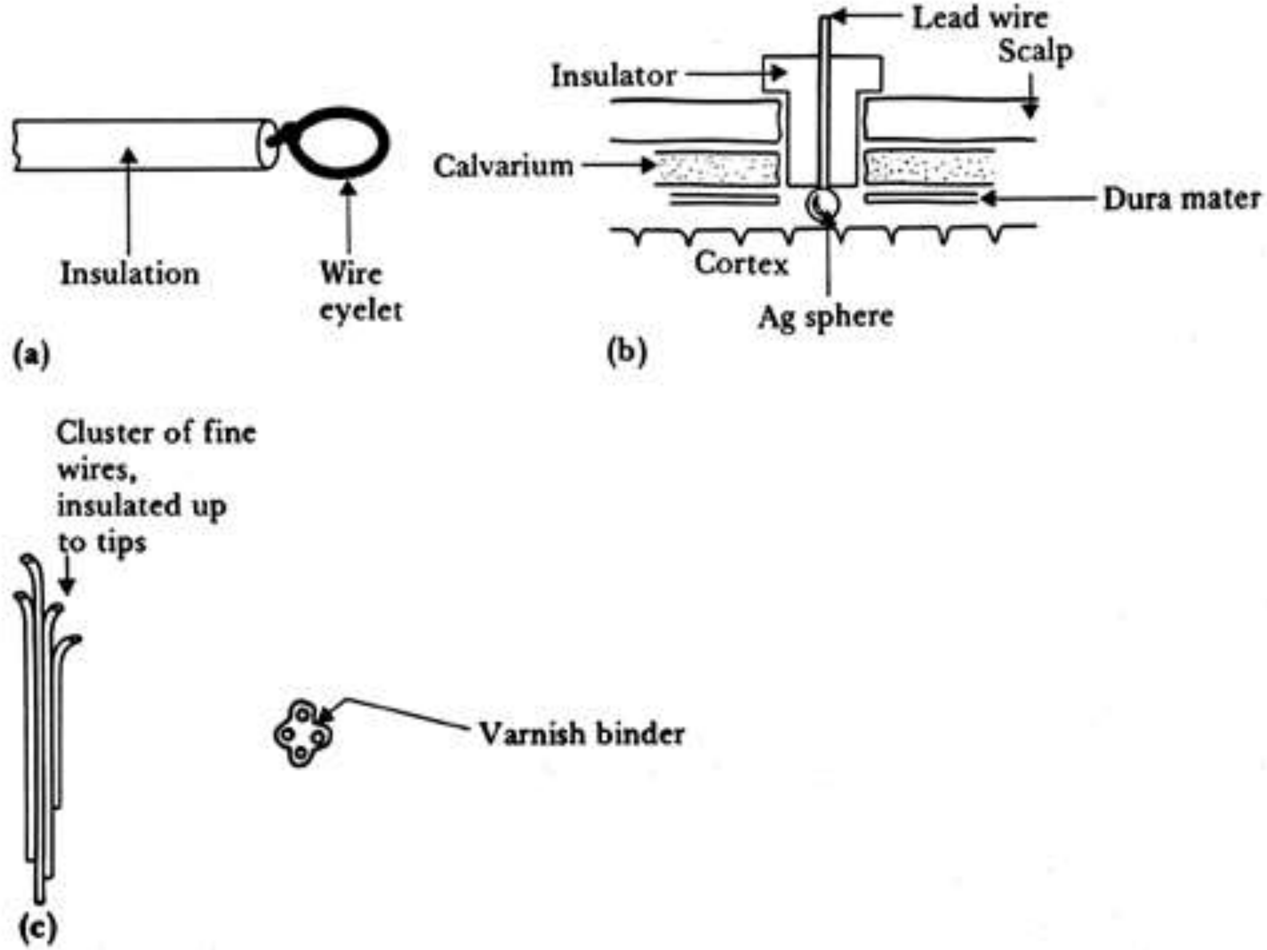
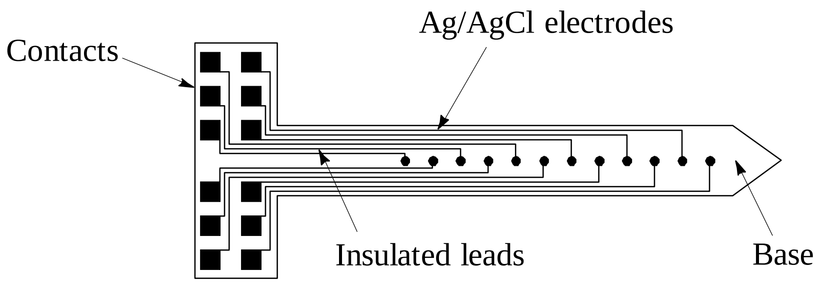
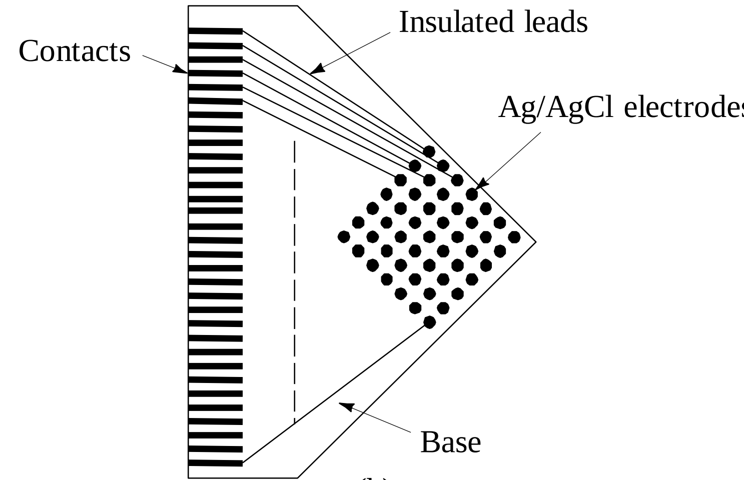


Figure 5.15 Implantable electrodes for detecting biopotentials (a) Wire-loop electrode. (b) Silver-sphere cortical-surface potential electrode. (c) Multielement depth electrode.

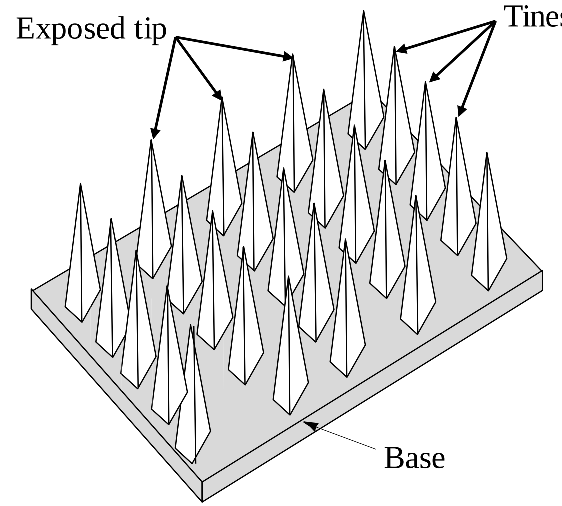


(a)



(b)

Figure 5.16 Examples of microfabricated electrode arrays. (a) One-dimensional plunge electrode array (after Mastrototaro *et al*., 1992), (b) Two-dimensional array, and (c) Three-dimensional array (after Campbell *et al*., 1991).



(c)

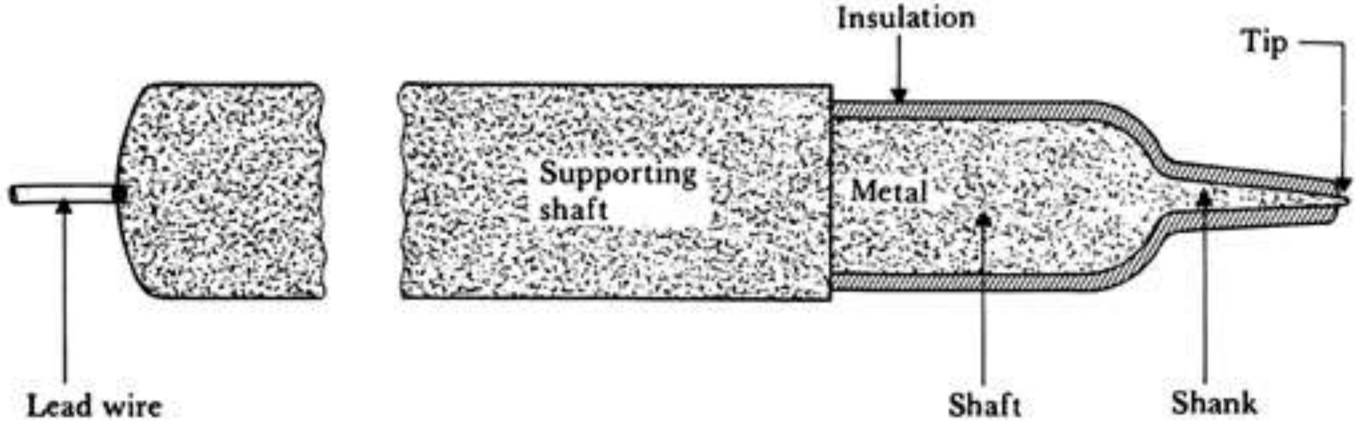


Figure 5.17 The structure of a metal microelectrode for intracellular recordings.

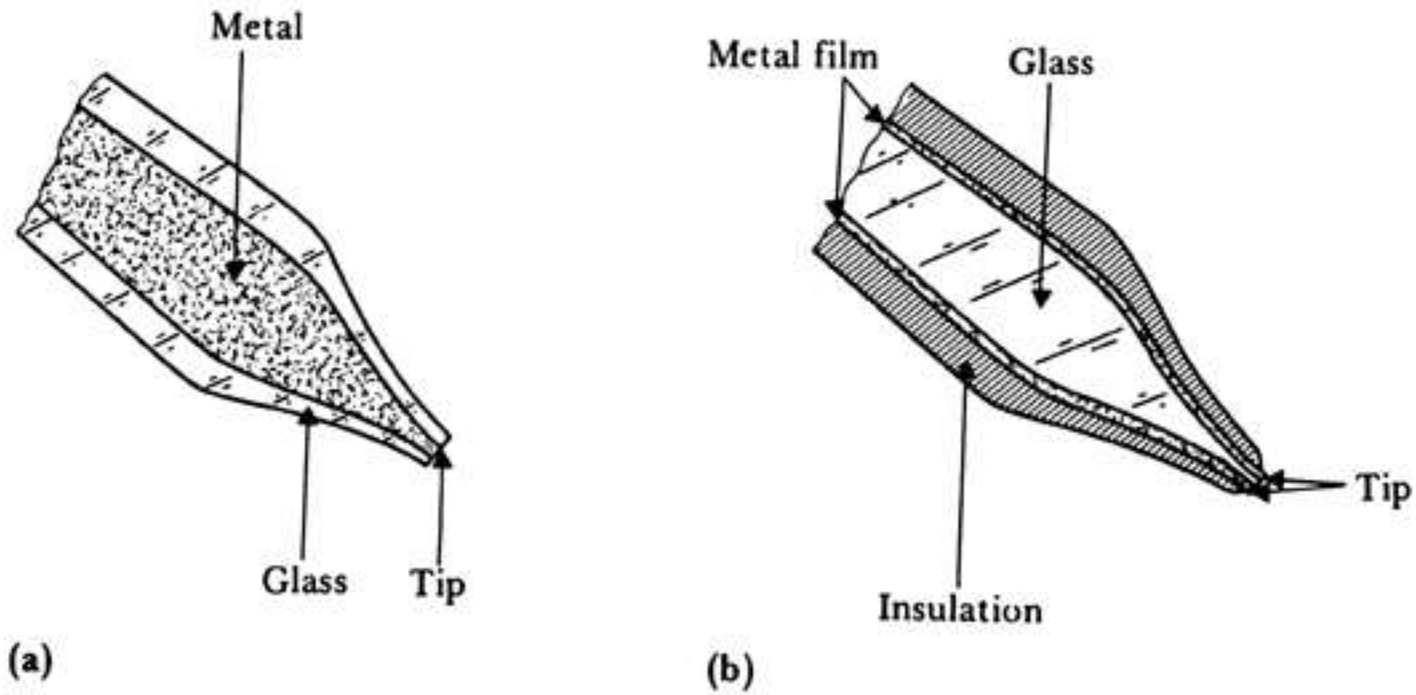


Figure 5.18 Structures of two supported metal microelectrodes (a) Metal-filled glass micropipet. (b) Glass micropipet or probe, coated with metal film.

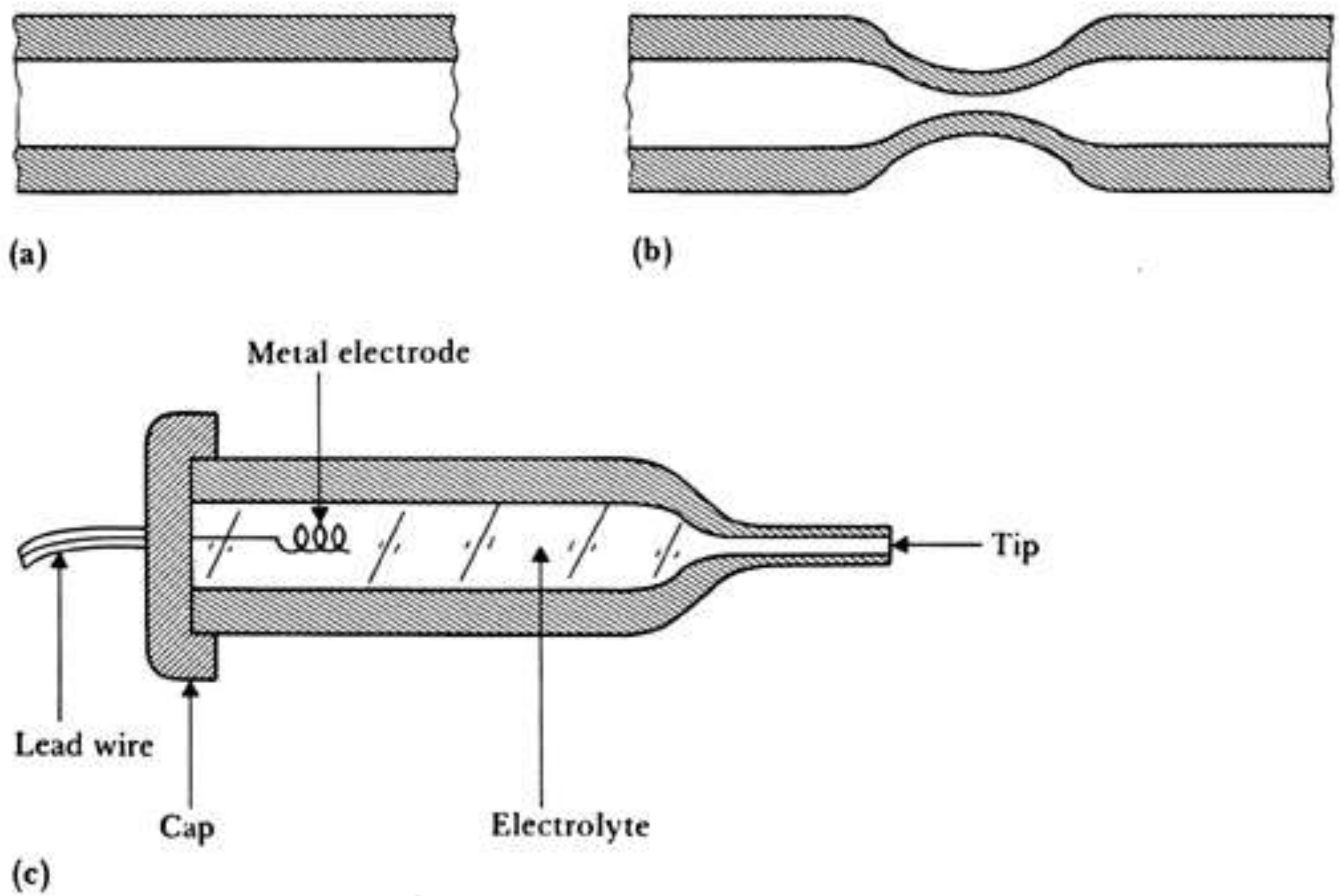


Figure 5.19 A glass micropipet electrode filled with an electrolytic solution (a) Section of fine-bore glass capillary. (b) Capillary narrowed through heating and stretching. (c) Final structure of glass-pipet microelectrode.

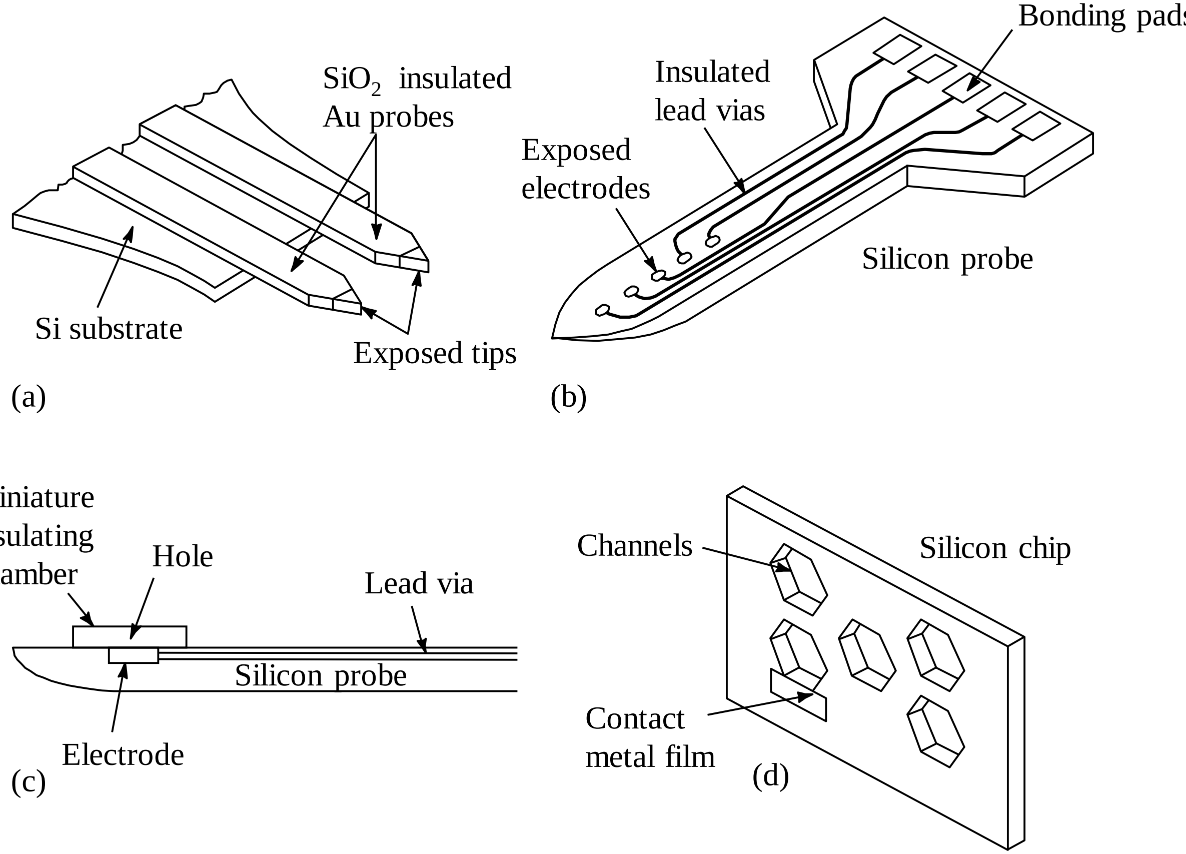


Figure 5.20 Different types of microelectrodes fabricated using microelectronic technology (a) Beam-lead multiple electrode. (Based on Figure 7 in K. D. Wise, J.B. Angell, and A. Starr, "An Integrated Circuit Approach to Extracellular Microelectrodes." Reprinted with permission from *IEEE Trans. Biomed. Eng.*, 1970, BME-17, pp. 238-246. Copyright (C) 1970 by the institute of Electrical and Electronics Engineers.) (b) Multielectrode silicon probe after Drake *et al*. (c) Multiple-chamber electrode after Prohaska *et al*. (d) Peripheral-nerve electrode based on the design of Edell.

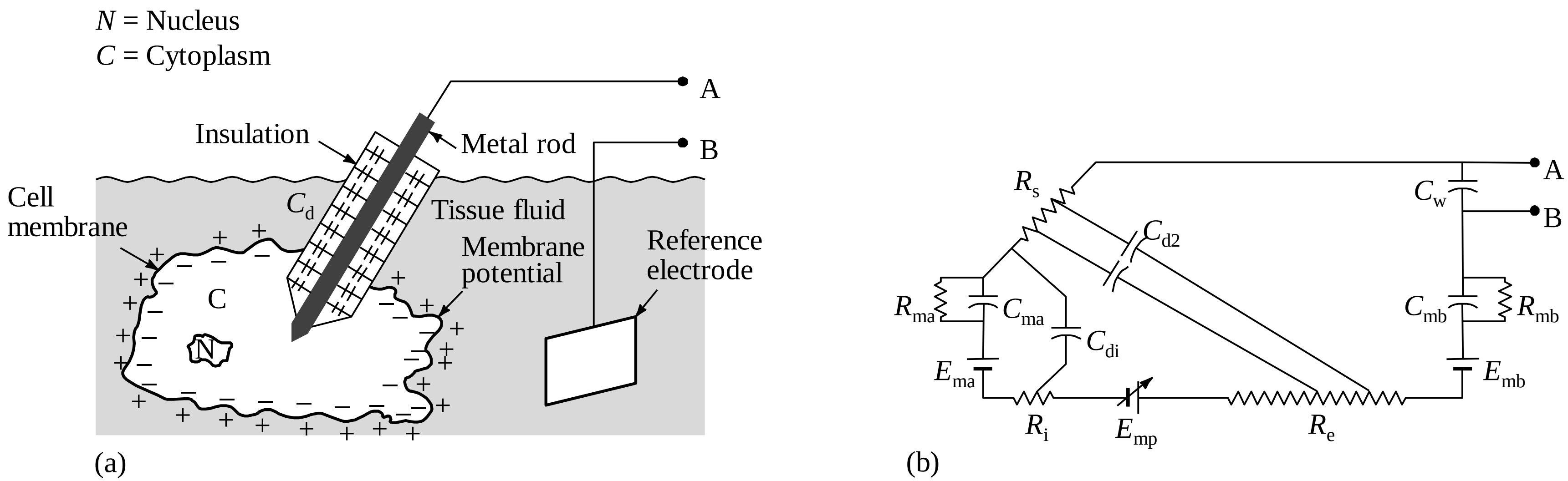
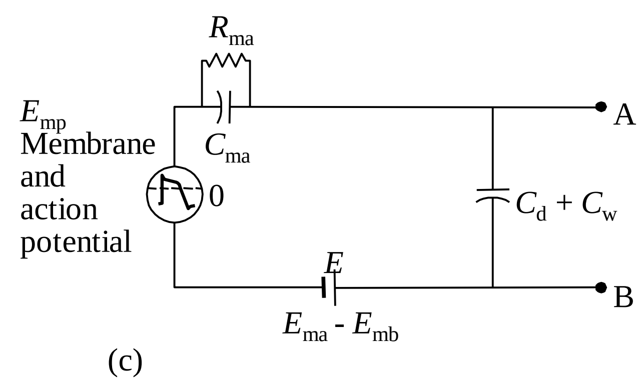


Figure 5.21 Equivalent circuit of metal microelectrode (a) Electrode with tip placed within a cell, showing origin of distributed capacitance. (b) Equivalent circuit for the situation in (a). (c) Simplified equivalent circuit. (From L. A. Geddes, *Electrodes and the Measurement of Bioelectric Events*, Wiley-Interscience, 1972. Used with permission of John Wiley and Sons, New York.)



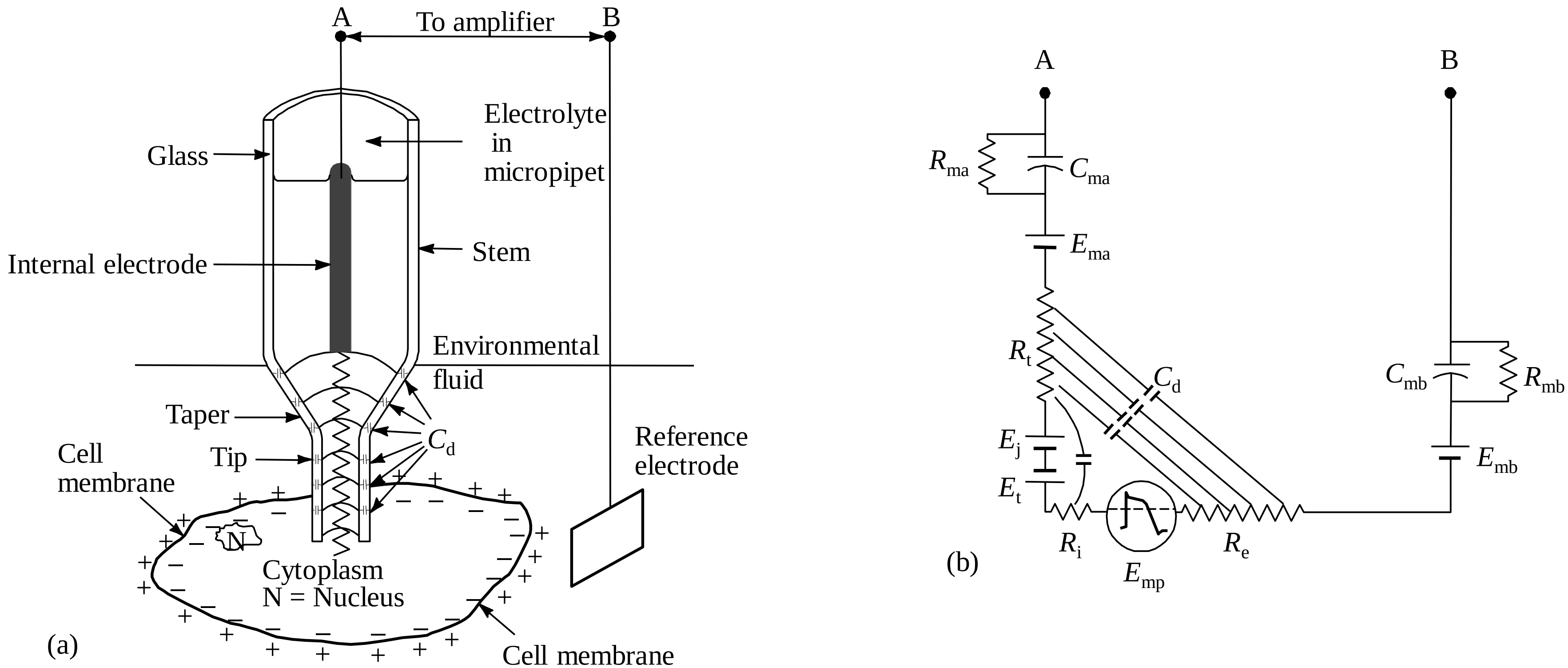
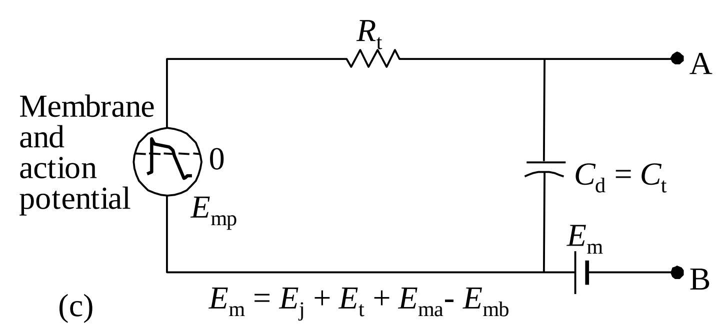


Figure 5.22 Equivalent circuit of glass micropipet microelectrode (a) Electrode with its tip placed within a cell, showing the origin of distributed capacitance. (b) Equivalent circuit for the situation in (a). (c) Simplified equivalent circuit. (From L. A. Geddes, Electrodes and the Measurement of Bioelectric Events, Wiley-Interscience, 1972. Used with permission of John Wiley and Sons, New York.)



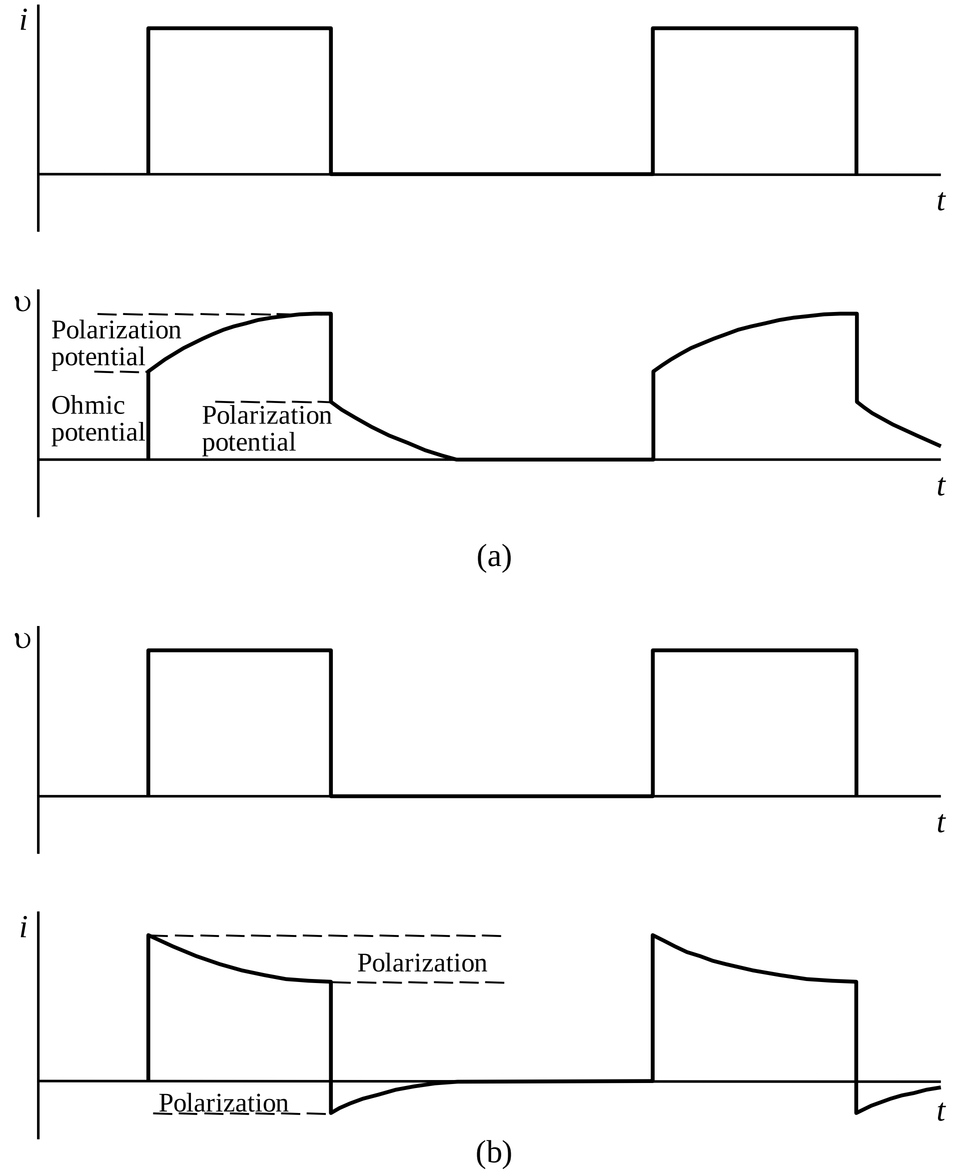


Figure 5.23 Current and voltage waveforms seen with electrodes used for electric stimulation (a) Constant-current stimulation. (b) Constant-voltage stimulation.