

Lecture 3 -- Neuroexcitability I -- Koester

*Electrical Equivalent Circuit Model of the Membrane:
Resting Potential and Passive Membrane Properties
Use of the Voltage Clamp to Analyze the Action Potential*

- I. The electrical signals carried by a neuron can be understood by representing the neuron by an electrical equivalent circuit model, consisting of:
 - A. Capacitors
 - B. Conductances
 - C. Batteries

- II. The lipid bilayer acts as a capacitor-
 - A. It consists of a lipid insulator that separates two conductors (ECF and cytoplasm).
 - B. It can store excess + and - charge (Q), although bulk electroneutrality is maintained (except for the region immediately adjacent to the membrane).
 - C. Separation of + and - charges on either side of the membrane gives rise to an electrical potential difference, the membrane potential ($V_m = Q/C$).
 - D. C is directly proportional to membrane area (because the lipid membrane is uniform in composition and thickness).
 - E. In order for membrane potential to change, Q must change, so capacitance acts to slow the rate of change of V_m in response to current flow across the membrane.

- III. Ion channels endow the membrane with two additional electrical properties:
 - A. Conductance (g)
 1. Virtually all current flow across the membrane is through ion channels
 2. $g = 1/R$
 - B. Electromotive force (EMF) (acts as a battery)
 1. Because of:
 - a. Selective conductance
 - b. Unequal ion distributions
 2. Battery value is determined by Nernst equilibrium potential

- IV. The resting membrane consists of channels that are permeable to K^+ , Na^+ , and Cl^- , in parallel with the membrane capacitance and ion pumps and carriers:
 - A. $V_m = (g_K \cdot E_K + g_{Cl} \cdot E_{Cl} + g_{Na} \cdot E_{Na}) / (g_K + g_{Cl} + g_{Na})$
 - B. g_K (and therefore E_K) predominate at rest
 - C. Active pumping of Na^+ and K^+ keeps the ionic batteries from running down

V. The membrane time constant:

- A. Membrane capacitance slows the rate of change of membrane potential
- B. Time constant (τ) = $R_m \times C_m$
- C. Affects the time course of synaptic potentials

VI. The membrane length constant

- A. The combination of membrane leakage channels and axial resistance causes membrane potential changes to decrement with distance
- B. Length constant (λ) = $\sqrt{r_m/r_a}$
- C. Affects the decay with distance of synaptic potentials

VII. Generation and conduction of the action potential-

- A. is needed for long distance communication via a digital pulse code
- B. has a threshold
- C. is all-or-none in height
- D. is conducted without decrement
- E. results form a positive feedback cycle involving g_{Na}

VIII. Use of the voltage clamp to analyze the action potential:

- A. The voltage clamp is a current generator with two functions:
 - 1. It steps V_m away from V_{rest}
 - 2. It clamps V_m at this value, in spite of the opening of voltage-gated ion channels
- B. When Na^+ channels open, the voltage clamp interrupts the feedback cycle by breaking the link between I_{Na} and depolarization
- C. Clamp I = membrane I (I_m)

Relevant reading: chapters 7 and 8 in “Principles”