Lecture 3:
Neuroexcitability I

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. $V_m = (g_K \bullet E_K + g_{Cl} \bullet E_{Cl} + g_{Na} \bullet E_{Na})/(g_K + g_{Cl} + g_{Na})$

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)