Lecture 04. Resting Potential

Watch the Pre-class video!

Reading (less important than the pre-class video)

Relevant reading Bear et al., pp. 70-73. Especially Box 3.3.

Learning Objectives:

1. To learn how the membrane potential changes when several ions are permeable, as described by the Goldman equation.

2. To learn how the properties of a membrane influence how the potential across the membrane changes with time and with distance along a process. These are the so –called passive properties of the membrane.

3. To learn the equations for the time and length constants with a focus on their functional importance and their application.

Lecture Outline

1. **Goldman equation.**

The Nernst potential describes an equilibrium potential when only one ion is permeable. Things are more complicated in neurons because the membrane can be permeable to multiple ions and the permeabilities can change in response to inputs from other neurons and changes in membrane voltage.

A. *Intuitively, if the permeability to an ion goes up, then we might expect that the membrane potential of a cell will move toward the equilibrium potential of that ion.*

B. *This idea that the membrane potential (V_m) at any time is governed by the equilibrium potentials of the individual ions along with their relative permeabilities is described quantitatively by the Goldman equation.*

V_m (in millivolts)=58 log $(P_k[K]_{out} + P_{Na}[Na]_{out} + P_{Cl}[Cl]_{in})/ (P_k[K]_{in} + P_{Na}[Na]_{in} + P_{Cl}[Cl]_{out})$

This equation is commonly written with relative permeabilities, with the permeability of K^+=1 and b and c representing the permeabilities of the other ions relative to it.

V_m =58 log $([K]_{out} + b[Na]_{out} + c[Cl]_{in})/ ([K]_{in} + b[Na]_{in} + c[Cl]_{out})$

2. **Passive properties:**

Signaling in the nervous system depends upon changes from the resting membrane potential that are produced by currents that flow when channels in the membrane open or close at synaptic connections or during action potentials. We need to understand something about what influences how currents entering the neuron at one place affect the local membrane potential, as well as more distant parts of the cell.

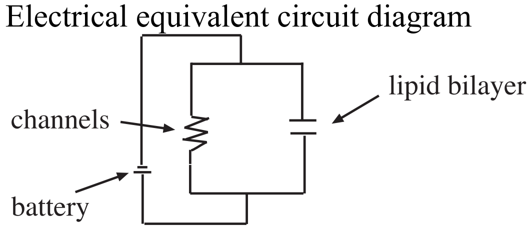
A. *Synapses are often very localized on a neuron.* They open channels that allow current to flow into the cell to affect the membrane potential at other places on the neuron.

B. *The speed and magnitude of the depolarization and the distance along the neuron that is depolarized are determined, in part, by properties of the neuronal cell membrane.*

C. *This is best seen by analogy with electrical circuits.*

Lipid bilayer behaves as a capacitor.
Channels provide variable resistance -high when closed and low when opened.
The concentration gradient provides a potential energy source – a battery.

Electrical equivalent circuit diagram



D. *Time constant-* If we inject a rectangular current into a neuron the potential rises (or falls when the current is turned off) slowly because of the combination of the capacitance and resistance of the cell.

The rise is described by:

$$V(t)=Vmax(1-e^{-t/tau})$$

The fall is described by.

$$V(t)=Vmax\ e^{-t/tau}$$

The membrane properties have the effect of slowing down potential changes, so they can sum with later ones…

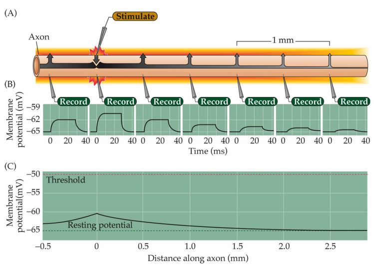
Tau = time constant = membrane resistance* membrane capacitance = $r_m c_m$

The larger the time constant, the slower the rise or fall of the potential in response to a current injection.

E. *Length constant* – Current coming in at one point on a cell will depolarize nearby membrane more than membrane farther away because:

Current leaks out through the membrane (across a resistance r_m) so there is less and less as one moves farther from where it came into the neuron.

There is a resistance to current flow inside the neuron (r_i) that makes it harder to depolarize sites far away.



NEUROSCIENCE, Third Edition, Figure 3.10 (Part 1) © 2004 Sinauer Associates, Inc.

The equation that defines the decay of the potential (V) with distance (x) is:

$V(x)=V\text{max}\ e^{-x/\text{lambda}}$

Lambda= length constant = $\text{sqrt}(r_m/ (r_o + r_i))$

length constant = $\text{sqrt}(r_m/r_i)$

The larger the length constant, the bigger the effect of a depolarization at one place on sites farther away.

This decay is a real problem for nerve cells because they need to transmit information over long distances… the decay seems incompatible with that. One major solution is:

Action potentials, our next topic.

Study Questions:

1. What is the key difference between the Goldman equation and the Nernst equation?

2. What happens to the membrane potential described by the Goldman equation when the permeability to one of the ions is increased?

3. What is the difference between the length and the time constant as described in words, not an equation?

4. How do the time and length constant influence the function of neurons in a circuit?