Medical Neuroscience | Tutorial Notes

Ionic Basis of the Resting Membrane Potential

MAP TO NEUROSCIENCE CORE CONCEPTS[1]

NCC2. Neurons communicate using both electrical and chemical signals.

LEARNING OBJECTIVES

After study of the assigned learning materials, the learner will:

1. Describe the concept of electrochemical equilibrium and relate this concept to the resting membrane potential of neurons.
2. Explain why the permeability of the neuronal plasma membrane at rest to K+ and the concentration gradient of this ion across the neuronal plasma membrane account for the resting membrane potential of neurons.
3. Use the Nernst equation to predict the resting membrane potential of neurons given knowledge of the concentration gradients of permeant ions.

TUTORIAL OUTLINE

I. Introduction: ionic movements produce electrical signals

   A. Two molecular mechanisms account for the generation of electrical signals in nerve cells (see **Figure 2.4**[2]): **ion pumps** and **ion channels**

      1. there are differences in the concentrations of specific ions across the nerve cell membrane; these **concentration gradients** are generated by ion pumps

      2. the nerve cell membrane is **selectively permeable** to certain ions; the passage of ions across the membrane occurs via the opening of ion channels

      3. thus, *PUMPS ESTABLISH THE CONCENTRATION GRADIENTS THAT PROVIDE THE "***DRIVING FORCE***" FOR THE DIFFUSION OF THE IONS THROUGH CHANNELS*

   B. Consider a model neuronal system at rest (see **Figure 2.5A** & **B**)

      1. an **electrochemical equilibrium** will be established when the inside of cells becomes just negative enough to impede the further (net) outflow of K^+ (in this case, electrochemical equilibrium is established at –58 mV)

      2. *"leak" of K^+ out of neurons accounts for the resting membrane potential*

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[1] Visit **BrainFacts.org** for *Neuroscience Core Concepts* (©2012 Society for Neuroscience) that offer fundamental principles about the brain and nervous system, the most complex living structure known in the universe.

[2] Figure references to Purves et al., *Neuroscience, 5th Ed.*, Sinauer Assoc., Inc., 2012. [click here]

a. factors needed for the generation of a bioelectric potential:

i. concentration gradient

ii. selectively permeable membrane

b. these factors are satisfied in neurons at rest for K^+ (see **Figure 2.4**)

3. very few ions need to flow across the plasma membrane to generate a membrane potential

a. concentrations of permeant ions are relatively unchanged by signaling

b. overall electrical neutrality is maintained because very few ions flow across permeable membranes and, in this case, Cl^- provides the opposite charge to balance the positive charge of K^+

c. the separation of charge that accounts for the resting membrane potential is confined to the inner and outer surfaces of the membrane

II. view an online animation that accompanies *Neuroscience, 5th. Ed.*, Chapter 2: Animation 2.1 The Resting Membrane Potential [click here]

III. Predicting the membrane potential

A. the Nernst equation

1. accounts for the equilibrium potential of a plasma membrane that is selectively permeable to one ionic species

$$E_x = \frac{58}{z} \log \frac{[X]_o}{[X]_i}$$

E_x	equilibrium potential for any ion
z	valence of the permeant ion (electrical charge)
$[X]_o$	concentration of ion "X" outside of the cell
$[X]_i$	concentration of ion "X" inside of the cell

2. in the example above (see **Figure 2.5B**),

$$E_K = \frac{58}{1} \log \frac{[1]_o}{[10]_i} = \mathbf{-58\ mV}$$

4. thus, for every 10-fold change in the concentration gradient of K^+, there will be a change of 58 mV in the equilibrium potential for K^+

5. consider the Study Questions below (end of handout)

B. Goldman equation

1. in a multi-ion environment, the *concentration gradients* of each ionic species AND the *relative permeabilities* of the plasma membrane to each ion must be considered to accurately predict the membrane potential

2. fortunately, for most neurons, we only need to be concerned with three ions: **Na^+**, **K^+**, and **Cl^-** (see **Table 2.1** for actual concentrations of these ions in mammalian neurons)

$$V \text{ or } E_m = 58 \log \times \frac{(P_K[K]_o + P_{Na}[Na]_o + P_{Cl}[Cl]_i)}{(P_K[K]_i + P_{Na}[Na]_i + P_{Cl}[Cl]_o)}$$

V voltage across the plasma membrane (membrane potential)
P permeability of the plasma membrane to each ion

3. consider the model system in **Figure 2.7A**
   a. if the membrane is permeable only to K^+, then the membrane potential will be –58 mV
   b. if the membrane is permeable only to Na^+, then the membrane potential will be +58 mV
   c. if the membrane is *equally* permeant to both K^+ and Na^+, then the membrane potential will be 0 mV
4. now consider the changes in membrane permeability that underlie the neuronal action potential (see **Figure 2.7B**)
   a. at rest the neuronal membrane is permeable to K^+, but not to Na^+ ($P_{K+} >> P_{Na+}$); thus, the resting membrane potential approaches E_K
   b. for a very brief interval (about 1 msec), the membrane may become highly permeable to Na^+ ($P_{K+} << P_{Na+}$); thus, at the peak of the action potential, the membrane potential approaches E_{Na}

IV. view an online animation that accompanies *Neuroscience, 5th. Ed.*, Chapter 2: Animation 2.2 Electrochemical Equilibrium [click here]

STUDY QUESTIONS

Suppose that extracellular sodium is 10 times greater than intracellular sodium, and the neuronal membrane is now selectively permeable only to sodium. What will be the resting membrane potential?

A. + 58 mV
B. +29 mv
C. -29 mV
D. -58 mV

Now, suppose that extracellular calcium is 10 times greater than intracellular calcium, and the neuronal membrane is now selectively permeable only to calcium. What will be the resting membrane potential?

A. + 58 mV
B. +29 mv
C. -29 mV
D. -58 mV

Next, suppose that the membrane is now permeable only to chloride ions and extracellular chloride is 10 times greater than intracellular chloride. What will be the resting membrane potential?

A. + 58 mV
B. +29 mv
C. -29 mV
D. -58 mV

Lastly, consider the situation for mainly neurons in the developing brain when intracellular chloride is about 10 times greater than extracellular chloride. If the neuronal membrane is only permeable to chloride ions, what will be the resting membrane potential?

A. + 58 mV
B. +29 mv
C. -29 mV
D. -58 mV