Lecture 06, 08 Sept 2005
Chapters 11 and 12

Vertebrate Physiology
ECOL 437 (aka MCB 437, VetSci 437)
University of Arizona
Fall 2005

instr: Kevin Bonine
t.a.: Kristen Potter

Good morning,
This is a reminder that Dr. Herman Gordan (UA Associate Professor, Cell Biology and Anatomy) will speak at Doings this Friday Sept 9th at 4pm (Gould-Simpson 601). The title of his presentation is:
“Self-organization of transmembrane kinases in synaptogenesis”
Hope to see you there.
Fiona Bailey

E. Fiona Bailey Ph.D., Research Assistant Professor, Department of Physiology, College of Medicine, The University of Arizona. Tucson AZ, USA.
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http://www.physiology.arizona.edu/labs/rnlab/fiona%20page.htm

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Nernst Question

Calculate $E_x$ if $[K^+]_{\text{inside}} = 140 \text{ mM}$ and $[K^+]_{\text{outside}} = 2.5 \text{ mM}$.

If the resting membrane potential is $-60 \text{ mV}$, which way will $K^+$ ‘want’ to move (in or out of the cell)?

OUT

Which way will $Na^+$ want to move?

IN

Which way will $K^+$ want to move if membrane potential is $-110 \text{ mV}$ or $30 \text{ mV}$?

IN OUT

Equilibrium Potential

- Calculate for a given type of ion using the simplified Nernst Equation:

$$E_x = \frac{0.058}{z} \log \frac{[X]_{\text{outside}}}{[X]_{\text{inside}}} \text{ Volts}$$

$$E_{Na} = \frac{0.058}{z} \log \frac{[Na^+]_{\text{outside}}}{[Na^+]_{\text{inside}}} \text{ mV}$$

$$E_{Na} = \frac{0.058}{z} \log \frac{120}{10} \text{ mV} = 63 \text{ mV}$$

remember Equilibrium potential ($E_x$ in mV)

when $[X]$ gradient = electrical gradient

Membrane Potential ($V_m$ in volts or mV)

- outside is zero by convention

- $V_{\text{rest}}$ for $K^+, Na^+$ about $-60 \text{ mV}$

Osmotic Properties of Cells and Relative Ion Concentrations

Permeabilities

$K^+ >> Na^+ ; Cl^-$

At Rest

$V_{\text{rest}}$ for $K^+, Na^+$ about $-60 \text{ mV}$
Nervous System

1 Sensory Neurons receive stimuli
2 Interneurons entirely in CNS
3 Motor Neurons effector organs incl. muscle, gland

Action Potential

- All-or-None from spike-initiating zone
- Changes in ion permeability...
- Changes in membrane potential
- Voltage-gated ion channels
  - Na\(^+\), K\(^+\), (Ca\(^{2+}\))

Action Potentials

- Moves information; high-speed communication
- Thoughts, Sensations, Memories, Movements etc.
- Moves SIGNAL without decrement
- AP possible because:
  1 Ionic gradients across membrane
  2 Creates electrochemical gradient and therefore source of potential energy
  3 When ion channels open, ions move down their electrochemical gradients and rapidly change the membrane potential (V_m)
- Na\(^+\) and K\(^+\) responsible for AP character...

Membrane Potential

Terms:
- Hyperpolarization 1 and 2
- Depolarization 3 and 4
- Threshold Potential see 4 (50% time get AP)
- Repolarization 3 and 4
Table 1-2: Examples of ion channels found in neurons

<table>
<thead>
<tr>
<th>Channel</th>
<th>Current flow</th>
<th>Characteristics</th>
<th>Subcellular Location</th>
<th>Function</th>
</tr>
</thead>
</table>
| Leak channel (type) | hlo | Membrane potential (K+ leaks out) | Reversibly blocked by tetraethylammonium (TEA) | Potassium permeable for 
| Voltage-gated Na+ channel | hNa | Rapidly activated by depolarization | Voltage-gated Na+ channel remains unactivated | Produces action potential of AP |
| Voltage-gated Ca2+ channel | hCa2+ | Activated by depolarization, not nearly as strongly as 
| Voltage-gated K+ channel | hK+ | Activated by depolarization, not nearly as strongly as 
| Voltage-gated Ca2+ channel (relaxation channel) | hCa2+ | Activated by depolarization, not nearly as strongly as 
| Voltage-gated K+ channel | hK+ | Activated by depolarization, not nearly as strongly as 

Action Potential

- Voltage-gated 
  Na+ channels
  - local current flow causes Vm change
  - AP is regenerative

- Refractory Periods
  - Absolute
  - Relative

~ Toilet Analogy...
How would you make the membrane in the axon hillock/spike initiation zone more, or less, likely to send an AP?
- Role of local current flow

(no APs past here)

- But can see local graded potential diminishing

- Receptor potential is graded and decremental

-Magnitude of graded receptor potential determines frequency of APs (~all of the same size)

- Neurotransmitter Release

- Alternate between graded psp and all-or-none APs

\[ \text{psp} = \text{postsynaptic potential} \]

**Excitatory or Inhibitory Postsynaptic Potentials**

**EPSP**

**IPSP**

**Graded current causing graded potential:**

\[ \text{Na}^+ \]

\[ \text{Ca}^{2+} \]

\[ \text{K}^+ \]

\[ \text{Cl}^- \]

How can you have IPSP where \( \text{Ex greater} \) (more +) than \( V_{\text{rest}} \)?
Reversal Potential
Opening channel for a given ion species X means Vm will move toward Ex
E_{rev} is the reversal potential
Can't change membrane potential beyond E_{rev} for a given ion(s) and its channels
Use Nernst to calculate for one ion species
Goldman equation for multiple ions

ACh opens for K+ and Na+, so E_{rev} between E_K and E_{Na}

EPSP and IPSP

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GLIAL:
- Schwann cells in peripheral nerves
- Oligodendrocytes in CNS

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Presynaptic inhibition
- How increase conduction velocity?
  1. Diameter
  2. Insulation
- Long axons require insulation (support cells)
- glial cells for myelination (fatty tissue) aka:
  - Schwann cells in peripheral nerves
  - Oligodendrocytes in CNS

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Synaptic Efficacy
- e.g., Cl, K+ or alter Ca^{2+}
NT release via exocytosis: the role of Ca^{2+}
Nodes of Ranvier and Saltatory Conduction

Multiple sclerosis caused by demyelination.

A given nerve bundle can have multiple axons, each with different conduction velocities.

**Table 6-1** The diameter of frog axons and the presence or absence of myelination control the conduction velocity.

<table>
<thead>
<tr>
<th>Fiber type</th>
<th>Average axon diameter (μm)</th>
<th>Conduction velocity (m·s⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Myelinated fibers</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aα</td>
<td>16.5</td>
<td>62</td>
</tr>
<tr>
<td>Aβ</td>
<td>14.0</td>
<td>25</td>
</tr>
<tr>
<td>Aγ</td>
<td>11.0</td>
<td>17</td>
</tr>
<tr>
<td>B</td>
<td>Approximately 3.0</td>
<td>4.2</td>
</tr>
<tr>
<td>Unmyelinated fibers</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>2.5</td>
<td>0.4–0.5</td>
</tr>
</tbody>
</table>

Source: Erlanger and Gasser, 1937.

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**Figure 12.4**

**Table 12.1** Kinds of synapses

<table>
<thead>
<tr>
<th>Characteristic Function</th>
<th>Chemical synapse</th>
<th>Metabolotropic synapse</th>
<th>Electrical synapse</th>
</tr>
</thead>
<tbody>
<tr>
<td>Characteristic function</td>
<td>Fast excitatory postsynaptic potential (EPSP)</td>
<td>Neuronal modulation</td>
<td>Electrical synapse</td>
</tr>
<tr>
<td>Type</td>
<td>Fast IPSP</td>
<td>Inhibition (fast IPSP)</td>
<td>Electrical coupling</td>
</tr>
<tr>
<td>Time course</td>
<td>Neuronal modulation</td>
<td>Inhibition (slow EPSP)</td>
<td>Electrical coupling</td>
</tr>
<tr>
<td>Effect</td>
<td>Excitation (fast EPSP)</td>
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*EPSP = excitatory postsynaptic potential; IPSP = inhibitory postsynaptic potential.