Neurobiology 360: Membrane Potential and the Action Potential

1a) An alien has crashed landed on earth and you have been asked to determine the basic properties of the alien’s nerve cell. You determine that the resting membrane potential is -30 mV. Design an experiment to test the ionic basis of the resting membrane potential.

Change the concentration of ions in the bathing solution and record the change in resting membrane potential.

1b) After conducting the previous experiment, as well as other experiments, you determine that Cl\(^-\) is the major contributor to the resting membrane potential. What does this tell you about the membrane?

The membrane at rest is more permeable to Cl\(^-\) compared to any other ion.

2a) What is the Na\(^+\) equilibrium potential (E\(_{Na}\)) for a cell in which the extracellular concentration of sodium ions is 150 mM and the intracellular concentration is 15 mM?

\[
E_{Na} = 58 \log \left( \frac{[150 \text{mM}]}{[15 \text{mM}]} \right) = 58 \text{mV}
\]

2b) What would the Na\(^+\) equilibrium potential (E\(_{Na}\)) be if the intracellular concentration of Na\(^+\) was increased 10 fold? What does this mean?

\[
E_{Na} = 58 \log \left( \frac{[150 \text{mM}]}{[150 \text{mM}]} \right) = 0 \text{mV}
\]

Sodium ions are in equilibrium across the membrane.

3) At rest, a cell has a resting membrane potential of -70 mV and is said to be in a steady state. What does steady state mean and how is it maintained? Is this the same as equilibrium why or why not?

Steady state means the cell is in an unvarying state. This is not the same as equilibrium, however, because each ion is at a different concentration inside and outside of the cell. This steady state is maintained by the Na\(^+\)/K\(^+\) pump which moves ions against their concentration gradients. This counterbalances the movement of ions through resting ion channels.

4) What is the difference between permeability and conductance?

Conductance measures the movement of charge across the membrane. Permeability measures the capability of ions to flow across the membrane, regardless of whether they are moving across the membrane.
5) Consider a creature from outer space whose neurons are found to have unusual action potential but function according to the same principles that human neurons do. The following ionic concentration ratios are measured:

<table>
<thead>
<tr>
<th>Ion</th>
<th>Extracellular Concentration (mM)</th>
<th>Intracellular Concentration (mM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ion 1 (A⁺)</td>
<td>10</td>
<td>1</td>
</tr>
<tr>
<td>Ion 2 (B⁻)</td>
<td>10</td>
<td>1</td>
</tr>
<tr>
<td>Ion 3 (C⁺)</td>
<td>10</td>
<td>1</td>
</tr>
</tbody>
</table>

a) The cell membrane is thought to be selectively permeable only to ion 1 (A⁺) at rest. What would the resting potential be?

\[
E_{A⁺} = 58 \log \left( \frac{[10\text{mM}]}{[1\text{mM}]} \right) = 58 \text{ mV}
\]

b) You now add a chemical that opens channels for ion 2 and the membrane potential stabilizes at -50mV. Is the membrane now more permeable to ion 1, ion 2, or both? Explain.

\[
E_{B⁻} = 58 \log \left( \frac{[1\text{mM}]}{[10\text{mM}]} \right) = -58 \text{ mV}
\]

The membrane is more permeable to Ion 2 because the resting membrane potential is closer to the equilibrium potential of Ion 2 than for Ion 1.

6) Describe the mechanism underlying the rising phase of the action potential. This is an example of a _______ positive _______ _______ feedback _______ loop.

When Na⁺ has entered the cell, voltage-gated Na⁺ channels will begin to open. Once threshold has been reached, sufficient voltage-gated Na⁺ channels are open to trigger a full action potential and thus allowing more Na⁺ to rush in the cell. As more Na⁺ rushes in, more voltage-gated Na⁺ channels will open until they are maxed out. The addition of Na⁺ (+ ions) into the cell causes the cell to depolarize (become more positive) which is why we have a rising phase in the action potential.

7) It is a physiological fact that it takes the same amount of energy to watch cartoons or presidential debates on television as it does to learn about nuclear physics, cardiac physiology, or study for an exam. Explain why your brain burns the same amount of energy doing each of these activities.

Simply stated, higher cognitive functions, like those mentioned above, require action potentials to be propagated in one cell and relayed to another. All action potentials, independent of the stimulus, are carried out in the same manner and thus are all regulated by the same mechanisms (Voltage gated Na⁺ channels, Voltage gated K⁺ channels, the Na⁺/K⁺ pump, etc, etc).