Anatomy of a Neuron

* Figure 1.1 of Purves, p. 2

Key Points

- Neurotransmitter release at chemical synapses
- Ion conductances at chemical synapses change the cell's membrane potential, $V_m$
- $A$'s in $V_m$ may initiate action potentials that propagate through the axon.
Membrane Potential

- $V_m$ is the electrical potential difference across the cell membrane. The sign reflects the inside absolute potential relative to the outside of the cell.

- The cell's lipid membrane is an insulator.

- Resting $V_m$: in absence of input, $V_m$ = negative, often $\sim -50$ or $-100$ mV but varies by cell type.

- $V_m$ is set up by charged molecules:

  - $\text{Na}^+, \text{K}^+, \text{Cl}^-, \text{Ca}^{2+}$
  
  $\text{Na}^+ \sim 140 \text{ mM}$
  $\text{K}^+ \sim 5 \text{ mM}$
  $\text{Cl}^- \sim 110 \text{ mM}$
  $\text{Ca}^{2+} \sim 1 \text{ mM}$

- Other proteins:

  - $\text{Na}^+, \text{K}^+, \text{Cl}^-, \text{Ca}^{2+}$
  
  $\text{Na}^+ \sim 5 \text{ mM}$
  $\text{K}^+ \sim 140 \text{ mM}$
  $\text{Cl}^- \sim 5 \text{ mM}$
  $\text{Ca}^{2+} \sim 0.1 \mu\text{M}$

- Other anions:

  - $\text{net - charge}$
Electrochemical Gradients are stored energy. They are maintained by active ion pumps (cells must do work to create these).

Equilibrium Potential of an ion:

Concentration Gradient

\[
\begin{array}{c}
\text{O} \\
\text{O} \\
\text{O} \\
\text{O} \\
\text{O}
\end{array}
\]


\[
\begin{array}{c}
\text{O} \\
\text{O}
\end{array}
\]

Electric Gradient

\[
\begin{array}{c}
++ \\
++ \\
++
\end{array}
\]

\[
\begin{array}{c}
+ \\
+
\end{array}
\]

Charged Molecule

\[
\begin{array}{c}
+ \quad + \\
+ \quad + \quad + \quad + \quad + \\
Chem. \downarrow \quad Electrical \downarrow \\
- \quad + \\
+ \quad +
\end{array}
\]

\[
\begin{array}{c}
(+) \\
(+) \\
(+) \\
(+) \\
Chem. \downarrow \\
- \\
(+) \\
(+) \\
(+) \\
(+) \\
Electrical \uparrow
\end{array}
\]

If a channel were to open for that molecule, which direction would the charged ion flow?

Equil. Pot: is the \( V_m \) for which the net flow of charged ion is 0. The chemical gradient is perfectly balanced by the electrical gradient of the membrane potential.
\[ E_{\text{ion}} = \frac{RT}{zF} \ln \frac{[\text{ion}]_{\text{out}}}{[\text{ion}]_{\text{in}}} \]

\[ E_{K^+} = \frac{RT}{(+1)F} \ln \left( \frac{5\text{mM}}{140\text{mM}} \right) \]

\[ \ln x \]

\[ < 1 \text{ so } E_{K^+} = - \]

\[ \ln x \text{ for } x > 1 \text{ is } + \]
\[ \text{for } x \leq 1 \text{ is } - \]

\[ z \text{ could be } + \text{ or } - \]

\[ E_{\text{Net}} \text{ is Positive} \]

\[(V_m - E_{\text{ion}}) \text{ therefore reflects the driving force on the ion when a channel for that ion opens} \]

\[ \text{Ion conductances, } g \]

\[ g = \frac{1}{R} \text{ units in Siemens, S.} \]

\[ \text{Protein channels create selective conductances, ie allow selective flow of ions across their membrane} \]
- The direction and magnitude of the flow depends upon $V_m - E_{ion}$.

  if $V_m = E_{ion}$, then no net flow occurs.

- Because ions carry charge, their flow is a current and therefore changes $V_m$.

- Note: takes relatively few ions to move to change $V_m$.

- An inward current: cations in or anions out

- Ion channels/conductances may be gated by chemicals or $V_m$ itself.

- Probability that the channel is open can be a function of $V_m$ or Conc.
Neurotransmitter Induced Conductances at a Chemical Synapse, Figure 5.3 pg 88

Excitatory - Na⁺, K⁺/Ca²⁺ flow into the cell, depolarize, i.e. \( \uparrow V_m \)

Inhibitory - Cl⁻ flow into the cell \( \downarrow V_m \)

- \( V_m \) changes due to synaptic currents can generate an action potential via voltage-dependent Na⁺ + K⁺ channels.

Action Potentials

- at rest, Na⁺ + K⁺ channels are closed.
- depolarization above a threshold induces opening of Na⁺ & K⁺ channels but Na⁺ more quickly
- Na⁺ open 1st, Na⁺ flows in, \( V_m \rightarrow E_{Na⁺} \)
  - the K⁺ channels open, K⁺ flows out, + starts to oppose Na⁺ current
  - Na⁺ channels naturally inactivate due to prolonged depolarization
  - K⁺ current pulls \( V_m \rightarrow E_{K⁺} \)
  - K⁺ channels close b/c \( V_m \) has decreased
- Cell returns to rest state
  - threshold + a long or short path return to a stable state were the 2 features of
  our 1st neuronal model