Ch 8: Neurons: Cellular and Network Properties, Part 1

Objectives:

Describe the Cells of the NS

Explain the creation and propagation of an electrical signal in a nerve cell

Outline the chemical communication and signal transduction at the synapse
Review of the Nervous System

New 3rd division: Enteric NS (p 246, and Chapter 21)
Cells of NS

1. **Nerve cell = Neuron**
   - Functional unit of nervous system
   - Excitable
   - Can generate & carry electrical signals

2. **Neuron classification either structural or functional (?)**
Cells of NS

1. Neurons
2. Neuroglia = Support cells
   - Schwann Cells (PNS)
   - Oligodendrocytes (CNS)
   - Astrocytes
   - Microcytes
   - Ependymal Cells
Some Terminology

- Pre- and Postsynaptic membrane, terminal, neuron, etc.
- Ganglion
- Interneuron
- Synaptic Cleft
- Neurotransmitter
- Sensory and Motor
Axonal Transport of Membranous Organelles

1. Peptides synthesized and packaged
2. Fast axonal transport along microtubule network
3. Vesicle contents released by exocytosis
4. Synaptic vesicles recycling
5. Retrograde fast axonal transport
6. Old membrane components digested in lysosomes

Retrograde or normograde transport
Axonal Transport

What is it? Why is it necessary?

**Slow axonal transport** (0.2 - 2.5 mm/day)
  Carries enzymes etc. that are not quickly consumed – Utilizes axoplasmic flow

**Fast axonal transport** (up to 400 mm/day)
  Utilizes kinesins, dyneins and microtubules
  Actively walks vesicles up or down axon along a microtubule
2. Neuroglia cells

**In CNS:**
1. **Oligodendrocytes** (formation of myelin)
2. **Astrocytes** (BBB, $K^+$ uptake)
3. Microglia (modified MΦ)
4. *(Ependymal cells)*

**In PNS:**
5. **Schwann cells** (formation of myelin)
6. Satellite cells (support)

*See Fig 8-5*
Resting Membrane Potential (Electrical Disequilibrium) Ch 5, p160-167

Recall that most of the solutes, including proteins, in a living system are ions.

Recall also that we have many instances of chemical disequilibrium across membranes.

Opposite (+ vs. -) charges attract, thus energy is required to maintain separation.

The membrane is an effective insulator.
Resting Membrane Potential (Electrical Disequilibrium) *Ch 5, p160-167*

Membrane potential = unequal distribution of charges (ions) across cell membrane

$K^+$ is major intracellular cation

$Na^+$ is major extracellular cation

Water = conductor

Cell membrane = insulator
Review of Solute Distribution in Body Fluids

Extracellular fluid (33%)

- Na⁺
- K⁺
- Cl⁻
- Ca²⁺
- Proteins

300 mOsM

Interstitial fluid (25%)

- Na⁺
- K⁺
- Cl⁻
- Phosphates⁻

300 mOsM

Cell membrane

- ATP

Intracellular fluid (67%)

- Na⁺
- K⁺

300 m OSM

Membranous organelles

Plasma 3.4 L (8%)

Capillary endothelium

Cannot cross

Size indicates relative concentration.
Electro-Chemical Gradients

- Allowed for, and maintained by, the cell membrane

- Created via
  - Active transport (Na\(^+\) pump)
  - Selective membrane permeability to certain ions and molecules
These Measurements are on a relative scale!
Resting Membrane Potential Difference

- All cells have it
- **Resting** → cell at rest
- **Membrane Potential** → separation of charges creates potential energy
- **Difference** → difference between electrical charge inside and outside of cell (ECF by convention 0 mV)
Measuring Membrane Potential Differences

A recording electrode is placed inside the cell. The voltometer measures the difference in electrical charge between the inside of a cell and the surrounding solution. This value is the membrane potential difference, or \( V_m \).

The ground (}): or reference electrode is placed in the bath and given a value of 0 millivolts (mV).

The chart recorder measures changes in membrane potential over time.
**Equilibrium Potential for K**\(^+\) (Ch 5, p 163)

= Membrane potential difference at which movement down concentration gradient equals movement down electrical gradient

**Definition:** electrical gradient equal to and opposite concentration gradient

Equilibrium potential for K\(^+\) = -90 mV
Resting Membrane Potential (Ch 5, p 160)

of most cells is between -50 and -90 mV (average ~ -70 mV)

Reasons:

- Membrane permeability: \( K^+ > Na^+ \) at rest

- Small amount of \( Na^+ \) leaks into cell

- \( Na^+ / K^+ \)-ATPase pumps out 3 \( Na^+ \) for 2 \( K^+ \) pumped into cell
Equilibrium Potential for Na⁺

- Assume artificial cell with membrane permeable to Na⁺ but to nothing else
- Redistribution of Na⁺ until movement down concentration gradient is exactly opposed by movement down electrical gradient
- Equilibrium potential for Na⁺ = + 60 mV
Ions Responsible for Membrane Potential

Cell membrane
- impermeable to Na\(^+\), Cl\(^-\) & Pr\(^-\)
- permeable to K\(^+\)

⇒ K\(^+\) moves down concentration gradient (from inside to outside of cell)
⇒ Excess of neg. charges inside cell
⇒ Electrical gradient created

Neg. charges inside cell attract K\(^+\) back into cell

<table>
<thead>
<tr>
<th>TABLE 8-2</th>
<th>Ion Concentrations and Equilibrium Potentials</th>
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</thead>
<tbody>
<tr>
<td>ION</td>
<td>EXTRACELLULAR FLUID (mM)</td>
</tr>
<tr>
<td>-------</td>
<td>--------------------------</td>
</tr>
<tr>
<td>K(^+)</td>
<td>5 mM (normal range: 3.5–5)</td>
</tr>
<tr>
<td>Na(^+)</td>
<td>145 mM (normal range: 135–145)</td>
</tr>
<tr>
<td>Cl(^-)</td>
<td>108 mM (normal range: 100–108)</td>
</tr>
<tr>
<td>Ca(^{2+})</td>
<td>1 mM</td>
</tr>
</tbody>
</table>
Change in Ion Permeability

- leads to change in membrane potential
- *Terminology:*

Stimulus → Depolarization → Repolarization → Hyperpolarization

Fig 5-37
Explain

• Increase in membrane potential
• Decrease in membrane potential
• What happens if cell becomes more permeable to potassium
• Maximum resting membrane potential a cell can have
• Membrane potential changes play important role also in non-excitable tissues!

• **Insulin Secretion** p 166
  – β-cells in pancreas have two special channels:
    • Voltage-gated Ca^{2+} channel
    • ATP-gated K^{+} channel

*Fig 5-38*
(a) **Beta cell at rest.** The $K_{ATP}$ channel is open and the cell is at its resting membrane potential.

1. Glucose in blood
2. Metabolism slows
3. ATP
4. $K_{ATP}$ channel open
5. Cell at resting membrane potential
6. Voltage-gated $Ca^{2+}$ channel closed
7. No insulin secretion

(b) **Beta cell secretes insulin.** Closure of $K_{ATP}$ channel depolarizes cell, triggering exocytosis of insulin.

1. Glucose in blood
2. Glycolysis and Citric acid cycle
3. ATP
4. $K_{ATP}$ channel closed
5. Less $K^+$ leaves cell
6. Cell depolarizes
7. $Ca^{2+}$ channel opens
8. $Ca^{2+}$ entry triggers exocytosis and insulin is secreted

Fig 5-38 p 167
Electrical Signals in Neurons

Changes in membrane potential are the basis for electrical signaling.

Only nerve and muscle cells are excitable (= able to propagate electrical signals).

**GHK Equation:**
Resting membrane potential = combined contributions of the conc. gradients and membrane permeability for Na⁺, K⁺ (and Cl⁻).
Control of Ion Permeability

• Gated ion channels – alternate between open and closed state
  – Mechanically gated channels
  – Chemically gated channels
  – Voltage-gated channels

• Net movement of ions de- or hyperpolarizes cell

2 types of electrical signals
  Graded potentials, travel over short distances
  Action potentials, travel very rapidly over longer distances