Neuroscience: Exploring the Brain

Chapter 3: The Neuronal Membrane at Rest

Introduction

• Action potential in the nervous system
  – Action potential vs. resting potential

Not at rest action potentials

Starring:
  water and its polar covalent bonds
  ions and distribution of + or – charges
  membranes

also starring
  proteins and enzymes
  diffusion, including concentration gradients
  electrical potential (VOLTAGE)
  electrical conductance
The Cast of Chemicals

- Cytosolic and Extracellular Fluid
  - Water
  - Key ingredient in intracellular and extracellular fluid
  - Key feature – uneven charge

The Cast of Chemicals

- Cytosolic and Extracellular Fluid (Cont’d)
  - Ions: Atoms or molecules with a net electrical charge
    - Cations
    - Anions
  - Spheres of hydration

The Cast of Chemicals

- Protein – enzymes, receptors, cytoskeleton
  - 20 amino acids
  - R group variable
    - Hydrophobic
    - Hydrophillic
    - other
The Cast of Chemicals

- **Protein**
  - Structure (Cont'd)
    - Peptide bonds
    - Polyamides (amino to carboxyl)
    - Four levels of protein structure

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The Cast of Chemicals

- **The Phospholipid Membrane**
  - Hydrophilic
    - Dissolve in water due to uneven electrical charge (e.g., salt)
  - Hydrophobic
    - Does not dissolve in water due to even electrical charge (e.g., oil)
  - Lipids are hydrophobic
    - Contribute to resting and action potentials
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< 5 nm

H₂O = < 1 nanometer
One billionth of meter

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channels

can be open
or gated by environment

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pumps - enzymes

sodium potassium pump
breaks down ATP in presence of internal Na⁺
Ion movement results from:

**DIFFUSION**
*Concentration gradient* (movement from high to low - relative difference in concentration between 2 locations)

**CHARGE**
*Voltage gradient* (same but volts)

Equilibrium occurs when CG balances VG

note this can be disproportionate

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CURRENT – movement of electrical charge

I

amps

positive – movement of + charge
negative – movement of - charge

(positive in direction)

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HOW MUCH CURRENT WILL FLOW?

1) ELECTRICAL POTENTIAL (voltage)
2) ELECTRICAL CONDUCTANCE
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potential
membrane potential
resting membrane potential
equilibrium potential
action potential – next chapter

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potential = voltage
force exerted –
difference between
(-) terminal (cathode)
(+) terminal (anode)
FLOW IS CURRENT
VOLTAGE IS DIFFERENCE (12V BATTERY)

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CONDUCTANCE - ABILITY TO TRAVEL

\( g \)
measured in siemens
metal is a good conductor
it offers little resistance
Resistance - inverse of conductance
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**HOW MUCH CURRENT WILL FLOW??**

Ohm’s law

\[ I = gV \]

**CURRENT** = **CONDUCTANCE** \( \times \) **VOLTS**

\( I = \) current

\( g = \) conductance

\( V = \) volts or potential difference

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**membrane potential**

**VOLTAGE ACROSS MEMBRANE**

**at any given moment**

- membrane is thin
- it "stores" charge
- it has "capacitance"

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**RESTING POTENTIAL**

- GREATER NEGATIVE CHARGE INTRACELLULARLY

**OUTSIDE**  \( \text{Na}^+ \) and \( \text{Cl}^- \) (also \( \text{CA}^{++} \))

1) at rest, most sodium channels closed, chloride open
2) sodium potassium pump is always pumping out \( \text{Na}^+ \)

**INSIDE**  \( \text{K}^+ \) and protein anions \( \text{A}^- \)

1) \( \text{K}^+ \) channels always open
2) \( \text{A}^- \) are too big to leave

-65 mV (by convention)
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Equilibrium potential

• no NET movement

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concentrated
dilute

no channels, no potential - no Vm

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diffusion rules! (for a while)

movement along concentration gradient
BUT REMEMBER

Ion movement results from:

**DIFFUSION**

*Concentration gradient* (movement from high to low - relative difference in concentration between 2 locations)

**AND**

**CHARGE**

*Voltage gradient* (same but volts)

A- left, so INSIDE becomes more -- and K+ will be pulled back in

Equilibrium occurs when CG BALANCES VG

REMEMBER this can be disproportionate

NO NET MOVEMENT
Nernst Equation
Calculates equilibrium potential of ion
\[ E = \frac{RT}{zF} \ln \left( \frac{c}{c^*} \right) \]
- \( E \) = potential (volts)
- \( c \) = concentration (moles)
- \( z \) = charge or valence of the transported substance
- \( R \) = gas constant (8.3143 Joules/mole/degree)
- \( T \) = temperature (298 degrees kelvin)
- \( F \) = Faraday constant (charge of 1 mole electrons or 96490 Joules/mole/volt)

Nernst Equation
equilibrium
balance of diffusion and electricity

\[ E_K \quad -82 \text{ mV} \]
\[ E_{Na} \quad +62 \text{ mV} \]

ionic driving force
- difference between membrane potential (whatever) and equilibrium potential

\[ V_m - E_{ion} \]
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Goldman equation
resting potential

• takes all ionic PERMEABILITY into account
Mostly K⁺ and Na⁺ and Cl⁻
• ~ 65 mV
(Nernst -equilibrium potential single ion)

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The Ionic Basis of The Resting Membrane Potential

• Equilibrium Potentials (Cont’d)
  • Four important points
    • Large changes in \( V_m \)
    • Minuscule changes in ionic concentrations
    • Net difference in electrical charge
      – Inside and outside membrane surface
    • Rate of movement of ions across membrane
      – Proportional \( V_m - E_{ion} \)
• Concentration difference known: Equilibrium potential can be calculated

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The Ionic Basis of The Resting Membrane Potential

• The Distribution of Ions
  Across The Membrane

<table>
<thead>
<tr>
<th>Ion</th>
<th>Concentration (mM)</th>
<th>Conductance (mS cm²)</th>
<th>Rate (ms⁻¹)</th>
<th>Trans. (m² s⁻¹)</th>
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</thead>
<tbody>
<tr>
<td>K⁺</td>
<td>150</td>
<td>1.2</td>
<td>60</td>
<td>0.01</td>
</tr>
<tr>
<td>Na⁺</td>
<td>16</td>
<td>1.1</td>
<td>50</td>
<td>0.04</td>
</tr>
<tr>
<td>Ca²⁺</td>
<td>10</td>
<td>1.0</td>
<td>120</td>
<td>0.03</td>
</tr>
<tr>
<td>Cl⁻</td>
<td>150</td>
<td>1.2</td>
<td>60</td>
<td>0.01</td>
</tr>
</tbody>
</table>

Notice Ca²⁺ small
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Sodium potassium pump
breaks down ATP in presence of internal Na+
70% of brain ATP
AGAINST concentration gradients K+ INSIDE NA+ OUTSIDE
Ouabain – poison arrow also Ca++ pumps

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why do you have to know this?

• **it is** THE DIFFERENCE BETWEEN LIFE AND DEATH

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K+ tightly regulated

• BBB
  – CNS
• astrocytes
K+ channels deformed
let in NA+
epilepsy

Potassium, euthanasia, capital punishment