Intracellular potentials
Intracellular microelectrode

The parts of a micropipette.
Replacing air with KCl in electrodes
<Patch Clamp Pipette>

Intracellular Electrode>

<Scanning Probe Tip>

IVF Injection Needle>

<Transgenic Needle>
Intracellular microelectrode

Electrode resistance (10 to 30 Mohms)
RC response of electrode to current injection

I

$V_m$

Time constant?
Electrode capacitance
AgCl → Ag⁺ + Cl⁻  Very low solubility

Conduction in metal

AgCl → Ag⁺ + Cl⁻  Very low solubility

Conduction in metal

Extracellular
capacitative charge transfer

Intracellular
direct charge transfer

DC charge transfer on electrode wire

Conduction in saline solution
Current injection into cells

(a)

(b)
Resting Potential

What do these have in common?

“rubbing salt in a wound”
Lethal injection cocktail
Dr. Kevorkian’s suicide machine
Hyperkalemia
Hypokalemia
Membrane ion distributions
Ionic basis of the resting potential

Unequal distribution of ion species across membrane
Selective permeability of ion species through membrane

Loss of $K^{??-}$: $Q = CV$ \(10^{-5} \text{ M K for } -58 \text{ mV}\)
The Nernst equation is given by:

$$E_K = \frac{RT}{ZF} \ln \left( \frac{[K]_o}{[K]_i} \right)$$

The table below lists the ion concentrations and Nernst potentials for frog muscle and squid axon:

<table>
<thead>
<tr>
<th>Ion</th>
<th>External (mM)</th>
<th>Internal (mM)</th>
<th>Nernst potential (mV)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Frog muscle</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>K</td>
<td>2.25</td>
<td>124</td>
<td>-101</td>
</tr>
<tr>
<td>Na</td>
<td>109</td>
<td>10.4</td>
<td>+59</td>
</tr>
<tr>
<td>Cl</td>
<td>77.5</td>
<td>1.5</td>
<td>-99</td>
</tr>
<tr>
<td><strong>Squid axon</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>K</td>
<td>20</td>
<td>400</td>
<td>-75</td>
</tr>
<tr>
<td>Na</td>
<td>440</td>
<td>50</td>
<td>+55</td>
</tr>
<tr>
<td>Cl</td>
<td>560</td>
<td>40</td>
<td>-66</td>
</tr>
<tr>
<td></td>
<td>Frog muscle</td>
<td>Squid axon</td>
<td></td>
</tr>
<tr>
<td>-------------</td>
<td>-------------</td>
<td>------------</td>
<td>-------------</td>
</tr>
<tr>
<td>Ion</td>
<td>External (mM)</td>
<td>Internal (mM)</td>
<td>Nernst potential (mV)</td>
</tr>
<tr>
<td>K</td>
<td>2.25</td>
<td>124</td>
<td>-101</td>
</tr>
<tr>
<td>Na</td>
<td>109</td>
<td>10.4</td>
<td>+59</td>
</tr>
<tr>
<td>Cl</td>
<td>77.5</td>
<td>1.5</td>
<td>-99</td>
</tr>
<tr>
<td>K</td>
<td>20</td>
<td>400</td>
<td>-75</td>
</tr>
<tr>
<td>Na</td>
<td>440</td>
<td>50</td>
<td>+55</td>
</tr>
<tr>
<td>Cl</td>
<td>560</td>
<td>40</td>
<td>-66</td>
</tr>
</tbody>
</table>
A: Electrode Penetration

- $3 \text{mM K}^+$
- $10 \text{mM K}^+$
- $40 \text{mM K}^+$
- $80 \text{mM K}^+$
- $100 \text{mM K}^+$
- $120 \text{mM K}^+$

$E_K$ (membrane potential)

B: Internal Potential (mV) vs. Potassium Concentration (mM)

$$V = 58 \log \left( \frac{[K]_o}{140} + 0.01 [Na]_o \right)$$
Squid giant axon- a model prep
40,000 APs can fire!
The graph illustrates the relationship between internal potential (millivolts) and internal potassium concentration (millimoles) at different external potassium concentrations. The curves are labeled as follows:

- **Outside Potassium = 540 Millimoles**
- **Outside Potassium = 100 Millimoles**
- **Outside Potassium = 10 Millimoles**

The x-axis represents the internal potassium concentration (millimoles), ranging from 0 to 600, and the y-axis represents the internal potential (millivolts), ranging from -60 to 60.
At Rest: \( I_{Na} = I_K \)?

\[
I_K = g_K (V_m - E_K) \quad I_{Na} = g_{Na} (V_m - E_{Na})
\]

\[
g_K (V_m - E_K) = g_{Na} (V_m - E_{Na})
\]
Other contributions to RP?
The Goldman Equation:

\[
V_m = \frac{RT}{F} \ln \frac{P_K[K]_i + P_{Na}[Na]_i + P_{Cl}[Cl]_i}{P_K[K]_o + P_{Na}[Na]_o + P_{Cl}[Cl]_o}
\]

Where:
- \( R \) is the gas constant (8.314 J/mol·K)
- \( F \) is the Faraday’s constant (96,500 Coul/mol)
- \( T \) is the temperature (273°C + 20°C = 293 K)

Ion Permeabilities:
- \( P_K \):
  - Internal: 1.0 cm/s
  - External: Not provided

Internal Concentrations:
- \( [K]_i \):
  - 265 mM

External Concentrations:
- \( [K]_o \):
  - 5.4 mM

Other Ions:
- \( [Na]_i \):
  - 17.4 mM
- \( [Na]_o \):
  - 207.3 mM
- \( [Cl]_i \):
  - 12.7 mM
- \( [Cl]_o \):
  - 238 mM

Membrane Potential:
- Resting Membrane Potential: \(-86.6 \text{ mV}\)
- Depolarization: \(g_{Na}^+\)
- Hyperpolarization: \(g_{K}^+\)
Changes in “RP” by changing ionic conductances