

Exercise 01: Reversal and Resting Potential

Theoretical Neuroscience I

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1 Nernst Equation

1.1 Reversal potentials

Question:

Compute the reversal potential for each ion species, assuming the following ionic concentrations:

Ion	$[\cdot]_{out}$	$[\cdot]_{in}$
K ⁺	5 mM	140 mM
Na ⁺	145 mM	15 mM
Cl ⁻	110 mM	13 mM

Can the membrane potential equal the reversal potential of more than one of these ions?

Answer:

We use the Nernst equation to calculate the reversal potential:

$$E_{rev} = \frac{RT}{zF} \ln \frac{[X]_{out}}{[X]_{in}} \approx \frac{1}{z} \cdot 26.70\text{mV} \cdot \ln \frac{[X]_{out}}{[X]_{in}}$$

The z values for potassium, sodium and chloride are 1, 1 and -1 respectively. Inserting the given values in the Nernst equation we obtain:

$$\begin{aligned} E_{K^+} &= \frac{1}{1} \cdot 26.70\text{mV} \cdot \ln \frac{5\text{mM}}{140\text{mM}} \approx 26.70\text{mV} \cdot -3.332 \approx -88.97\text{mV} \\ E_{Na^+} &= \frac{1}{1} \cdot 26.70\text{mV} \cdot \ln \frac{145\text{mM}}{15\text{mM}} \approx 26.70\text{mV} \cdot 2.269 \approx 60.57\text{mV} \\ E_{Cl^-} &= \frac{1}{-1} \cdot 26.70\text{mV} \cdot \ln \frac{110\text{mM}}{13\text{mM}} \approx -26.70\text{mV} \cdot 2.136 \approx -57.02\text{mV} \end{aligned}$$

The membrane potential can only equal the reversal potential of more than one ion at a time, if either two ions of the same charge have the same concentration ratio or if two ions of opposite charge have inverse concentration ratios. At different times, if the membrane potential changes over time, it can be equal to the reversal potential of different ions.

1.2 Driving forces

Question:

For the ions listed above, sketch the driving force ΔV (in units of mV) as a function of the membrane potential V_{mem} in the range of $-100\text{mV} \leq V_{\text{mem}} \leq +100\text{mV}$!

Answer:

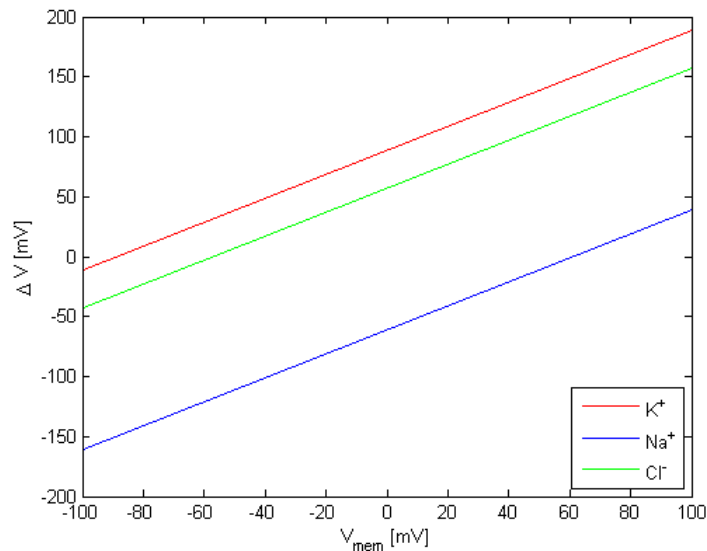


Figure 1: The driving force ΔV as a function of the membrane potential V_{mem} for the potassium, sodium and chloride ions.

2 Goldman equation

Question:

1. Assuming the concentrations you used for solving the Nernst equation, calculate the resting potential **for equal permeabilities** ($b = c = 1$)!
2. Calculate the resting potential for $b = 0.03$ and $c = 0.1$!

Answer:

We insert the given values into the Goldman equation:

$$E_{\text{rest}} = 27\text{mV} \cdot \ln \frac{[\text{K}^+]_{\text{out}} + b[\text{Na}^+]_{\text{out}} + c[\text{Cl}^-]_{\text{in}}}{[\text{K}^+]_{\text{in}} + b[\text{Na}^+]_{\text{in}} + c[\text{Cl}^-]_{\text{out}}}$$

1.

$$E_{\text{rest}} = 27\text{mV} \cdot \ln \frac{5\text{mM} + 145\text{mM} + 13\text{mM}}{140\text{mM} + 15\text{mM} + 110\text{mM}} \approx -13.12\text{mV}$$

2.

$$E_{\text{rest}} = 27\text{mV} \cdot \ln \frac{5\text{mM} + 0.03 \cdot 145\text{mM} + 0.1 \cdot 13\text{mM}}{140\text{mM} + 0.03 \cdot 15\text{mM} + 0.1 \cdot 110\text{mM}} \approx -71.68\text{mV}$$