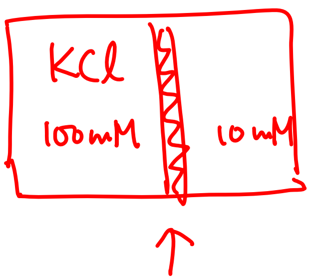
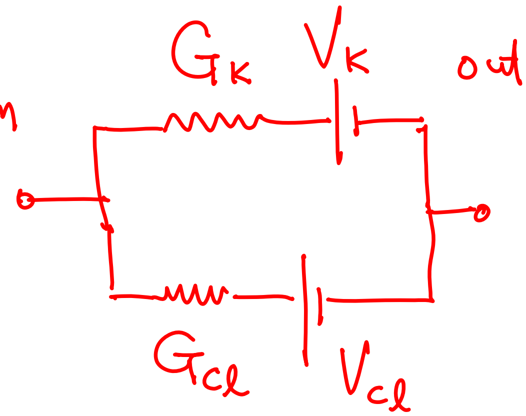
Recitation #10   6.021J 2006   Jay Han

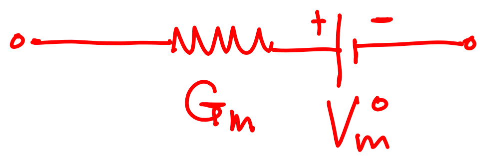
Previously



⟹



permeable to K^+ & Cl^-



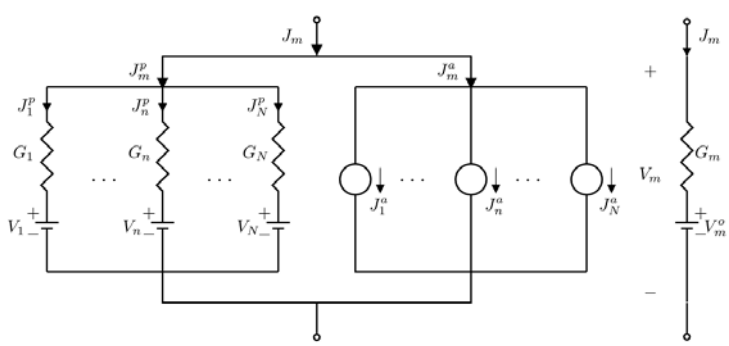
$V_K = -60mV$

$V_{Cl} = 60mV$

$$V_m^o = \frac{G_K}{G_K + G_{Cl}} V_K + \frac{G_{Cl}}{G_K + G_{Cl}} V_{Cl}$$

However, this is not sustainable. (Why?)

Active transport mechanism needed



$J_m = J_m^p + J_m^a$

Electrogenic pump

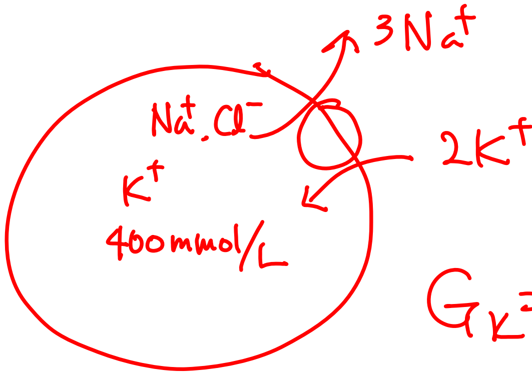
$\sum_n J_n^a \neq 0$

$$V_m^o = \underbrace{\sum_n \frac{G_n}{G_m} V_n}_{\text{"passive" part}} - \underbrace{\frac{1}{G_m} \sum_n J_n^a}_{\text{"active" part}}$$

Problem 2. The membrane of a cell is known to contain sodium/potassium pumps and supports passive electrodiffusion of sodium, potassium, and chloride ions. The potassium conductivity is 8 times the sodium conductivity. The sodium/potassium pump drives 3 molecules of sodium outward for every 2 molecules of potassium that is driven inward. The cell is allowed to come to quasi-equilibrium in a very large bath that contains 460 mmol/L Na^+, 40 mmol/L K^+, and 500 mmol/L Cl^-. At quasi-equilibrium, the cell contains 400 mmol/L K^+ and unknown concentrations of Na^+ and Cl^-. The cell also contains unknown concentrations of charged macromolecules which cannot pass through the cell membrane. The cell's volume is constant, so there is no water transport across the cell membrane. The resting potential is -50 mV. Assume that the temperature is such that $(RT/F)\ln 10 = 60$ mV.

Na^+ 460 mmol/L
K^+ 40 mmol/L
Cl^- 500 mmol/L

$V_m^o = -50\text{mV}$



$G_K = 8G_{Na}$

a) Determine the concentration of chloride ions inside the cell or explain why it cannot be determined from the available information.

In quasiequilibrium, $J_n^p + J_n^a = 0$ for all ionic species. Since there is no active transport for chloride ions, $J_{Cl}^a = J_{Cl}^p = 0$

$$J_{Cl}^p = G_{Cl}(V_m^o - V_{Cl}) \quad \text{at rest (quasi-equilibrium)}$$

$$\therefore \; V_{Cl} = V_m^o$$

$$-50\text{mV} = \frac{60\text{mV}}{(-1)} \log_{10}\left(\frac{500\text{mmol/L}}{C_{Cl}^i}\right)$$

$$C_{Cl}^i = 500\,\frac{\text{mmol}}{\text{L}} \times 10^{-5/6} \cong 73\text{ mmol/L}$$

b) Determine the Nernst equilibrium potential for sodium or explain why it cannot be determined from the available information.

Again, at quasiequilibrium

$$J^p_{Na} + J^a_{Na} = 0$$
$$J^p_K + J^a_K = 0$$

From the stoichiometry of pump operation,

$$\frac{J^a_{Na}}{J^a_K} = -\frac{3}{2}$$

$$\therefore \quad \frac{J^p_{Na}}{J^p_K} = \frac{-J^a_{Na}}{-J^a_K} = -\frac{3}{2}$$

$$\therefore \quad \frac{G_{Na}(V_m^o - V_{Na})}{G_K(V_m^o - V_K)} = -\frac{3}{2}$$

$$\frac{G_{Na}}{G_K} = \frac{1}{8},$$

$$V_m^o = -50\,mV$$

$$V_K = 60\,mV \times \log_{10}\left(\frac{40}{400}\right) = -60\,mV$$

$$\therefore \quad (-50\,mV - V_{Na}) = -12 \times (-50\,mV + 60\,mV) = -120\,mV$$

$$\therefore \quad V_{Na} = 70\,mV$$

c) The pump is blocked by adding a trace concentration of ouabain to the bath. The cell quickly reaches a new resting potential. Is the new resting potential greater than, less than, or the same as the old resting potential? Explain.

$$V_m^o = \underbrace{\sum_n \frac{G_n}{G_m} V_n}_{\text{"passive" part}} - \underbrace{\frac{1}{G_m} \sum_n J_n^a}_{\text{"active" part}}$$

ouabain will block the active current, therefore making $J_n^a = 0$. Before adding Ouabain, the total active current

$$\sum_n J_n^a > 0 \quad \text{(outward)}$$

because per each cycle the pump puts one additional charge to extracellular space.

Therefore, the direct contribution of the pump to the resting potential was negative. If we eliminate this term (by blocking the pump) V_m^o will increase.