# BASIC ELECTROPHYSIOLOGY: QUESTIONS

## • Q1. THE CHARGE ON THE MEMBRANE

The membrane capacitance is 10nF/mm$^2$. A certain neuron can be approximated as a sphere of radius 20$\mu$m and has a resting potential of $-65$mV.
[Q] What is the total capacitance of the cell?
[Q] What is the membrane charge when the neuron is at its resting potential?
The charge on an electron is $1.602 \times 10^{-19}C$.
[Q] How many ions does the membrane charge correspond to?
The molarity of internal free charge carriers is given in table 1.
[Q] What is the total number of charge carriers in the cell?
[Q] What is the ratio of charge carriers on the membrane to those in the bulk of the cell?

## • Q2. DIFFUSION IN A CHANNEL

An ion of concentration $N$, with fixed internal $N^i$ and external $N^e$ concentrations is diffusing through a trans-membrane channel. The internal side of the membrane is at $x = 0$ at $V^i$ and the external at $x = a$ at $V^e$. The protein forming the channel is itself charged, so that the voltage $V(x)$ inside the channel cannot be assumed linear and so the induced drift velocity $v$ is not necessarily constant. The density $N$ obeys the diffusion and continuity equations

$$\frac{\partial N}{\partial t} = D\frac{\partial^2 N}{\partial x^2} - \frac{\partial}{\partial x}(vN) \quad \text{and} \quad J = vN - D\frac{\partial N}{\partial x} \tag{1}$$

[Q] Use this equation to derive the general steady-state, zero-flux (when $J = 0$) density of ions in the channel as a function of $V(x)$ using the forms for $D$ and $v$ given in the lecture.
[Q] If the voltage changes linearly along the channel, how does the density change with position down the channel?
In the derivation of the GHK equation a linear change of the voltage, between the inside and outside, was assumed.
[Q] Is the derivation of the Nernst equation for the equilibrium potentials conditional on this assumption?
[Q] How does a non-linear $V(x)$ affect the derivation of the Goldman current and GHK equation for ions with the same $z$.
[Q] What about for mixed ions with $z = \pm 1, \ \pm 2$?

## • Q3. THE NERNST AND GHK EQUATIONS

Table 1 gives the molarities for Sodium, Potassium and Chlorine in neural tissue.
[Q] What are their equilibrium potentials at 37°C?
[Q] Using table 1, calculate the resting potential of the membrane using the GHK equation derived in the lectures.
The linearised form of the Goldman current for an ion $s$ is

$$I_s = g_s(V - E_s) \quad \text{where} \quad g_s = \frac{P_s z_s^2 q}{V_T} N_s^e N_s^i \left( \frac{\log(N_s^e/N_s^i)}{N_s^e - N_s^i} \right). \tag{2}$$

[Q] What are the relative values of $g_s$ for the ionic species? (Drop the $q/V_T$ factor.)
Now consider the sum of the linear, ohmic approximations which give the leak current

$$g_L(V - E_L) = g_{Na}(V - E_{Na}) + g_K(V - E_K) + g_{Cl}(V - E_{Cl}) \tag{3}$$

[Q] What is the form of $E_L$ as a function of the conductances and equilibrium potentials?
[Q] What does the ohmic assumption predict for the resting potential?

| ion | external $[N^e]$ (mM) | internal $[N^i]$ (mM) | relative permeability |
|---|---|---|---|
| $Na^+$ | 437 | 50 | 0.02 |
| $K^+$ | 20 | 397 | 1 |
| $Cl^-$ | 556 | 40 | 2 |

Table 1: Molarity in mM of ionic species for the squid giant axon. Molarity M is the number of moles (where one mole of a quantity is $6.02 \times 10^{23}$ units) per litre of fluid. There are one thousand litres in a cubic metre.