

ÉCOLE POLYTECHNIQUE
FÉDÉRALE DE LAUSANNE

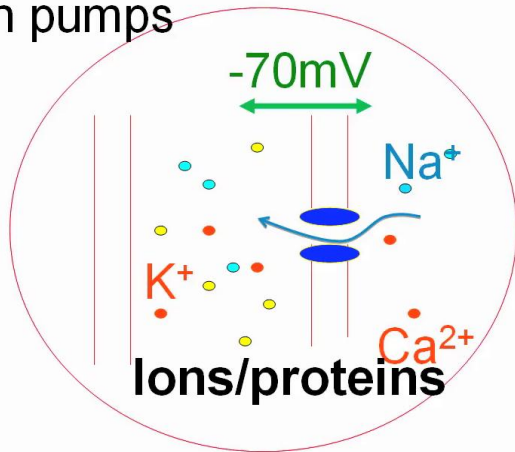


Neuronal Dynamics – 2.2. Resting potential

Cell surrounded by membrane

Membrane contains

- ion channels
- ion pumps



Resting potential -70mV

→ how does it arise?

Ions flow through channel

→ in which direction?

Neuron emits action potentials

→ why?

Welcome to part two of week two. In part one, I left you with a set of three questions.

Notes

Summary



Neuronal Dynamics – 2. 2. Resting potential



Resting potential -70mV
→ how does it arise?

Ions flow through channel
→ in which direction?

Neuron emits action potentials
→ why?

→ **Hodgkin-Huxley model**

*Hodgkin&Huxley (1952)
Nobel Prize 1963*

Now in this part, I will start to answer the first off these questions. Why is there a difference in potential between the inside of the cell and the outside of the cell?

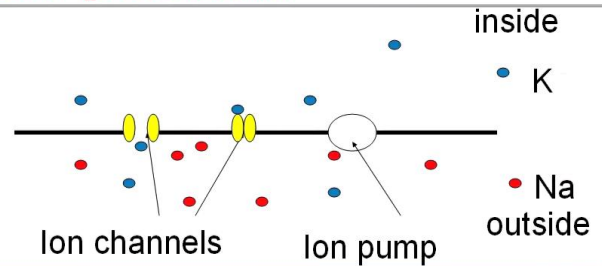
Notes

Summary

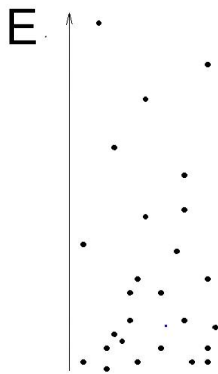


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Neuronal Dynamics – 2.2. Reversal potential



Ion pump $\Leftrightarrow$ Concentration difference



🔍 ✎ 📄 ➡

Now in order to answer this question, we have to remember that the cell is surrounded by a membrane. Embedded in the membrane, there are ion channels and ion pumps. Ion pumps push sodium ions from inside the cell towards the outside. Therefore, we have a difference in concentration between the inside of the cell and the outside. At the same time, these ion pumps transport potassium from the outside of the cell to the inside. I will argue that the difference in concentration necessarily gives rise to a difference in potential. Now in order to understand why, let us look at the case of air molecules. We all know that in the high mountains, the air is thinner than in the valleys. The concentration, or density, of molecules decreases as we move up the mountain. The reason is that air molecules have a certain mass. They have a weight. And pushing them up, you have to work against the gravitational forces that try to pull the molecules back towards the ground. On the other hand, because of a finer temperature, air molecules move around. And at equilibrium, there are always a few air molecules high up in the air. But most of them are down at the bottom. The density decreases with elevation.

Notes

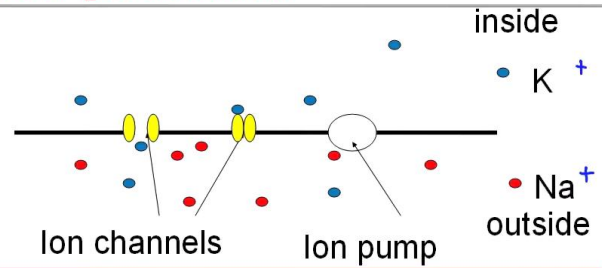
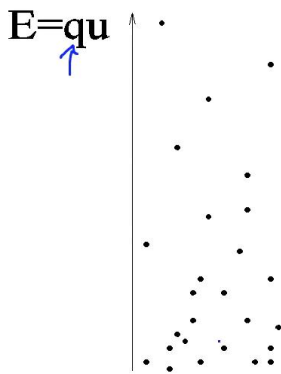
Summary



0m 32s

Neuronal Dynamics – 2.2. Reversal potential

density



Ion pump $\Leftrightarrow$ Concentration difference

Mathetical derivation

It decreases very generally with energy. Now for our air molecules, the energy is the gravitational energy, which is higher the higher the molecules are up in the air. For the case at hand, we talk about ions. Sodium-- Na plus-- potassium-- K [? a ?] plus-- are positively charged ions. For positively charged ions, where q is the charge, the energy corresponds to the charge times the potential. So if there is a gradient in potential-- the potential increases up here-- then positively charged ions are unlikely to sit at the region of high potential. Rather, they want to fall down to the region of low potential. The dependence upon the energy is exponential. This dependence is called the Boltzmann distribution. And I will now show that from the Boltzmann distribution, you can derive how a concentration difference gives rise to a voltage difference.

Notes

Summary



2m 25s

Neuronal Dynamics – 2.2. Nernst equation

n_1 (inside)

n_2 (outside)

Δu

$n \propto e^{-\frac{E}{kT}}$

$E = q \cdot u$

$$\frac{n_1}{n_2} = \frac{e^{-\frac{E_1}{kT}}}{e^{-\frac{E_2}{kT}}} = e^{-\frac{1}{kT}(E_1 - E_2)} = e^{-\frac{q}{kT}(u_1 - u_2)}$$

Nernst equation

$$\ln \frac{n_1}{n_2} = -\frac{q}{kT}(u_1 - u_2) \Rightarrow \Delta u = u_1 - u_2 = -\frac{kT}{q} \ln \frac{n_1}{n_2}$$

↑ voltage
↑ inside
↑ out
← inside concentration
← outside

So let's start from the Boltzmann distribution. And note that the energy for charged particles is q times u . Let's look at sodium. Ion pumps push sodium outside the cell. So the density of sodium is much higher outside the cell than it is inside the cell. If you compare the density, or concentration, inside to that outside, you can do this by using the Boltzmann formula. So I have e to the minus E over kT . k is the Boltzmann factor, T , the temperature. e to the minus E over kT . Now here it's n_1 . It's the inside energy, 1, outside energy, 2. The ratio of exponentials can be written as a difference, E_1 minus E_2 . Now I use the expression for the energy of charged particles and find q over kT u_1 minus u_2 . Let's take the logarithm. So the logarithm of n_1 over n_2 is minus q over kT , u_1 minus u_2 . I'm interested in the voltage difference-- Δu , u_1 minus u_2 . And if I solve for u_1 minus u_2 , I have minus kT over q logarithm n_1 over n_2 . u_1 is the potential inside the cell. u_2 is outside the cell. n_1 is the concentration inside the cell. n_2 is the concentration outside the cell. The relation between these ratio of concentrations-- the concentrations inside and outside and the voltage difference-- this ratio is described by the equation I just derived, which is called the Nernst equation.

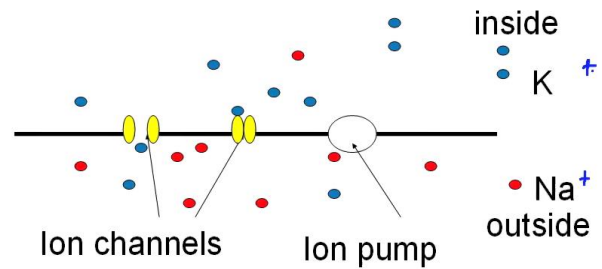
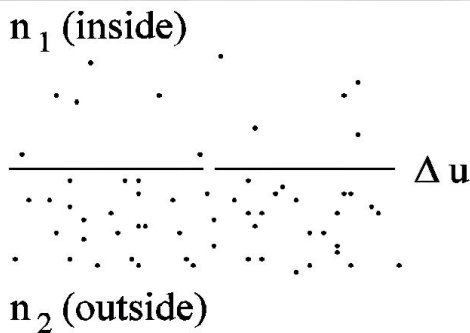
Notes

Summary



3m 39s

Neuronal Dynamics – 2.2. Nernst equation



Nernst

$$\Delta u = u_1 - u_2 = \frac{-kT}{q} \ln \frac{n(u_1)}{n(u_2)}$$

Reversal potential

✎ ✏ ✂ ➡

Let me summarize. The ion pumps cause a concentration difference. The concentration difference gives rise to a voltage difference, which is described by the Nernst equation. And this voltage difference is also called the reversal potential. Now let's discuss the meaning of this. The Boltzmann distribution describes an equilibrium distribution. So in the same way, this voltage difference corresponds to a hypothetical equilibrium. There are more sodium ions outside the cell than there are inside. The sodium ions outside and inside would be at equilibrium if there were a potential difference, Δu , between the inside and the outside. But sodium is not the only type of ion. There is also potassium. Potassium ions also have a different concentration inside than outside. For potassium, there's also a voltage derived from the Nernst equation. And at this voltage, potassium ions would be at equilibrium, given the concentration difference caused by the ion pumps. However, the results of the hypothetical equilibrium potential for potassium and the hypothetical equilibrium potential for sodium is not the same. But there can be only one single difference in potential between the inside and outside.

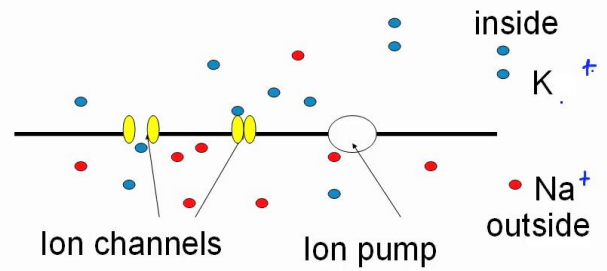
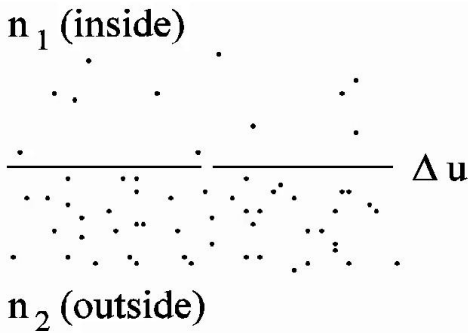
Notes

Summary



7m 19s

Neuronal Dynamics – 2.2. Nernst equation



Nernst

$$\underline{\Delta u} = u_1 - u_2 = \frac{-kT}{q} \ln \frac{n(u_1)}{n(u_2)}$$

Reversal potential

Concentration difference $\Leftrightarrow$ voltage difference

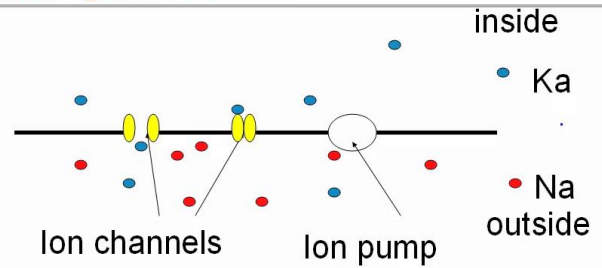
The Nernst equation gives it a hypothetical equilibrium potential, which is also called the reversal potential, for each ion type. The total equilibrium potential is a compromise between the reverse potential of sodium, potassium, and other ion types that you might find in the cell. To summarize, the concentration difference gives rise to a voltage difference via the reversal potential.

Notes

Summary



Neuronal Dynamics – 2.2. Reversal potential



Ion pump → Concentration difference

Concentration difference ⇔ voltage difference

Reversal potential

Nernst equation

This voltage difference is described by the Nernst equation. It's specific for each ion type. For each ion type, we have a reversal potential, which is the potential at which this ion type would be at equilibrium. Now in order to get you a little bit more familiar with the notions I just discussed, I would like you to take five minutes or so-- take out a calculator. Type in concentrations for sodium and potassium. And try to calculate the reversal potential for each ion type.

Notes

Summary

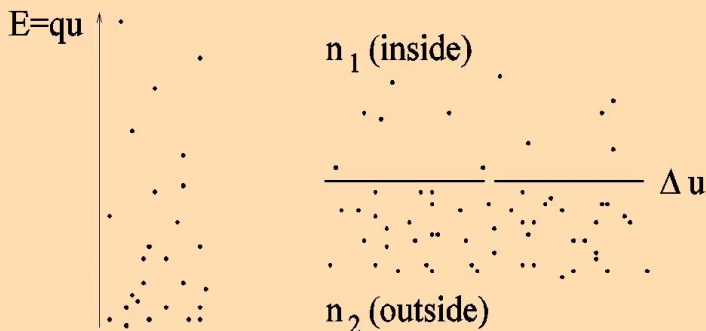


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Exercise – 2.2. Reversal potential of ion channels

Reversal potential

$$\Delta u = u_1 - u_2 = \frac{-kT}{q} \ln \frac{n(u_1)}{n(u_2)}$$



Calculate the reversal potential for Sodium

Postassium

Calcium

given the concentrations

What happens if you change the temperature T from 37 to 18.5 degree?

An additional question is how would this calculated reversal potential change if you go from a temperature of 37 degrees to half that temperature?

Notes

Summary



10m 52s