

# Electrochemical potential of protons

In cellular respiration, the proton pump uses energy to transport protons from the mitochondrial matrix across the inner mitochondrial membrane. It is an active pump that allows the creation of a concentration gradient from the outer to the inner mitochondrial membrane. Differences in pH and electrical charge create an electrochemical potential that produces energy for the cell using a similar principle to a battery.

## Definition

Electrochemical potential is therefore a gradient of ions or protons (electrochemical gradient) that can move across the membrane. In biological processes, it determines the direction in which this ion or proton will move, either by diffusion or active transport.

## Formula

- Electrochemical potential is defined as:

$$\Psi = -\Delta\phi + (2,3 RT/F) \log (C_{\text{cation,ex}} / C_{\text{cation,in}})$$

Where:

$\Delta\phi$  is the electric potential across the membrane (in V)

R is gas constant (8,314 J.K<sup>-1</sup>.mol<sup>-1</sup>)

T is absolute temperature (in K)

F is Faraday constant (96,49 kC.mol<sup>-1</sup>)

- Thus, the electrochemical potential itself consists of two parts.
  - From the electrical potential that is caused by the change in charge across the lipid membrane.
  - From the difference in chemical concentrations on both sides of the membrane.

The tendency of an electrically charged particle to pass through a membrane depends on the difference in electrochemical potentials on each side of the membrane. The difference in chemical concentrations can be compared to the potential energy available for work inside the cell. This energy, stored in the form of chemical potential, is stored by the process of oxidative phosphorylation into ATP for later use.

The mitochondrial membrane is impermeable to protons in the direction of the matrix, therefore more protons accumulate here than in the matrix itself. The excess protons are then flushed through the ATP-synthase during oxidative phosphorylation and the formation of ATP.

## Zero electrochemical potential

The electrochemical potential of an ion is zero at the level of the equilibrium/reversal potential (also known as the Nernst potential), when the value of the membrane potential is in electroosmotic equilibrium. This means that for this membrane potential, the electrical force due to the potential difference and the chemical force due to the concentration difference (or osmotic difference) are equal and act in opposite directions. The amount of incoming and outgoing ions is the same. If we are only talking about the transition of a single ion, we can determine the value of the equilibrium potential using the Nernst equation.

## Nernst equation

$$E_X = \frac{R \cdot T}{n \cdot F} \cdot \ln \frac{[X]_e}{[X]_i}$$

$E_X$  is the electrochemical equilibrium potential of the ion X (V)

R is universal gas constant [8.314472 J/(mol.K)]

T is the absolute temperature in K (body temperature 37 °C = 310.15 K)

n is the valence of the ion (e.g +1 for K<sup>+</sup> a Na<sup>+</sup>, +2 for Ca<sup>2+</sup>, -1 for Cl<sup>-</sup> etc.)

F is Faraday's constant (96485.3399 C/mol)

ln is the natural logarithm

$[X]_e$  is the extracellular concentration of the X ion

$[X]_i$  is the intracellular concentration of the X ion

The transfer of electrons of the respiratory chain is associated with the pumping of protons by complexes I, III and IV across the inner mitochondrial membrane from the matrix to the intermembrane space. The flow of protons results in:

- Generating a pH gradient across the inner mitochondrial membrane, the pH in the matrix is higher than the pH

- in the cytosol, where the pH is around 7.
- Generating a pH gradient across the inner mitochondrial membrane, the pH in the matrix is higher than the pH in the cytosol, where the pH is around 7.

## Protonmotive force

### Definition

The protonmotive force expresses the dependence of secondary active transport on the membrane potential and the ratio of  $H^+$  concentrations outside and inside the cell; it is not quite the correct designation (it is not about force) for the electrochemical potential divided by the Faraday constant. Analogously, we can talk in general about the ion motive force. The pH gradient ( $\Delta pH$ ) drives  $H^+$  back into the matrix, thereby amplifying the effect of the membrane potential ( $\Delta\Psi$ ), which pulls protons back through the ATP-synthase complex. The sum of  $\Delta pH$  and  $\Delta\Psi$ , or protonmotive force (PMF,  $\Delta p$ ), can be measured in millivolts (mV). In a typical cell, the PMF of respiring mitochondria is in the range of 180 to 190 mV and is formed from a membrane potential of 160 to 170 mV and a pH gradient of about 0.3 to 0.5 units.

If the particles in the solution are electrically charged, such as  $H^+$  ions, then these particles not only have chemical energy in the form of chemical potential  $\mu$ , but also electrical energy.

### Sources

1. Alberts et al., 2002
2. <https://biomikro.vscht.cz/vyuka/bc/prednaska10.pdf>
3. Medical biophysics – Leoš Navrátil, Jozef Rosina and the team
4. [http://che1.lf1.cuni.cz/html/Bioenerg0809\\_CZE.pdf](http://che1.lf1.cuni.cz/html/Bioenerg0809_CZE.pdf)
5. [https://en.wikipedia.org/wiki/Electrochemical\\_gradient](https://en.wikipedia.org/wiki/Electrochemical_gradient)

### Links

- Electrode events/Electrochemical potential
- Proton

