Nernst Equation

David C. Sterratt*
University of Edinburgh, Edinburgh, UK

Synonyms

Equilibrium potential

Definition

The Nernst equation describes how the equilibrium potential for an ion species (also known as its Nernst potential) is related to the concentrations of that ion species on either side of a membrane permeable to the ion.

Detailed Description

Physical Basis of the Equilibrium Potential

The membrane potential is the electric potential difference that exists across a membrane which is permeable to an ionic species and which separates solutions of the ionic species at differing concentrations. For example, cell membranes are often permeable to potassium, and the concentration of potassium inside the cell is greater than the concentration outside the cell. Negatively changed anions balance out the positive charge of potassium ions so that the charge inside and outside the cell is neutral, and the membrane is assumed to be impermeable to the anions (Fig. 1).

In this situation, potassium ions from the more concentrated solution inside the cell will tend to diffuse through the membrane to the lower-concentration solution outside. Because potassium ions

![Fig. 1 A cell containing high, balanced concentrations of potassium ions and anions inside and low, balanced concentrations of the same ions outside. The membrane is permeable to the potassium ions but not the anions. At equilibrium, the outside of the membrane is positively charged relative to the inside, which gives rise to the equilibrium membrane potential](image)

*Email: david.c.sterratt@ed.ac.uk
are positively charged, this will cause a build-up of positive charge on the outside of the cell membrane and an equal and opposite build-up of negative charge on the inside. Thus, the electric potential outside the cell is greater than that inside, and the membrane potential, by convention defined as the potential inside minus the potential outside, will be negative. This potential difference corresponds to an electric field that exerts an inward force on the potassium ions, thus opposing their diffusion down the concentration gradient from inside to outside. The potential difference at which the electric and diffusive influences on the ions balance out is known as the equilibrium potential or the Nernst potential. At this potential, there is no net flow of the ion species through the membrane.

The Nernst Equation
In a cell, the Nernst equation (Nernst 1888) relates the equilibrium potential $E_X$ for an ion of type $X$ with valency $z_X$ to the concentrations $[X]_{out}$ and $[X]_{in}$ of the ion outside and inside the cell:

$$E_X = V_{in} - V_{out} = \frac{RT}{z_XF} \ln \frac{[X]_{out}}{[X]_{in}}$$

where $F$ is Faraday’s constant, $R$ is the molar gas constant, and $T$ is the temperature in kelvins.

Examples

1. The intracellular and extracellular concentrations of potassium ions in squid giant axon are $[K^+]_{in} = 400$ mM and $[K^+]_{out} = 20$ mM, respectively. Since potassium ions carry a single positive charge, the valency $z_K = 1$, and using the values of $R = 8.314 \text{ J K}^{-1} \text{ mol}^{-1}$ and $F = 9.648 \times 10^4 \text{ C mol}^{-1}$, the equilibrium potential for potassium at 6.3 °C (279.3 K) is obtained by substituting these values into the Nernst equation:

$$E_K = \frac{8.314 \times 279.3}{1 \times 9.648 \times 10^4} \ln \frac{20}{400} = -72 \text{ mV}$$

2. The intracellular and extracellular concentrations of chloride ions in squid giant axon are $[Cl^-]_{in} = 40$ mM and $[Cl^-]_{out} = 560$ mM, respectively. Since chloride ions carry a single negative charge, the valency $z_{Cl} = -1$, and the equilibrium potential for chloride at 6.3 °C is:

$$E_{Cl} = \frac{8.314 \times 279.3}{-1 \times 9.648 \times 10^4} \ln \frac{560}{40} = -64 \text{ mV}$$

Derivation
The Nernst equation can be derived from the Nernst-Planck equation of electrodiffusion (Johnston and Wu 1995; Hille 2001; Sterratt et al. 2011). Diffusion is assumed in one dimension (labeled $x$), through the membrane. At equilibrium, no current flows, so the flux in the Nernst-Planck equation is set to zero to give: $\frac{1}{|X|} \frac{d[X]}{dx} = -z_XF \frac{dV}{dx}$. This equation can be rearranged and integrated:

$$\int_{V_{in}}^{V_{out}} dV = \int_{[X]_{in}}^{[X]_{out}} \frac{RT}{z_XF[X]} d[X].$$

The Nernst equation results from evaluating this integral.

Alternatively, the Nernst equation can be derived from thermodynamic principles (Hille 2001).
Cross-References

▶ Goldman-Hodgkin-Katz Equations

References

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