Biophysical Chemistry, 47 (1993) 139–141
Elsevier Science Publishers B.V., Amsterdam

BIOCHE 01760

The volume flows of electrolyte solutions across a horizontally mounted membrane

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(Received 18 December 1992; accepted in revised form 4 February 1993)

Abstract

The Kedem–Katchalsky–Zelman model equations for transmembrane transport in multicomponent ionic and heterogeneous solutions have been modified. The validity of this model for binary and ternary solutions was verified using a cell with a horizontally mounted membrane. In the cell, volume flux of HCl, KCl, H_2SO_4 and/or ammonia aqueous solutions was measured as a function of gravitational configurations. The experimental findings are interpreted in terms of a convective gravitational instability that reduces boundary layer dimensions and increases the permeability coefficient of the complex system: boundary layer/membrane/boundary layer. A concentration-gradient Rayleigh number is used in a mathematical model for the gravitationally sensitive membrane flux.

Keywords: Membrane tranport; Kedem–Katchalsky–Zelman model; Rayleigh–Taylor convective instability; Multicomponent electrolyte systems

Gravitational effects on transmembrane volume and solute fluxes of the nonelectrolyte solutions were reported in previous papers [1–6]. From these papers, the conclusion was drawn that the influence of the gravitational field on transmembrane tranport manifests itself in Rayleigh-Taylor instability [1,2], asymmetry and amplification of osmotic and diffusive transport [3–6] and gravielectric effect [7]. These findings were interpreted in terms of a convective gravitational instability that reduces boundary layer dimensions and increases the permeability coefficient of the complex system: boundary layer/membrane/boundary layer. A model equation of the transport across a horizontally mounted membrane was presented in [6,7]. In this model a concentration-gradient Rayleigh number is used.

In the present communication the results of experimental studies upon osmotic transport in a single-membrane system containing binary and ternary electrolyte solutions are described. This communication is a completion of the previous paper [6].

Studies of osmotic flows were carried out by means of methods of measurement that have been described in previous papers [1,4,6]. In the experiments, we used a Nephron membrane and aqueous HCl, H_2SO_4, KCl and/or ammonia. Suitable values of the permeability parameters of this membrane are listed in Table 1. No external

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Table 1

Values of the Nephron membrane (σ, ω) and complex: boundary layer/Nephron membrane/boundary layer (σ^*, Ω) transport parameters for H_2SO_4, HCl, KCl and ammonia. σ and σ^* denotes reflection coefficients; ω and Ω permeability coefficients. These parameters are defined by expressions listed in Table 1 in ref. [6]

Coefficient	Value of parameter			
	H_2SO_4	HCl	KCl	Ammonia
σ ($\times 10^2$)	0.11	0.08	0.04	0.01
ω (mol/N per s) ($\times 10^9$)	3.80	3.32	2.54	2.68
σ^* ($\times 10^2$)				
Configuration A	0.003	0.002	0.002	0.0004
Configuration B	0.044	0.03	0.02	0.003
Ω (mol/N per s) ($\times 10^9$)				
Configuration A	0.21	0.10	0.05	0.78
Configuration B	1.92	1.42	0.86	0.20

mechanical stirring was used. Each experiment was performed for gravitational configurations of the membrane system: first, with water in the vessel above the membrane and the solution below (configuration A); second, with these positions reversed (configuration B).

Figures 1 and 2 depict experimental data for binary or ternary solutions in the cell membrane compartment opposite to the compartment filled with water. The results in Fig. 1 were obtained with solutions of fixed ammonia content and varying H_2SO_4 (curves 1 and 1*), HCl (curves 2 and 2*) and KCl (curves 3 and 3*) concentrations. For solutions containing 0.5 M ammonia, progressive addition of H_2SO_4, HCl or KCl increases the density from below that of water to a value above it. Fig. 2 gives results at constant H_2SO_4, HCl or KCl and variable ammonia concentrations. Here, progressive ammonia addition to 0.2 M H_2SO_4, 0.2 M HCl or 0.3 M KCl lowers the density from above that of water a value below it. In [1], the manner in which J_v varies is related to the gravitational instability or stability of the boundary layers, i.e., if the experimental value of J_v is low, the boundary layers are stable and, conversely, for high values of J_v, the layers are unstable.

The model equations for volume transmembrane transport [6,7] in a ternary electrolyte solutions transform to the following form

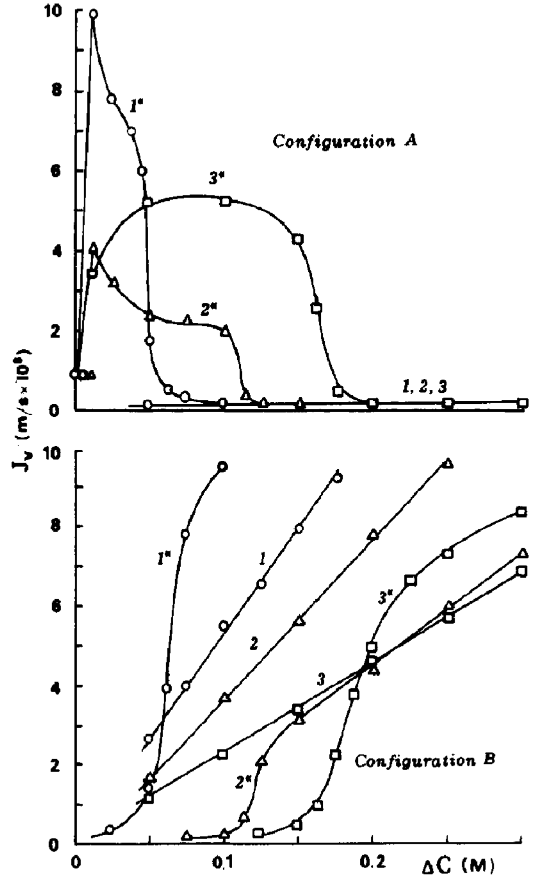

Fig. 1. Experimental volume flux across a cell membrane as a function of the concentration difference: H_2SO_4 (curves 1 and 1*), HCl (curves 2 and 2*) and KCl (curves 3 and 3*) for configuration A (upper) and B (lower). Plots 1, 2 and 3 – no ammonia, plots 1*, 2* and 3* – 0.5 M ammonia.

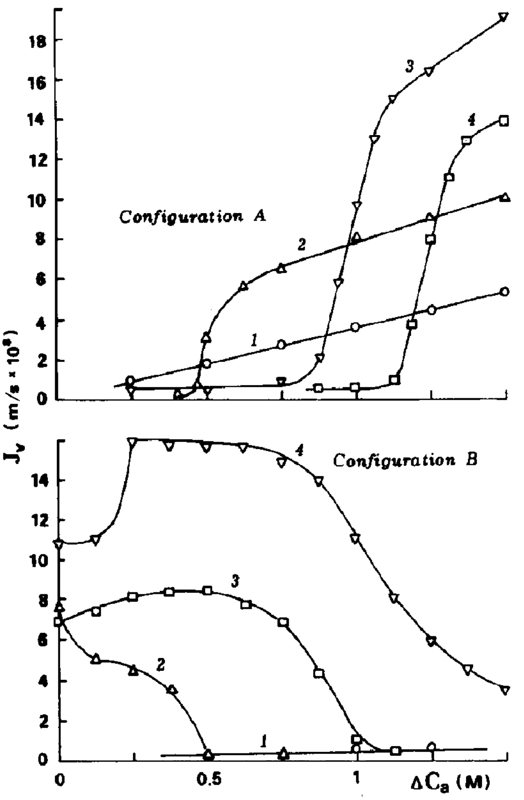

Fig. 2. Experimental volume flux across a cell membrane as a function of the ammonia concentration difference for configuration A (upper) and B (lower): (○) no H_2SO_4, HCl and KCl, (△) 0.2 *M* HCl, (▽) 0.2 *M* H_2SO_4, (□) 0.3 *M* KCl.

$$J_v = \eta\left[\Delta P \pm RT \sum_{i=1}^{2} \frac{\Omega_i(C_i)}{\omega_i} \zeta_i \sigma_i \, \Delta C_i\right] \tag{1}$$

$$\eta = L_p\left\{1 \mp \left(\prod_{i=1}^{2} \omega_i\right)^{-1} L_p \sum_{i=1}^{2} \sigma_i \bar{C}_i(\sigma_i - \sigma_i{}^*)\right\}^{-1} \tag{2}$$

$$\frac{\Omega_i(C_i)}{\omega_i} = \frac{1}{1 + 2RT\omega_i\left[\dfrac{R_c^* \nu}{g\left(\dfrac{\rho}{\rho_0} - 1\right) D_i^2}\right]^{1/3}} \tag{3}$$

where J_v is the volume flux, L_p the hydraulic conductivity of the membrane, ΔP the hydrostatic pressure difference, $\bar{C}$ the average solute concentration, σ and σ^* the reflection coefficient of the membrane and complex: boundary layer/membrane/boundary layer, respectively, ΔC the concentration difference, ζ the Van't Hoff coefficient $(1 \le \zeta \le 2)$, RT the product of the gas constant and absolute temperature, ω and Ω the permeability coefficient of membrane and complex: boundary layer/ membrane/ boundary layer, respectively, R_c^* the critical value of the concentration Rayleigh number, ν the kinematics viscosity, g the gravitational acceleration, ρ and ρ_0 the density of solution and solvent, respectively, and D the diffusion coefficient.

Qualitative agreement only between experimental data and calculated results for J_v is obtained.

References

1 A. Ślęzak, K. Dworecki and J.E. Anderson, J. Membrane Sci. 23 (1985) 71.
2 A. Ślęzak, J. Membrane Sci. 26 (1986) 115.
3 A. Ślęzak and B. Turczyński, Stud. Biophys. 113 (1986) 37.
4 A. Ślęzak and B. Turczyński, Biophys. Chem. 24 (1986) 173.
5 A. Ślęzak, B. Turczyński and Z. Nawrat, J. Non-Equilib. Thermodyn. 14 (1989) 205.
6 A. Ślęzak, Biophys. Chem. 34 (1989) 91.
7 A. Ślęzak, Biophys. Chem. 38 (1990) 189.