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Non Equilibrium Thermodynamic Studies on Membrane Phenomena "Streaming Potential and Streaming Current"

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Abstract: ***Streaming potentials and streaming currents developed during the streaming of water and aqueous solutions of NaCl, KCl and $MgCl_2$ in the concentration range 10^{-4} to 10^{-4} mol/l through progesterone plug membrane have been measured and their dependence on applied pressure differences has been investigated. The results have been explained on the basis of the theory of non-equilibrium thermodynamics. It has been observed that streaming potentials and streaming currents both depend linearly on applied pressure differences and Saxen's relationship holds good.***

Keywords: Streaming Potential, Streaming current, Membrane Permeant conductance

1. Introduction

Out of the four electrokinetic phenomena streaming potential has not been extensively studied [1-4]. Streaming potential studies in biological systems have been demonstrated in the case of the gall bladder of fishes [5] and the rates small intestines [6]. Rastogi *et al.* [7] observed that for weakly charged membranes streaming potentials depends linearly on pressure. A non linear dependence of streaming potential and streaming current on applied pressure difference has also been observed during the streaming of water and methanol water mixture through Zeocarb-225 membranes [8]. However such studies with membranes of biologically important materials are rare [9-11]. It was therefore, decided to make such investigations on membranes made up of biologically important materials. For this purpose, progesterone (female sex hormone), a biologically important material was chosen to make plug membrane and various aqueous electrolyte solutions viz NaCl, KCl and $MgCl_2$ were used as permeants. The results have been analyzed in the light of the theory of non-equilibrium thermodynamics.

2. Experimental

Materials and Methods

Progesterone obtained from Sigma Chemical Company (Saint Louis, USA) was used as such to prepare membrane plug. NaCl, KCl and $MgCl_2$ (AR, BDH) and distilled water (conductance of the order of 10^{-6} S) were used in these studies. Various solutions of $MgCl_2$ were prepared from its stock solution standardized by EDTA titration. A known amount of progesterone powder was soaked in water for 24 hours, it was filtered dried and mixed with a small amount of araldite (5%) it was then cast in the form of a plug by mechanical compression [12] in a pyrex glass cell having a small constriction in the middle. The thickness of the membrane was 5.02 x 10^{-4} m and the area of the surface was nearly 3.24 x 10^{-4} m^2.

Reversible silver-silver chloride electrodes were prepared with anodic deposition of the chloride ions on a silver disc attached with a silver rod from 0.1 NaCl solution at 0.4 mA/cm^2. It was found that the anodically formed chloride layer on silver disc was very thin.

Measurement of streaming potential

Streaming potential measurements were carried out using a digital multimeter (HIL, 2142) which is an accurate bright red 3 ½ digit LED display instrument provided with seven segments. The experimental set-up used for the measurement of streaming potential is shown in fig. 1

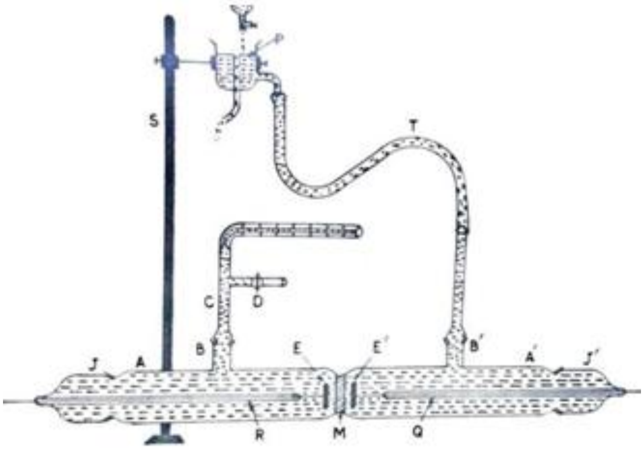

Figure 1: Experimental Setup For Permeability Measurement

two silver-silver chloride electrodes were in contact with the two faces of the membrane. The permeants were streamed through the membrane under the action of various known pressure differences applied by maintaining constant differences in the levels of the liquid across the membrane. Constancy of the applied pressure difference was ensured by adjusting the reservoir at constant heights. A steady streaming potential was developed after about five minutes which was measured with the multimeter shown in fig. 2

Figure 2: Digital Multimeter, HIL, 2142.

The streaming currents at various pressure differences were measured with a DC electrometer amplifier (Type EA, 810 A; Trombay Electronic Instruments Co. India) sensitive to 0.20 x 10^{-13} ampere per division fig. 3.

Figure 3: Electrometer Amplifier Type 810a, (Tei India)

The streaming currents could be measured correct to $^{+}1.5\%$. The experimental cell used was the same as used in the measurement of streaming potential. All the measurements were carried out in an air thermostat maintained at 25^{+} 0.5^{0}C.

3. Results and Discussion

According to the theory of nonequilibrium thermodynamics, electric current I, developed through a permeant-equilibrated membrane under the simultaneous action of pressure difference ΔP and electric potential difference $\Delta\phi$ is given by [13-14]

$$I = L_{21}\left(\frac{\Delta P}{T}\right) + L_{22}\left(\frac{\Delta\phi}{T}\right) \qquad (1)$$

Where L_{21} and L_{22} are the phenomenological coefficients.

The streaming potential built up across the membrane due to a pressure difference ΔP in the absence of electric current I is given by

$$-(\Delta\phi)_{I=0} = \frac{(L_{21})_{sp}}{L_{22}} . \Delta P \qquad (2)$$

Where L_{22} is the conductance of membrane equilibrated with the permeant system and it has been measured directly with the help of a Toshniwal conductivity Bridge at 50 Hz.

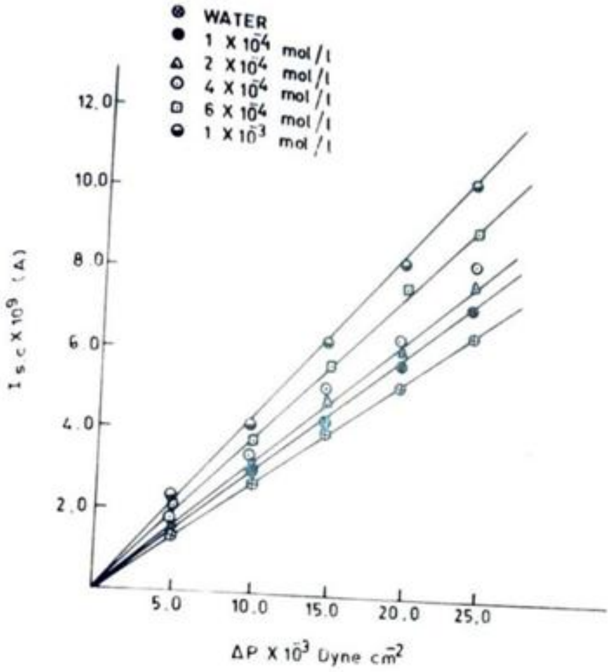

Figure 4: Dependence of Streaming Current I_{sc} on Applied Pressure Difference ΔP, Progestrone / Aqueous NaCl.

For

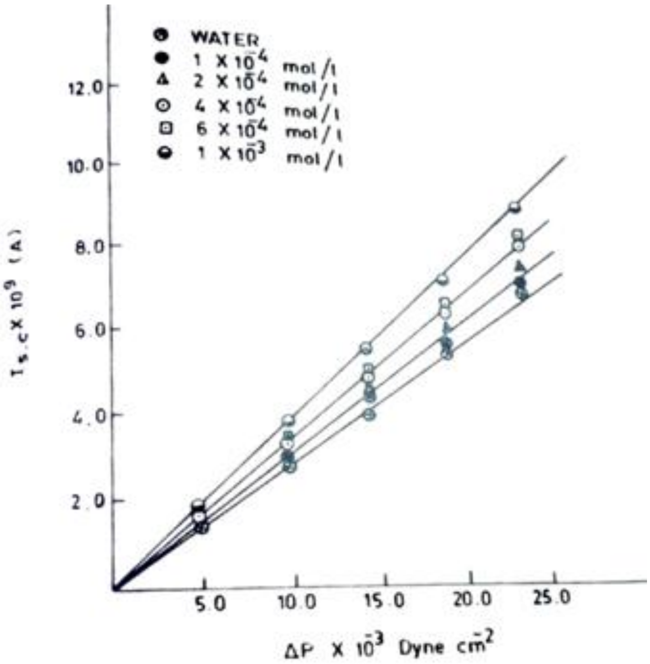

Figure 5: Dependence of Streaming Current I_{SC} on Applied Pressure Difference ΔP, Progestrone/ Aqueous KCl.

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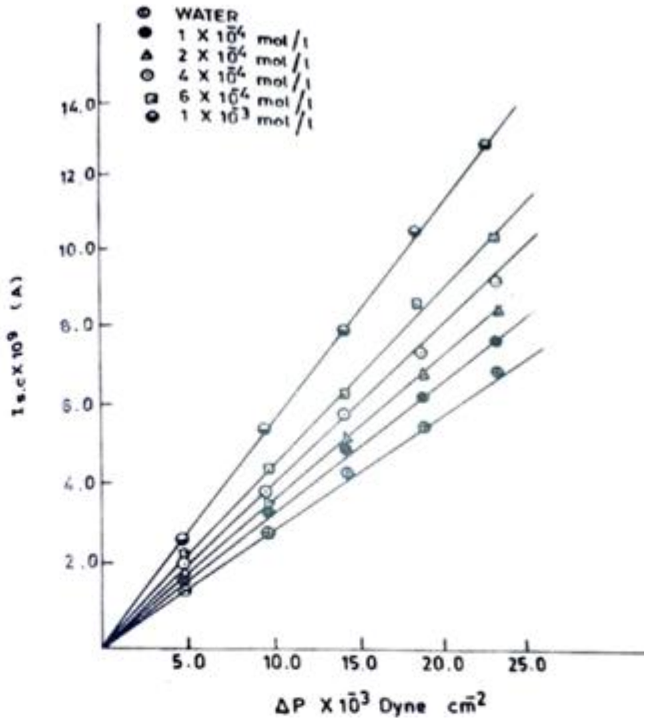


Figure 6: Dependence of Streaming Current $I_{S.C}$ on Applied Pressure Difference ΔP, Progestrone / Aqueous $MgCl_2$

For

Linear dependence of streaming potential $(\Delta\phi)_{I=0}$ on applied pressure difference P for NaCl, KCl and $MgCl_2$ solution at various concentrations is observed.. The values of $(L_{21})_{sp}$ were obtained from the slopes of these linear plots and L_{22} values.

When $\Delta\phi = 0$ equation (1) gives a current according to the following equation

$$(I)_{\Delta\phi=0} = \left(\frac{L_{21}}{T}\right)_{sc} . \Delta P \qquad (3)$$

$(I)_{\Delta\phi=0}$ is called streaming current. The streaming current $(I)_{\Delta\phi=0}$ have also been found to vary linearly with applied pressure difference P in the same concentration range for NaCl, KCl and $MgCl_2$ solutions.

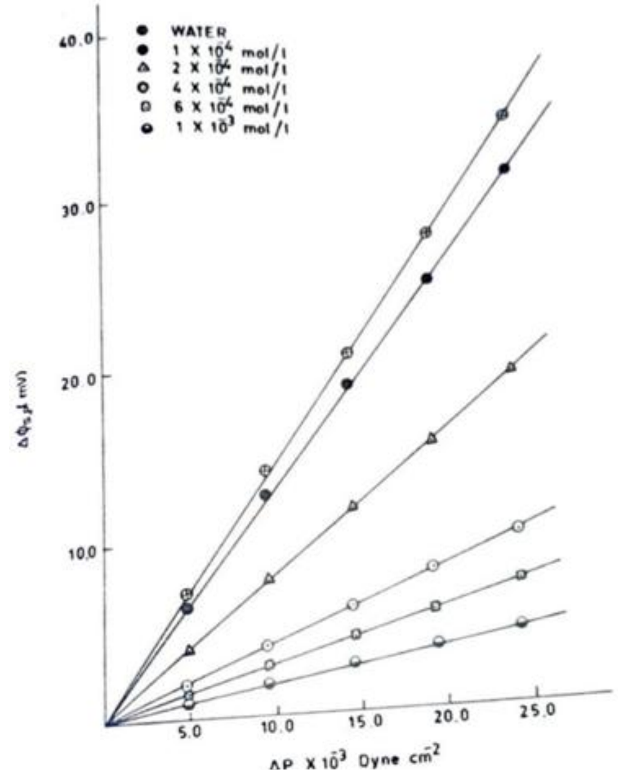


Figure 7: Dependence of streaming current I_{SC} on Applied Pressure Difference $\Delta\phi_{SP}$, for Progestrone / Aqueous NaCl

$I=0$

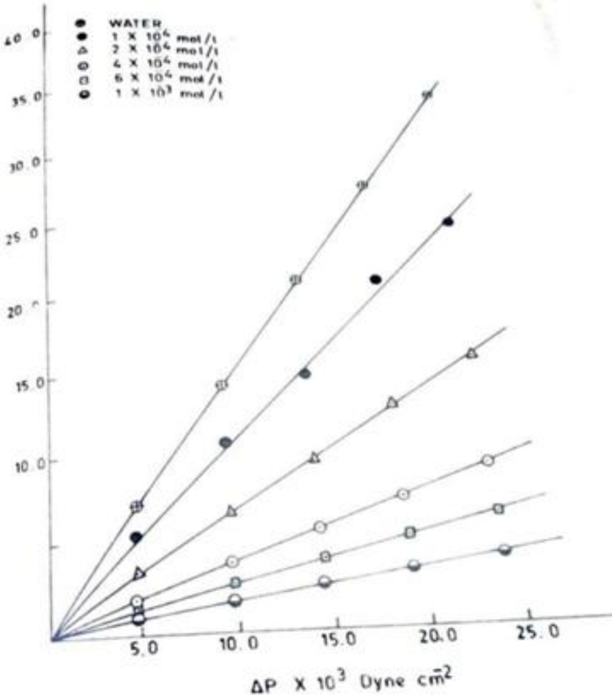


Figure 8: Dependence of streaming potential current $I_{S.C}$ on Applied Pressure Difference $\Delta\phi_{sp}$, for Progestrone / Aqueous KCl

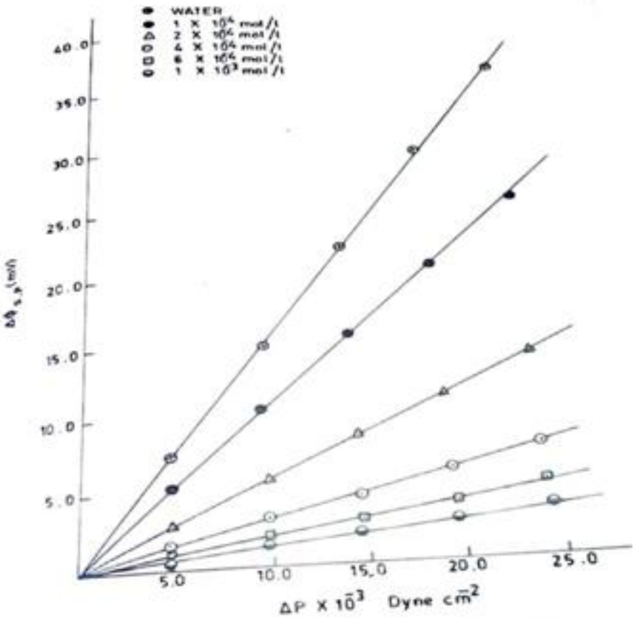
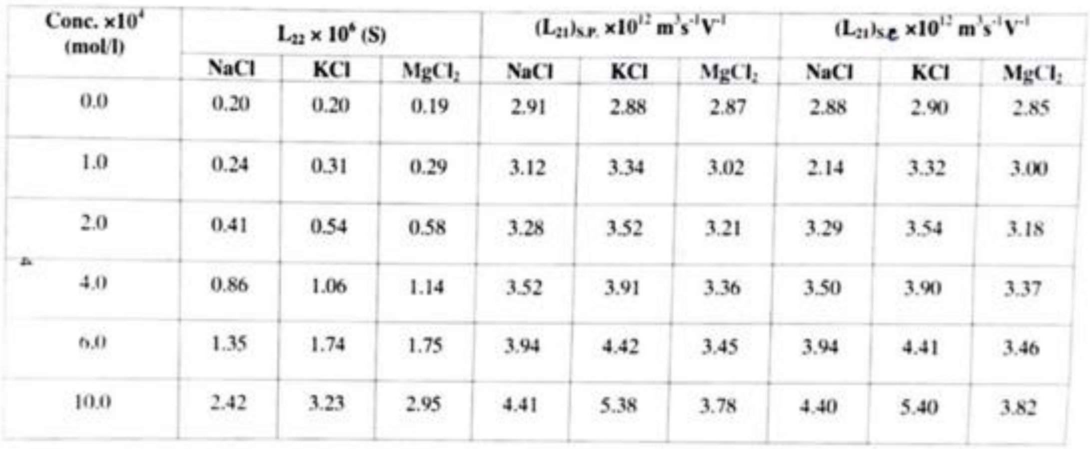


Figure 8: Dependence of streaming potential current I_{sc} on applied pressure Difference $\Delta\phi_{sp}$, for Progestrone/ Aqueous $MgCl_2$

The slopes yield the values of $(L_{21})_{SP}$ and $(L_{21})_{SC}$ are nearly equal showing thereby that Saxen's relationship holds good in the case of streaming potential and streaming current.

Table 1: Phenomenological coefficients from streaming potential and streaming current data, for progesterone/ aqueous electrolyte systems



Conc. ×10^4 (mol/l)	L_{22} × 10^6 (S)			$(L_{21})_{S.P.}$ ×10^{12} $m^3s^{-1}V^{-1}$			$(L_{21})_{S.C.}$ ×10^{12} $m^3s^{-1}V^{-1}$		
	NaCl	KCl	$MgCl_2$	NaCl	KCl	$MgCl_2$	NaCl	KCl	$MgCl_2$
0.0	0.20	0.20	0.19	2.91	2.88	2.87	2.88	2.90	2.85
1.0	0.24	0.31	0.29	3.12	3.34	3.02	2.14	3.32	3.00
2.0	0.41	0.54	0.58	3.28	3.52	3.21	3.29	3.54	3.18
4.0	0.86	1.06	1.14	3.52	3.91	3.36	3.50	3.90	3.37
6.0	1.35	1.74	1.75	3.94	4.42	3.45	3.94	4.41	3.46
10.0	2.42	3.23	2.95	4.41	5.38	3.78	4.40	5.40	3.82

4. Acknowledgement

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List of Symbols (Notations and Units)

$(\Delta\phi)_{I=0}$	**Streaming potential**	Milli Volts (MV)
ΔP	**Pressure difference**	dynes cm^{-2} x 10^{-3}
$\Delta\phi$	**Electrical Potential difference**	Volts (V)
I	**Electrical current**	Ampere (A)
$(I)_{\Delta\phi=0}$	**Streaming current**	Ampere (A) X 10^{9}
$(L_{21})_{SP}$	**Phenomenological coefficient for streaming potential**	m^{3} s^{-1} v^{-1}
$(L_{21})_{SC}$	**Phenomenological coefficient for streaming current**	m^{3} s^{-1} v^{-1}
L_{22}	**Conductance of membrane-permeant Siemen**	(S) =ohm^{-1}