



EVALUATION OF MEMBRANE SELECTIVITY IN LEAD (II) MOLYBDATE PARCHMENT SUPPORTED MEMBRANE VIA BI-IONIC POTENTIAL AND CONDUCTIVITY MEASUREMENT

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Abstract

The transport of ions over a parchment-impregnated Lead (II) Molybdate membrane was examined. The parchment paper was treated with PbCl_2 and Na_2MoO_4 solution salts to incorporate PbMoO_4 precipitate. This reduces pore size and raises the effective fixed charge, which affects transport phenomena in membranes. The membrane conductivity in contact with a 1:1 electrolyte was measured experimentally to assess the membrane's selectivity with preset inter-membrane mobility ratio values. The membrane's ion selectivity has been determined to be $\text{K}^+ > \text{Na}^+ > \text{Li}^+$, indicating the weak field strength of the charged groups attached to it.

Keywords: Lead(II) molybdate artificial membrane, Membrane potential, Bi-ionic potential, Membrane conductance, Membrane selectivity

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1. Introduction:

Ion-exchange membranes (IEMs) are employed in a number of electro-membrane processes, including electrodialysis, water-splitting electrodialysis, electrode ionisation, and others. IEMs may also be used to desalinate seawater, [1]–[3] separate amino acids, separate lactate from fermentation broths [4], [5] and for additional reasons [6], [7]. Cation-permeable membranes with excellent permeability and selectivity are useful for a variety of electrochemical applications. The core requirements for each application are the same: adequate selectivity, permeability, and stability [8].

This paper describes the preparation of parchment impregnated Lead(II) molybdate membrane and the values of membrane selectivity which have been calculated with the help of observed bi-ionic potential values and experimentally observed membrane conductance values.

2. Materials and method:

The Na_2MoO_4 (S.D. Fine Limited, India), PbCl_2 (Ranbaxy, India), and parchment paper (Amol Group of Companies, Mumbai, India) used in the fabrication of the artificial membrane. The

remaining reagents were of analytical grade.. For electrochemical characterisation, the monovalent chlorides of the Na, K, and Li electrolytes were used.

2.1. Membrane preparation:

Using the interaction approach proposed by Beg and colleagues [9]–[11], a parchment-impregnated artificial Lead(II) Molybdate membrane was fabricated. The flat lip of a beaker with a 0.2M Na_2MoO_4 solution was tied to parchment paper after it had been immersed in deionized water for around two hours. In a porcelain dish with a 0.2M PbCl_2 solution, the beaker was suspended for 72 hours. A further 72 hours were passed after the two solutions (the fresh solution) were switched. As a result, the combination of parchment paper and inorganic precipitate acts as an artificial membrane. To get rid of free electrolytes, deionized water was used to wash the membrane.

2.2. Measurement of bi-ionic potential

A Systronics digital potentiometer model 318 was used to determine bi-ionic potential by setting up an electrochemical cell of the type given in Fig. 1.

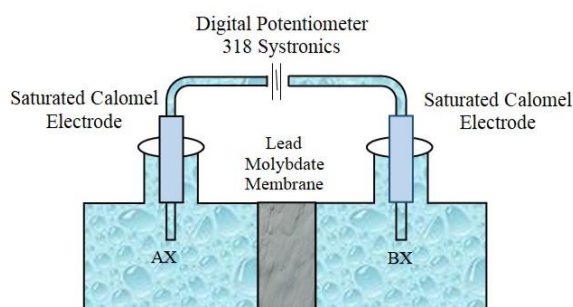


Fig.1: Electrochemical set up for bi-ionic potential measurements

Aqueous solutions of NaCl, KCl, LiCl (BDH, AR grade) were used in the investigation. . A pair of magnetic stirrers was used to stir the solutions on both sides of the membrane swiftly in order to eliminate or at least limit the impact of film control diffusion [12]. The entire cell was submerged in a water thermo-state that was kept at a constant $25 \pm 0.1^\circ\text{C}$

2.3. Measurement of electrical conductance

The synthetic membrane was sandwiched between two half cells. To equilibrate the membrane, the

half cells were initially filled with electrolytes (KCl, NaCl, or LiCl) (Fig. 2). The solutions were replaced with pure mercury, but the surface liquids were not removed. To obtain consistent results, any trapped air was removed from the membrane-solution interface. The electrical connections were made using platinum electrodes. The membrane conductance was measured at 103 Hz using a Systronics direct reading conductivity metre 303. All measurements were conducted at a temperature of $25 \pm 0.1^\circ\text{C}$. [13].

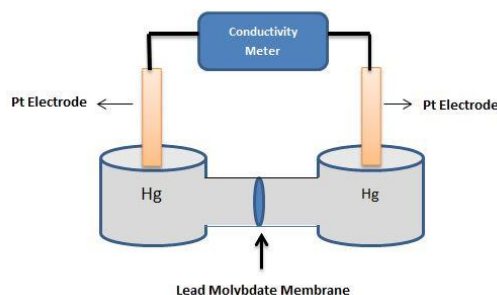


Fig. 2: Measurement of electrical conductance

2.4. Characterization of the Lead(II) molybdate membrane:

The electrochemical properties of the membrane are influenced by membrane parameters such as water uptake, porosity, thickness, swelling, etc., so it is required to characterize the complete membrane [14] [15].

2.4.1. Water uptake percentage

The following method was used to calculate the water uptake or membrane's water percentage.

:

$$\text{Water uptake (\%)} = \left(\frac{W_w - W_d}{W_w} \right) \times 100$$

Where

W_w denotes the weight of the wet artificial membrane and

W_d denotes the weight of the dry artificial membrane

2.4.2. Membrane porosity

The porosity (Φ) of membrane was calculated by using the following equation:

$$\text{Membrane Porosity} = \left(\frac{W_w - W_d}{AL\rho_w} \right)$$

Table 1: Water uptake, Porosity, Thickness, and Swelling properties of parchment impregnated Lead(II) molybdate artificial membrane

Water uptake as % weight of wet membrane	1.097
Porosity (Φ)	0.0661
Thickness (cm)	1.059
Swelling (%)	0.98

A parchment-impregnated artificial membrane will absorb water based on the vapour pressure in the surrounding environment. Because of the high order of water absorption, swelling, and porosity with decreasing membrane thickness, diffusion across the membrane seems to occur mostly through exchange sites [14], [16]

Where

A = Area of membrane (cm^2), L = thickness of membrane (cm), and ρ_w = density of water (g/cm^3).

2.4.3. Membrane thickness

By using screw gauze the membrane thickness was determined by taking the average thickness of the membrane.

2.4.4. Membrane swelling

The difference between the average dry membrane thickness and the membrane equilibrated in a 1M sodium chloride solution over a 24-hour period was used to determine the swelling of the membrane.

3. Results and discussion:

Table 1 shows the results of water uptake, porosity, thickness, and swelling of a parchment impregnated Lead(II) molybdate membrane.

The total Bi-ionic potential for ions of equal valence is given by the following equation:

$$E_{BIP} = (RT/FZ) \ln \bar{D}_i a'_i \bar{\lambda}_j / \bar{D}_j a'_j \bar{\lambda}_i \quad (1)$$

Where

a'_i / a'_j = Activity ratio of solutions

\bar{D}_i / \bar{D}_j = Diffusion coefficient of ions in membrane phase

$\bar{\lambda}_i / \bar{\lambda}_j$ = Ratio of activity coefficient of ions;

R, T, Z and F have their usual meaning.

According to Wyllie and Kannan [17], [18] equation (1) reduces to (2).

$$E = (RT / FZ) \ln a_i' \bar{U}_i / a_j' \bar{U}_j \quad (2)$$

Provided $\bar{U}_i = \bar{U}_j$ and the diffusion are replaced by mobilities. Wyllie [18] expressed the intramembrane mobility ratio as

$$\bar{U}_i / \bar{U}_j = \bar{t}_i / \bar{t}_j = \bar{m}_i \bar{\lambda}_i / \bar{m}_j \bar{\lambda}_j \quad (3)$$

Where

\bar{t}_i / \bar{t}_j = Membrane transference ratio

\bar{m}_i and \bar{m}_j = Steady state equilibrium concentration of i and j in the respective junction zone.

$\bar{\lambda}_i$ = Conductivity of the membrane when it is wholly in i form and

$\bar{\lambda}_j$ = Conductivity of the membrane when it is wholly in j form.

Furthermore, it was shown that $\bar{m}_i / \bar{m}_j = K_{ji}$, K_{ji} is the selectivity. This on substitution into equation (3) gives:

$$\bar{U}_i / \bar{U}_j = K_{ji} (\bar{\lambda}_i / \bar{\lambda}_j) \quad (4)$$

As a result, the membrane chemical and electrical characteristics were connected to the mobilities ratio.

The bi-ionic potential values across a parchment-impregnated Lead(II) molybdate membrane at different concentrations of monovalent electrolyte combinations are presented in Table 2 and illustrated in Fig. 3.

Table 2: Experimental values of bi-ionic potential E_{BIP} (mV) across Lead(II) molybdate membrane in contact with various monovalent electrolyte ion pairs at same concentration at $25 \pm 0.1^\circ\text{C}$

Concentration (mol/L)	Electrolyte Ion Pair		
	KCl-NaCl	KCl-LiCl	NaCl-LiCl
0.1/0.1	7.9	2.8	8.5
0.05/0.05	8.6	2.9	8.9
0.02/0.02	9.8	4.3	10.9
0.01/0.01	11.9	6.8	13.9
0.005/0.005	12.8	8.8	19.9
0.001/0.001	13.9	9.8	20.8

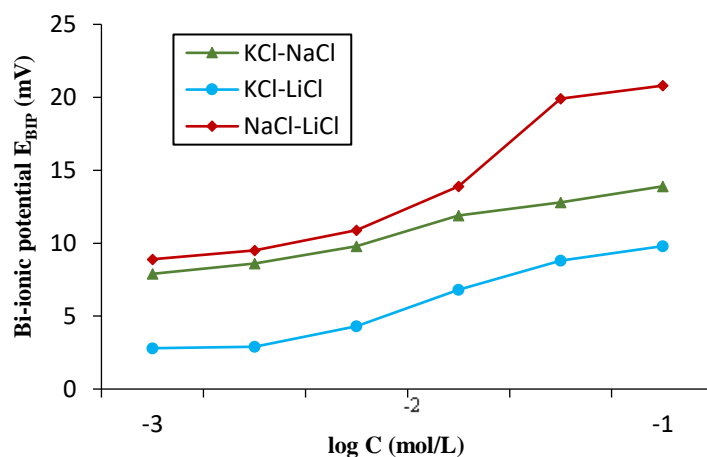


Fig. 3: Plots of bi-ionic potential E_{BIP} (mV) against log C (mol/L) for Lead(II) molybdate membrane using monovalent electrolyte ion pairs

The intra membrane mobility ratio was calculated using Equation (2), and the results are shown in Table 3.

An interesting point with regard to the values of \bar{U}_i / \bar{U}_j is that the mobility ratio undergoes

considerable change with the concentration of the external solution. This behaviour was observable with each electrolyte pair.

Table 3: Values of the intramembrane mobility ratio of various monovalent electrolyte ion pairs across Lead(II) molybdate membrane

Concentration (mol/L)	Electrolyte Ion Pair		
	$\bar{U}_{K^+} / \bar{U}_{Na^+}$ KCl-NaCl	$\bar{U}_{K^+} / \bar{U}_{Li^+}$ KCl-LiCl	$\bar{U}_{Na^+} / \bar{U}_{Li^+}$ NaCl-LiCl
0.1/0.1	2.05	2.44	2.30
0.05/0.05	2.07	2.40	2.27
0.02/0.02	2.15	2.62	2.52
0.001/0.001	2.35	2.83	2.80
0.005/0.005	2.40	2.98	3.00
0.001/0.001	2.60	3.44	3.21

To gain knowledge of selectivity K_{ij} from the predetermined values of \bar{U}_i / \bar{U}_j the ratio of electrical conductivities $\bar{\lambda}_i / \bar{\lambda}_j$, required in equation (4) must be known. When the membrane was completely in form i or form j, a measurement

of its conductance was performed. The membrane conductance values at different salt concentrations are presented in Table 4. The values are relatively more dependent on the concentration of the salts within the membrane as appeared in Fig.4.

Table 4: Experimental values of membrane electrical conductance $\times 10^{-2}$ (mhos) across Lead(II) molybdate membrane at $25 \pm 0.1^\circ\text{C}$

Concentration (mol/L)	Electrolytes		
	KCl	NaCl	LiCl
0.1/0.1	9.95	8.6	7.60
0.05/0.05	6.46	5.9	4.92
0.02/0.02	4.46	3.9	3.40
0.001/0.001	3.75	3.8	2.45
0.005/0.005	2.98	2.28	0.86
0.001/0.001	2.30	0.85	0.55

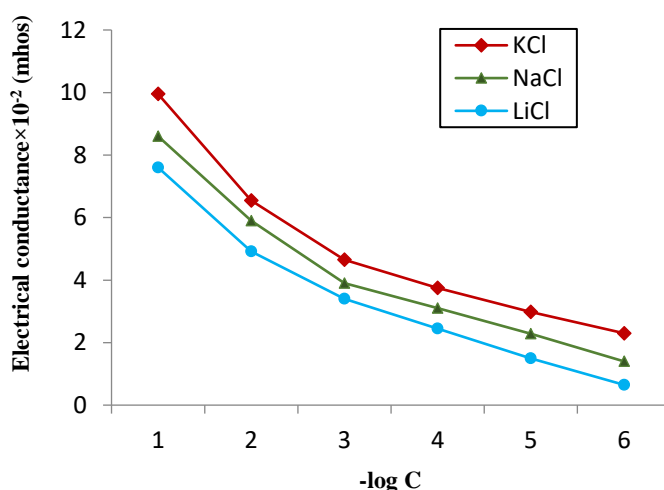


Fig. 4: Plots of electrical conductance (mhos) against $-\log C$ for Lead(II) molybdate membrane

This suggests that the membrane has a low selectivity constant value and a relatively strong Donnan absorption of anion.

Table 5 contains the selectivity K_{ji} data for the Lead(II) molybdate membrane that were calculated using the data from Tables 3-4, based on the ratio of their electrical conductivity and intra membrane mobility. The intra membrane

mobility ratio measurements also indicate that $K^+ > Na^+ > Li^+$ is the membrane selectivity sequence for cations. Based on the Eisenman-Sherry model of membrane selectivity [18], [19] this order of selectivity indicates that the charged groups affixed to the membrane matrix have a weak field strength.

Table 5: Values of the selectivity K_{ji} ($K_{ij} = 1/K_{ji}$) evaluated from intramembrane mobility ratio and the ratio of electrical conductivities at various electrolyte concentration for Lead(II) molybdate membrane

Concentration (mol/L)	Selectivity		
	K_{NaK}	K_{NaLi}	K_{LiK}
0.1/0.1	0.98	2.09	2.10
0.05/0.05	1.00	2.10	2.18
0.02/0.02	1.56	2.40	2.48
0.001/0.001	2.02	2.62	2.52
0.005/0.005	2.15	2.39	2.75
0.001/0.001	2.41	2.72	2.56

According to Eisenman and Sandblom [19] derived the following equation (5)

$$\frac{P_i}{P_j} = K_{ji} \frac{\bar{U}_i}{\bar{U}_j} \quad (5)$$

Equation (5) suggests that the permeability ratio P_i/P_j can be calculated, provided that the mobility ratio \bar{U}_i/\bar{U}_j and the ion exchange constant K_{ji} of a membrane for the ions are

known the values of permeability ratio derived in this way from predetermined values of \bar{U}_i/\bar{U}_j and K_{ji} for lead(II) molybdate membrane are given in Table 6. Table 6 shows data indicating the membrane's weak selectivity, which rises as the bathing solution concentration decreases.

Table 6: Values of Permeability ratio P_i/P_j of various monovalent electrolyte pairs across Lead(II) molybdate membrane

Concentration (mol/L)	Permeability ratio		
	P_{K^+}/P_{Na^+}	P_{K^+}/P_{Li^+}	P_{Na^+}/P_{Li^+}
0.1/0.1	0.90	2.38	2.48
0.05/0.05	1.79	2.41	2.58
0.02/0.02	2.16	2.92	2.99
0.001/0.001	2.57	3.68	3.67
0.005/0.005	2.63	3.99	3.98
0.001/0.001	2.98	3.73	4.15

The e.m.f. (bi-ionic potential) of the cell of the type shown in the experiment part has been related to the fixed charge concentration (ϕ_x) by the equation:

$$E_{BIP} = (RT/F) \ln \frac{\sqrt{1 + (\phi_x M_A / 2a)^2} - (\phi_x M_A / 2a)}{\sqrt{1 + (\phi_x M_B / 2a)^2} - (\phi_x M_B / 2a)} \quad (6)$$

Where $\phi_x M_A$ and $\phi_x M_B$ are the concentrations of the fixed ions on the membrane phase. equation (6) may be used to compute BIP across a membrane if the membrane's effective fixed charge density and external salt solution concentrations are known. Table 7 shows the BIP values calculated from predetermined values of the membrane's effective fixed charge density [19]. For comparison, the observed values have been incorporated in the same table. These values are found to be closer together.

Table 7: Theoretically and experimentally observed bi-ionic potential E_{BIP} (mV) values across Lead(II) molybdate membrane at $25 \pm 0.1^\circ C$

Concentration (mol/L)	Electrolyte ion pairs					
	Experimental			Theoretical		
	KCl-NaCl	KCl-LiCl	NaCl-LiCl	KCl- NaCl	KCl- LiCl	NaCl-LiCl
0.1/0.1	7.9	2.8	8.6	7.2	2.5	7.4
0.05/0.05	8.6	2.8	8.9	7.8	3.8	8.9
0.02/0.02	9.8	4.3	10.9	10.3	4.4	12.8
0.001/0.001	11.9	6.8	13.9	13.4	7.6	13.9
0.005/0.005	12.8	8.9	19.9	13.9	9.0	19.8
0.001/0.001	13.8	9.5	20.9	14.8	9.8	20.9

It is widely known that bi-ionic potential [20] is a measure of membrane selectivity for ions with the same sign. Equation (7) has been found to predict bi-ionic potential values in the same way as equation (1) does, as long as the $\bar{\gamma}_B / \bar{\gamma}_A$ remains constant.

$$E_{BIP} = \frac{RT}{F} \ln \frac{\bar{U}_A a'_A \bar{\gamma}_B}{\bar{U}_B a'_B \bar{\gamma}_A} \quad (7)$$

This equation can be written as

$$E = \frac{RT}{F} \ln \frac{\bar{U}_A a'_A}{\bar{U}_B a'_B} \quad (\text{if } \bar{\gamma}_A = \bar{\gamma}_B) \quad (8)$$

and

$$E_{BIP} = \frac{RT}{F} \ln \frac{\bar{t}_A}{\bar{t}_B} \quad (9)$$

Where

Table 8: Experimental values of bi-ionic potential across parchment impregnated Lead(II) molybdate membrane keeping the concentration of one electrolyte constant and varying the concentration of other salt and vice-versa

Concentration (mol/L)	Electrolyte ion pairs					
	KCl-NaCl	NaCl-KCl	NaCl-LiCl	LiCl-NaCl	KCl-LiCl	LiCl-KCl
0.1/0.5	10.6	2.0	12.6	-7.8	11.5	-5.0
0.1/0.01	16.8	-11.0	22.7	-22.8	19.9	-17.9
0.1/0.005	24.9	-20.4	33.5	-35.8	28.6	-28.8
0.1/0.001	31.9	-27.7	42.8	-46.9	37.4	-39.6

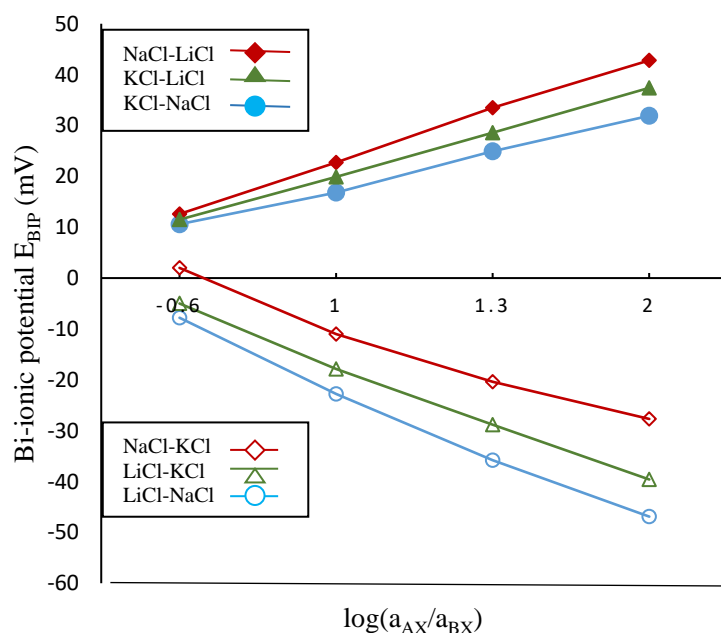


Fig. 5: Plots of bi-ionic potential E_{BIP} (mV) against $\log(a_{AX} / a_{BX})$ for Lead(II) molybdate membrane

Good straight lines, as required by equation (8), are achieved. The potential for the junction of two straight lines at the same activity, i.e. $a_{AX} / a_{BX} = 1$, yields the transport ratio value using equation

(9). Table 9 shows the transfer ratio determined for several monovalent electrolyte pairings for the Lead(II) molybdate membrane.

Table 9: Transport ratio obtained for different monovalent electrolyte ion pairs across the parchment impregnated Lead(II) molybdate membrane

Membrane	Transport ratio		
	$\bar{t}_{K^+} / \bar{t}_{Na^+}$	$\bar{t}_{K^+} / \bar{t}_{Li^+}$	$\bar{t}_{Na^+} / \bar{t}_{Li^+}$
Lead(II) Molybdate	2.18	2.11	2.08

These results also point towards the order of selectivity of cations transporting through the membrane which is as follows:

$K^+ > Na^+ > Li^+$

Conclusion:

The ion-interaction method was successfully employed to fabricate the parchment-impregnated Pb(II) molybdate membrane. Using non-equilibrium thermodynamics, the values of bi-ionic potential across the membrane were calculated using various combinations of monovalent electrolytes at the same concentration. Perfect Donnan exclusion of co-ions was achieved in the dilute limit of the external solution, and the membrane's selectivity sequence for alkali metal cations was $K^+ > Na^+ > Li^+$. The electrical conductivity of the parchment impregnated membrane was measured at $25 \pm 0.1^\circ\text{C}$ to evaluate its selectivity based on preset intra-membrane permeability ratio data. The electrochemical parameters are the most essential aspects that contribute to displaying the superior performance of a perfect ion-selective membrane.

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References:

1. L. Melnik, O. Vysotskaja, and B. Kornilovich, "Boron behavior during desalination of sea and underground water by electrodialysis," *Desalination*, vol. 124, no. 1–3, pp. 125–130, Nov. 1999, doi: 10.1016/S0011-9164(99)00096-X.
2. K. P. Singh, R. Dobhal, R. K. Prajapati, S. Kumar, Sanjesh, and M. A. Ansari, "Preparation of isoproturon and 2,4-dichlorophenoxy acetic acid imprinted

membranes: Ion transport study," *Desalin. Water Treat.*, vol. 24, no. 1–3, pp. 176–189, 2010, doi: 10.5004/DWT.2010.1497.

3. F. Jabeen and Rafiuddin, "Membrane potential and fixed-charge density across TiPO4- VPO4 composite membranes for uni-univalent electrolyte solution," *J. Porous Mater.*, vol. 16, no. 3, pp. 257–265, Jun. 2009, doi: 10.1007/S10934-008-9195-X.
4. V. K. Shahi, S. K. Thampy, and R. Rangarajan, "The effect of conducting spacers on transport properties of ion-exchange membranes in electrodriven separation," *Desalination*, vol. 133, no. 3, pp. 245–258, Apr. 2001, doi: 10.1016/S0011-9164(01)00105-9.
5. M. Minagawa, A. Tanioka, P. Ramírez, and S. Mafé, "Amino Acid Transport through Cation Exchange Membranes: Effects of pH on Interfacial Transport," *J. Colloid Interface Sci.*, vol. 188, no. 1, pp. 176–182, Apr. 1997, doi: 10.1006/JCIS.1997.4765.
6. V. K. Shahi, S. K. Thampy, and R. Rangarajan, "Chronopotentiometric studies on dialytic properties of glycine across ion-exchange membranes," *J. Memb. Sci.*, vol. 203, no. 1–2, pp. 43–51, Jun. 2002, doi: 10.1016/S0376-7388(01)00745-1.
7. J. H. Choi, S. H. Kim, and S. H. Moon, "Recovery of lactic acid from sodium lactate by ion substitution using ion-exchange membrane," *Sep. Purif. Technol.*, vol. 28, no. 1, pp. 69–79, Jul. 2002, doi: 10.1016/S1383-5866(02)00014-X.
8. V. K. Shahi, R. Prakash, G. Ramachandraiah, R. Rangarajan, and D. Vasudevan, "Solution–Membrane Equilibrium at Metal-Deposited Cation-Exchange Membranes: Chronopotentiometric Characterization of Metal-Modified Membranes," *J. Colloid Interface Sci.*, vol. 216, no. 1, pp. 179–184, Aug. 1999, doi: 10.1006/JCIS.1999.6292.
9. M. N. Beg, F. A. Siddiqi, and R. Shyam, "Studies with inorganic precipitate membranes: Part XIV. Evaluation of effective fixed charge densities," *Can. J. Chem.*, vol. 55, no. 10, pp.

- 1680–1686, May 1977, doi: 10.1139/v77-237.
- 10.M. N. Beg, F. A. Siddiqi, R. Shyam, and I. Altaf, “Studies with inorganic precipitative membranes. XI. Membrane potential response, characterization and evaluation of effective fixed charge density,” *J. Electroanal. Chem.*, vol. 89, no. 1, pp. 141–147, May 1978, doi: 10.1016/S0022-0728(78)80039-4.
- 11.M. Nasim Beg, F. A. Siddiqi, S. P. Singh, P. Prakash, and V. Gupta, “Studies with inorganic precipitate membrane: evolution of thermodynamically effective fixed charge density and test of the most recently developed theory of membrane potential based on the principles of non-equilibrium thermodynamics,” *Electrochim. Acta*, vol. 24, no. 1, pp. 85–88, Jan. 1979, doi: 10.1016/0013-4686(79)80046-8.
- 12.M. N. Beg and M. A. Matin, “Studies with nickel phosphate membranes: evaluation of charge density and test of recently developed theory of membrane potential,” *J. Memb. Sci.*, vol. 196, no. 1, pp. 95–102, Feb. 2002, doi: 10.1016/S0376-7388(01)00582-8.
- 13.K. MuftahElsherif, A. El-Hashani, A. El-Dali, and R. El-kailany, “Bi-ionic Potential Studies for Silver Thiosulphate Parchment-Supported membrane,” *Acad. MuftahElsherif, A El-Hashani, A El-Dali, R El-kailanyacademia.edu*, Accessed: May 09, 2022. [Online]. Available: https://www.academia.edu/download/33172292/Bi-ionic_potential1.pdf
- 14.M. Arsalan and Rafiuddin, “Fabrication, characterization, transportation of ions and antibacterial potential of polystyrene based $\text{Cu}_3(\text{PO}_4)_2/\text{Ni}_3(\text{PO}_4)_2$ composite membrane,” *J. Ind. Eng. Chem.*, vol. 20, no. 5, pp. 3568–3577, Sep. 2014, doi: 10.1016/J.JIEC.2013.12.050.
- 15.A. Ansari, A. K. Shukla, and M. A. Ansari, “Potentiometric determination of fixed charge density and antibacterial activity of barium molybdate model membrane,” *Malaysian J. Chem.*, vol. 23, no. 3, pp. 92–107, Sep. 2021.
- 16.A. Ansari, A. K. Shukla, and M. A. Ansari, “Potentiometric determination of fixed charge density and antibacterial activity of barium molybdate model membrane,” *Malaysian J. Chem.*, vol. 23, no. 3, pp. 92–107, Sep. 2021
- 17.K. Spiegler, M. Wyllie, G. Oster, and A. Pollister, *Electrical potential differences*. 1956. Accessed: Oct. 19, 2021. [Online]. Available: https://books.google.com/books?hl=en&lr=&id=U3BQAAQBAJ&oi=fnd&pg=PA277&dq=KS+Spiegler,+1956&ots=P-g2_F1AG7&sig=PzFzI3XwZD5XcbKzEmIb0Ed9laY
- 18.M. R. J. Wyllie, “Ion-exchange membranes. I. Equations for the multi-ionic potential,” *J. Phys. Chem.*, vol. 58, no. 1, pp. 67–73, 1954, doi: 10.1021/J150511A017/ASSET/J150511A017.FP.PNG_V03.
- 19.G. Eisenman, J. Sandblom, E. N.-B. journal, and undefined 1978, “Interactions in cation permeation through the gramicidin channel. Cs, Rb, K, Na, Li, Tl, H, and effects of anion binding,” *cell.comG Eisenman, J Sandblom, E NeherBiophysical journal, 1978•cell.com*, Accessed: Apr. 20, 2022. [Online]. Available: [https://www.cell.com/biophysj/pdf/S0006-3495\(78\)85491-5.pdf](https://www.cell.com/biophysj/pdf/S0006-3495(78)85491-5.pdf)
- 20.T. Xu, K. H.-S. and purification technology, and undefined 2004, “A simple determination of counter-ionic permselectivity in an ion exchange membrane from bi-ionic membrane potential measurements: permselectivity of anionic,” *ElsevierT Xu, K HuSeparation Purif. Technol. 2004•Elsevier*, Accessed: Apr. 20, 2022. [Online]. Available: <https://www.sciencedirect.com/science/article/pii/S1383586604000802>