Recent Advances of Electrochemical Impedance Spectroscopy in Biological Lipid Bilayer Membranes

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Computational Science and Engineering

Research Question

What is the role of EIS in extracting the lipid bilayer membrane electrical properties?

Introduction

Lipid Bilayer Membranes (LBMs) form the cellular boundaries that biologically and chemically separate the intracellular from the extracellular environment for biological cells. They also encapsulate many cellular organelles such as the Golgi Apparatus, mitochondria, and endoplasmic reticulum. With remarkably high flexibility, they form very complex and robust conformations such as in the Golgi apparatus; consequently, the mechanical dynamics and electrical characteristics of LBMs are the subjects of active research.

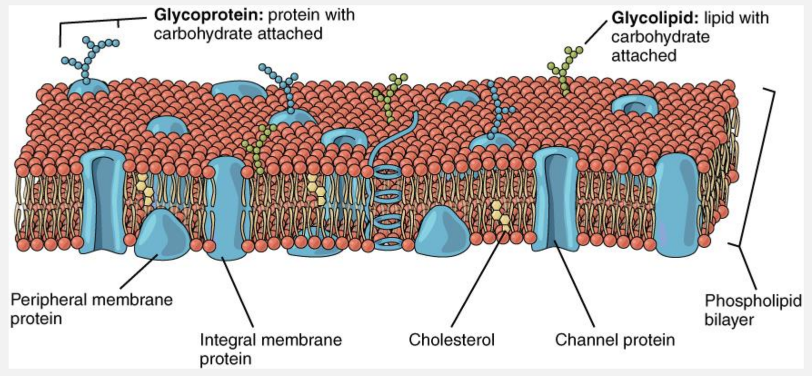

Figure. 1. Cell membrane and its components

Electrochemical Impedance Spectroscopy (EIS) is an efficient and widely used method or characterizing the dielectric properties of biological systems. Unlike di-electrophoresis, EIS is non-invasive and does not need labeling to measure the dielectric properties. In addition to that, it is based on an electrical impedance model, which can be much more accurately described, when compared to the fluid mosaic model, the classical bilayer mechanics theory, and other models that attempted to describe the dynamics of LBMs.

In this work, we investigate the recent advances in electrochemical impedance spectroscopy of biological lipid bilayer membranes and compare the results of different works reported in the literature on biological phospholipid bilayer membranes. Values of electrical resistivity of phospholipid bilayer membranes that are reported in the literature vary by as much as six orders of magnitude.

Results

Various techniques have been applied to identify cell membranes' characteristics, and functions, such as fluorescence microscopy, fluorescence correlation spectroscopy, and electrochemical impedance spectroscopy (EIS). Among these methods, the EIS is widely used to investigate the electrical properties of biological membranes. Considering all chemical and electrical processes in the model are complex and require simultaneous simulation of chemical and electrical phenomena.

In this work, we used EIS of the system in each of the two experiments were collected for an input voltage of 10 mV RMS from 100 kHz to 0.1 Hz at 2-second intervals. The EIS spectra of the LBM on the aperture and for the aperture before the deposition of the LBM in both the PLA and the glass apparatus are shown in fig. 4. It can be noticed from the figure that the value of the impedance consistently increases for both cases when the LBM is deposited across an aperture in a PLA apparatus and in a glass apparatus.

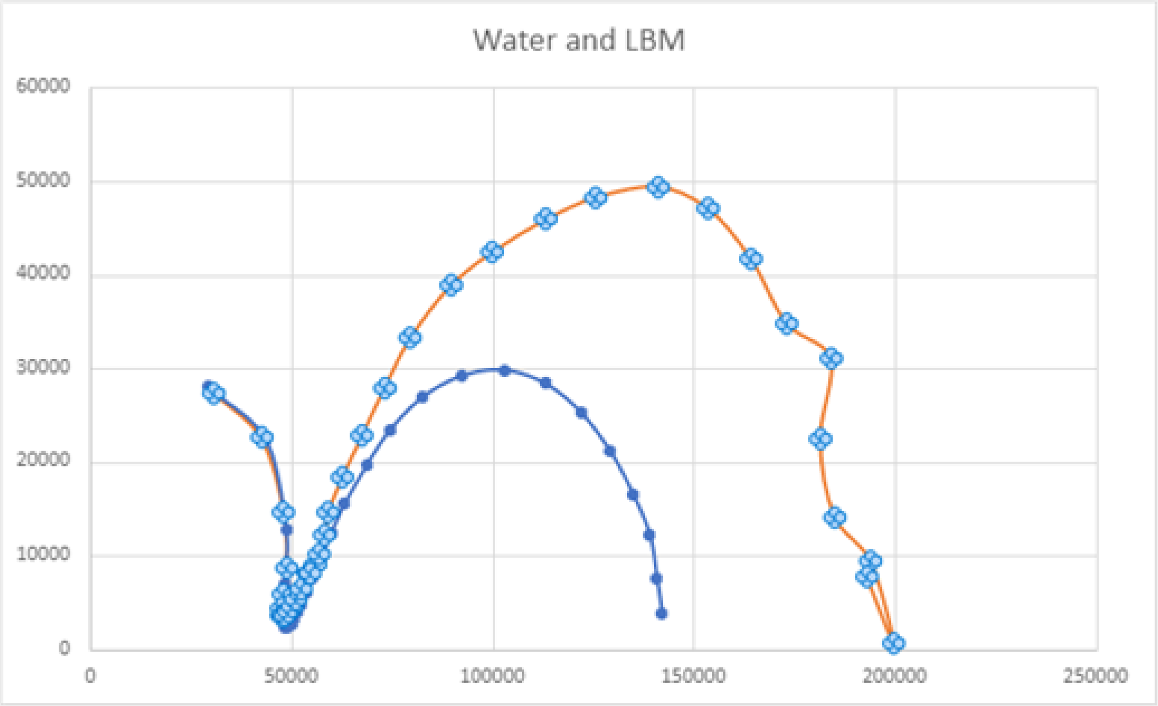

Figure 3.. The EIS spectra of the phosphatidylserine LBM across an aperture in an apparatus made from glass [1]

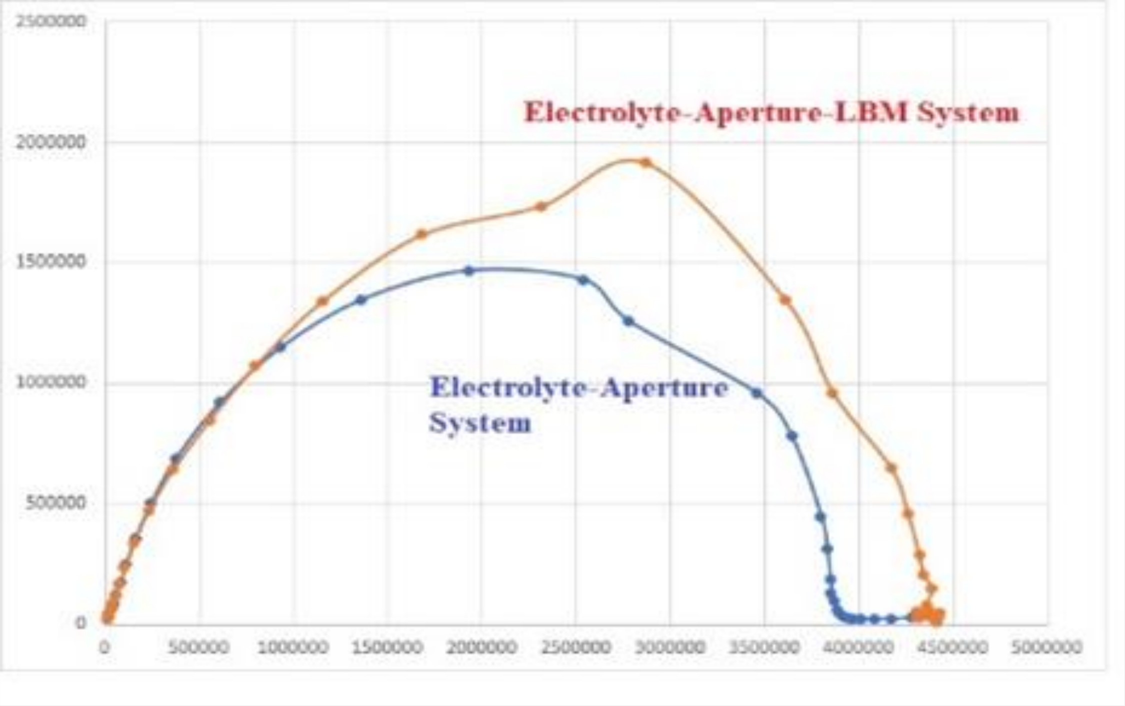

Figure 4. The EIS spectra of the phosphatidylserine LBM across an aperture in an apparatus made from glass (Left) and in a PLA apparatus [1]

Methods

Electrochemical Impedance Spectroscopy (EIS) is an AC electrochemical measurement technique that could measure the system's impedance at various frequencies. Electrochemical impedance is usually measured by applying the potential or injecting a small variable current over different frequencies and recording the response through the system or cell, including the size and phase of system impedance.

In recent years, this technique has received much attention, especially in microbiology, to identify living components' characteristics for various reasons. Because EIS is very sensitive to the surface, it makes it much more accurate than other techniques. It is possible to see many small changes through the application of EIS to biological systems. Also, since EIS is a non-invasive and mark-free method, it is the best choice for analytical electrochemistry than other techniques.

The quantitative evaluation of EIS was obtained using equivalent electrical circuits (EECs), Fig. 2, which model electrochemical impedance spectroscopy and demonstrate the performance of the electrochemical process with electrical elements, such as resistance and capacitance.

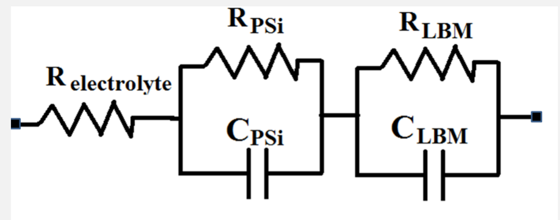

Figure 2.. The equivalent electrical circuits (EEC)

Also, several methods can be found in the literature for lipid bilayer membrane deposition, such as lipid vesicle spreading, Langmuir- Blodgett, and Langmuir- Schaefer techniques which offer the advantage of tight packing of the lipid molecules, spin coating.

In this work, the EIS technique has been used to form the lipid bilayer as demonstrated in our work in reference.

The synthetic phospholipid 1,2-diphytanoyl-sn-glycero-3-phosphoserine (C46H89NO10PNa) was purchased from Avanti Polar Lipids, Inc and was used to form the LBM due to its long fatty acid chain in order to spontaneously favor the formation of bilayer membranes over micelles.

Conclusions

EIS is a powerful tool for mark-free data analysis and characterization of biological cells. Also, it provides information about the characteristics and properties of the membrane and cytoplasmic conductivity in a range of cycles.

In this work, we investigated the electrical properties of lipid bilayer membranes, by the EIS method, formed across an aperture in a glass apparatus. Both apparatuses resulted in resistance and capacitance values about close to each other when compared to results reported for other similar phospholipids. The resistivity we report here results is in closer agreement with known values of human tissue and natural lipid bilayer membranes.

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