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Electrical Properties of Lipid Membrane – Role of Bathing Solution

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Abstract

Motivation. The nonlinearity in the I-V characteristics of lipid bilayer membrane in symmetric bathing solution has been explained earlier as due to the semiconducting nature of lipid molecules and mechanism of charge conduction in inhomogeneous system. It is of interest to know the exact conduction mechanism of lipid membranes in asymmetric bathing solutions.

Method. The membrane system was constructed by filling the smooth circular pores (porosity G-4) of an otherwise very tightly packed polycarbonate film with a solution of oxidized cholesterol in n-decane. Planar lipid membrane (PLM) was formed when bathing solution was added on both sides. The bathing solutions were saturated with acrydine orange (an electron donor) and iodine (an electron acceptor).

Results. The I-V charactertistics curves were drawn from the experiment and were found to be different in forward and in reverse biased conditions.

Conclusions. The I-V behaviour of the lipid membrane in asymmetric bathing solution is seen to show a diode like behaviour of the system.

Keywords. asymmetric bathing solution, planar lipid membrane, I-V characteristics

Abbreviations and notations

BLM, Bilayer lipid membrane
I, current
S_v, noise power
PLM, planar lipid membrane
V, voltage
f, frequency

1 INTRODUCTION

As in all inhomogeneous systems, the I-V characteristics of a lipid membrane is nonlinear, irrespective of the nature of the bathing solution it is embedded in. The temperature dependence of conductivity reveals the intrinsic semiconducting nature of the membrane [1-6].

However, depending on the nature of the bathing solution, the detailed feature of this characteristic curves change. Presence of electron acceptors or electron donors in the bathing solution change the intrinsic semiconducting nature of the lipid membrane to an extrinsic one which is reflected in their non ohmic behaviour at higher field value [7]. Flicker noise measurements were carried out to understand the conduction mechanism in details. It was inferred that the number and diameter of the thermally created hydrophilic pores due to increment of electric field were responsible for such non ohmic nature of the lipid membranes [8,9].

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We have recently communicated our result which shows that use of an asymmetric bathing solution confers a diode like behaviour in these lipid membranes [10].

2 MATERIALS AND METHODS

Cholesterol, purchased from Sigma Chemical Company (St. Louis, MO) was oxidized and then recrystallized from n-octane. Analytical grade chemicals from E. Merck Ltd**.** (Worli, Mumbai, India) were used without further purification. Iodine was purified by resublimation.

The membrane system was constructed by filling the smooth circular pores (porosity G-4) of an otherwise very tightly packed polycarbonate film with a solution of oxidized cholesterol in n-decane. Planar lipid membrane (PLM) was formed when bathing was added on both sides. This system is similar in some respect to the more frequently used bilayer lipid membrane (BLM) but overcomes many of its deficiencies. The major advantage of PLM is that it is much more stable compared to the fragile BLM and an asymmetry in bathing solution can be maintained across the

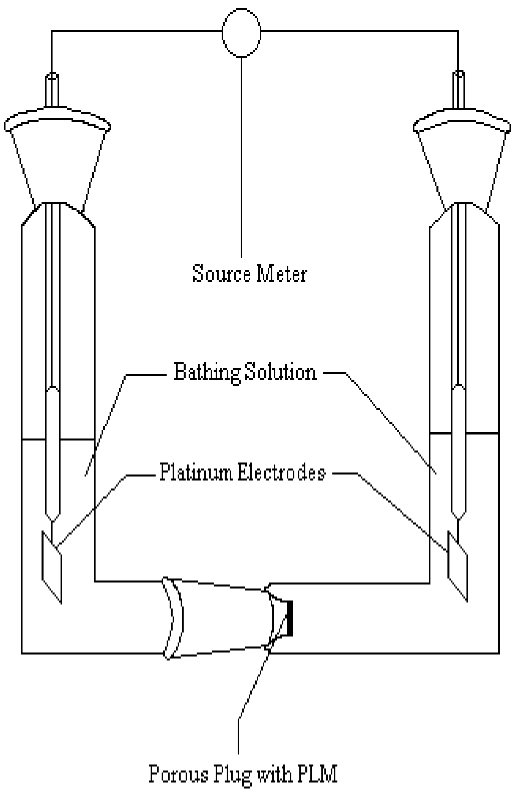


Fig. 1

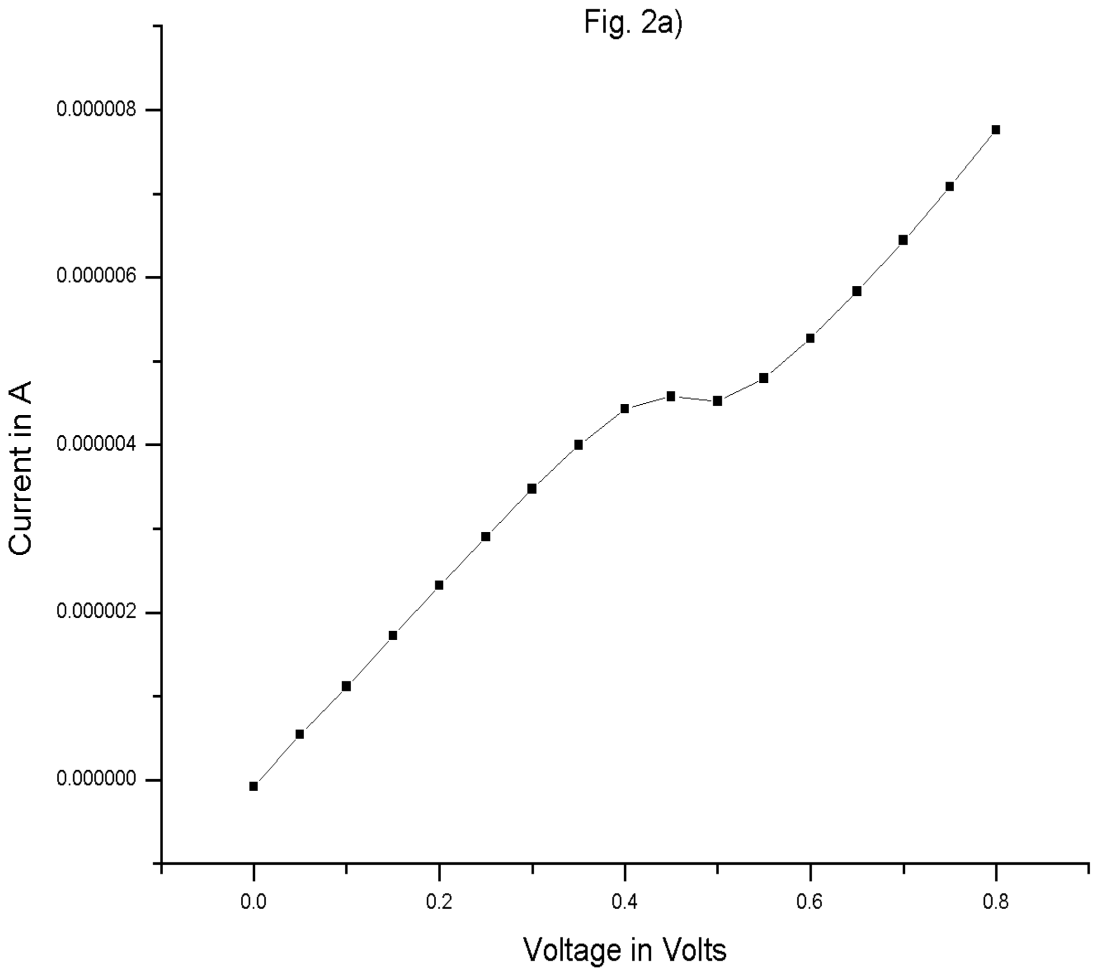
membrane. Because of its stability, PLM has been used as a model for thylakoid membrane and a device for solar energy conversion [11].

Platinum electrodes of 1 cm square were used (inter electrode distance ~ 6 cm) for the application of electric field across the membrane (Figure 1). For asymmetric bathing solution, double distilled water, one saturated with iodine (electron acceptor) and the other saturated with acridine orange (electron donor), both of concentration 1 mM, were used on two sides of the membrane.

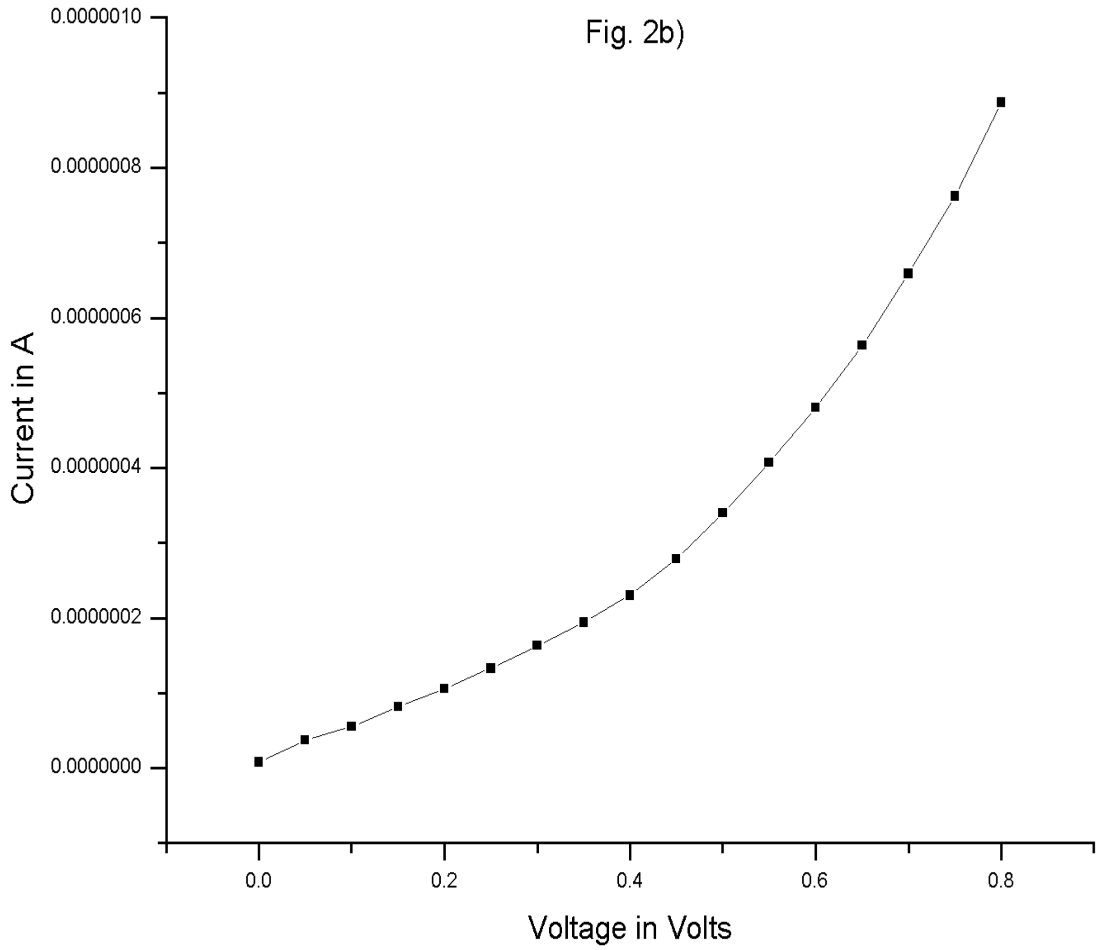
A Keithley source meter 2400 was used to supply a constant dc voltage across the membrane and to measure the corresponding current values.

3 RESULTS AND DISCUSSION

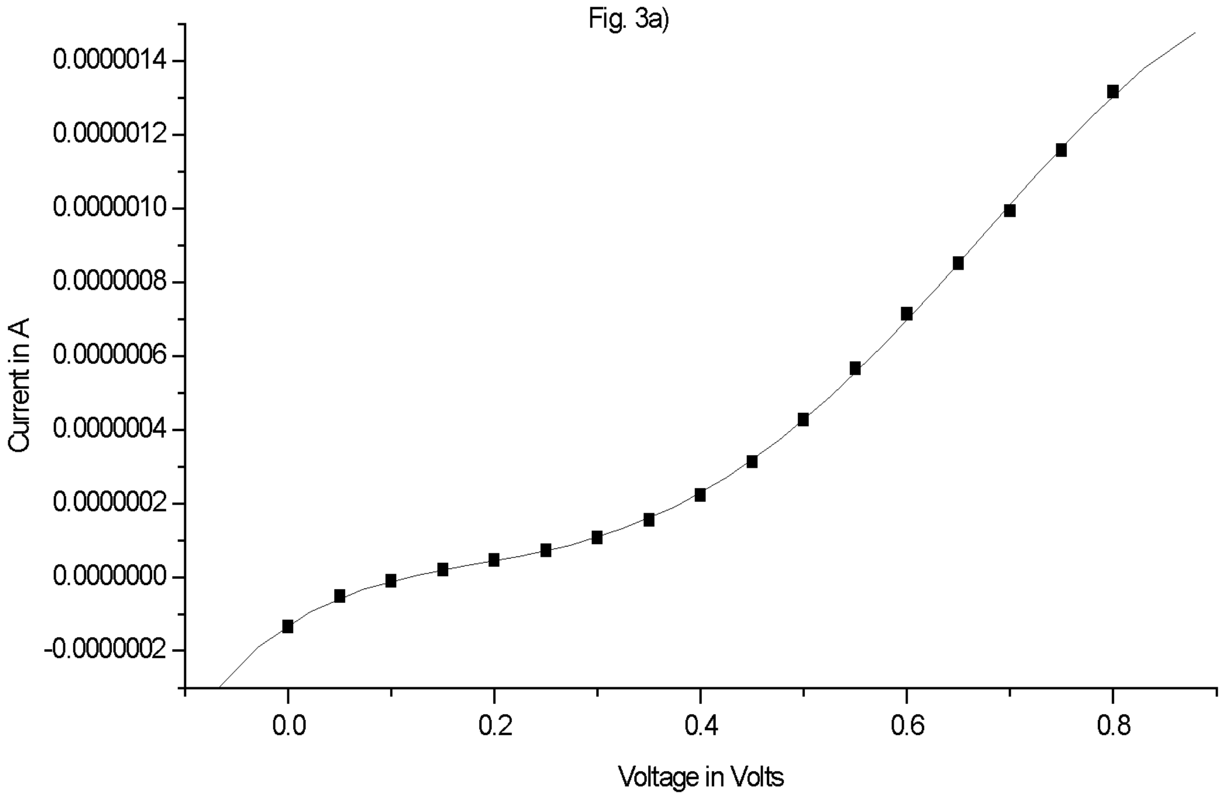
The I-V characteristics of PLM of oxidized cholesterol under symmetric condition using either saturated (1mM) aqueous solution of iodine (solution A) or saturated (1mM) aqueous solution of



acridine orange (solution B) are displayed in Figs 2a and 2b. The next set of figures, Figs.3a and 3b, are the changes observed when the arrangement of symmetric solutions is replaced by the asymmetric arrangement. Comparison of the figures 2 and 3 shows some striking similarity, which perhaps reflects the characteristics of the constituent lipid molecules present in the bathing solution and their effect on the semiconducting property of the lipid aggregate.



Above a threshold voltage, the I-V characteristics in all cases show a nonlinear dependence of current on voltage. In case of symmetric bathing solution this has been explained in terms of field induced pore formation and the semiconducting property of lipid molecules [7]. This conclusion was further supported by noise spectrum measurement in this system [8], where we have shown that the noise power S_v has a 1/f dependence. The decrease in slope of the S_v – V plot at the onset of non-linearity is the signature of pore formation in the lipid aggregates in hydrated state. In the presence of iodine, which is an electron acceptor, the intrinsic semiconducting nature of the lipid molecules changes to an extrinsic one (p- type) whereas the effect of acridine orange (an electron donor) is to induce an n-type semiconductivity [12].

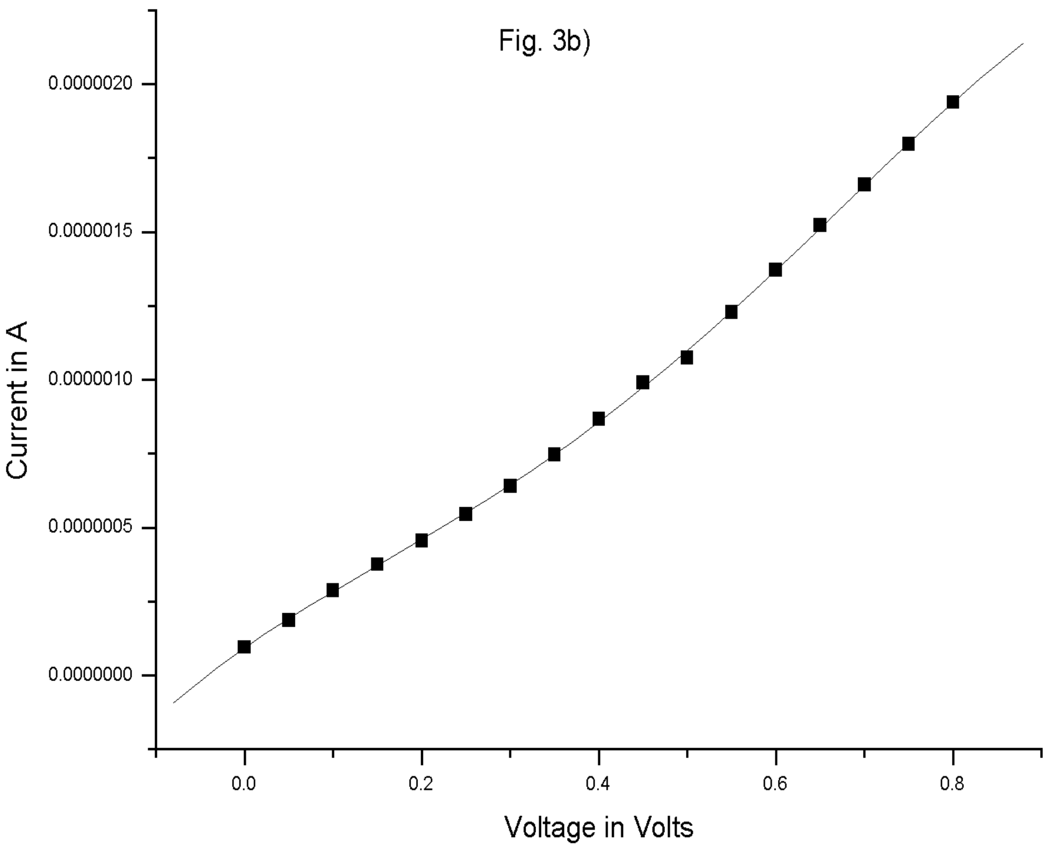


This change in the semiconducting property of the lipid molecules is manifested in the finer details of the I-V characteristics. The field induced pores help to facilitate the ion transport across the membrane and the size, frequency and conductivity of these pores are also nonlinear functions of the applied bias [2,4]. Under the asymmetric condition, when the side containing solution A is positively biased (forward bias), there is a stepwise increase in the value of current with voltage, whereas when this side is negatively biased (reverse bias), the current increases continuously with voltage.

We believe that it is possible that in the case of forward biasing the primary charge carriers (holes or electrons) are transported across the membrane and the current increases with voltage. At higher applied voltage, ions from the bathing solution move towards the PLM, some of which pass through the thermally created hydrophilic pores in the membrane and the rest inject electrons at the lipid-water interface by virtue of the double electrode behaviour of the membrane [13,14]. These electrons tend to recombine with the holes thereby limiting the increase in current but subsequently, after. the process of recombination is over, the current increases with increasing voltage again.

In the reverse biasing condition, the majority charge carriers from the n-side and p-side do not participate in the current conduction. Here the electrons injected at the interface are the charge carriers and hence the current continues to increase with an increase in the applied field.

Such behaviour of the system under forward and reverse bias conditions resembles that of a diode. When the bathing solutions on the two sides of the semiconducting lipid membrane are different, they will have initially different Fermi levels which, when brought to equilibrium due to



transfer of charge across the membrane, will build up a charge on either side of the membrane accompanied by an electrostatic potential barrier. This phenomenon is similar to the depletion region in a p-n junction. Under this condition an asymmetric current-voltage characteristics will be observed depending on the polarity of the bias.

4 CONCLUSIONS

Charge-conduction across lipid membranes is an important key feature in all life-sustaining processes. Our use of planar lipid membranes as a model for investigation of this mechanism has shown that in certain circumstances the lipid membranes can exhibit diode-like behaviour thus exerting influence on charge-conduction across them.

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