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Electrophoretic Mobility Estimated from the Transient Current in a Parallel Plate Cell

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Abstract — The electrophoretic mobility of charge carriers is fundamentally important to the electrical conduction mechanisms insulating liquids. Applications include separation and manipulation of biological cells, imaging using liquid toners and electronic displays such as e-paper. Reported here is a simple method for experimentally estimating the electrophoretic mobility of charge carriers in liquids using a parallel plate electrode cell. The gap d between the electrodes of area A is filled with the liquid. When a step voltage V is applied to the driven electrode, the transient current is measured in the grounded electrode and is describe well by (1).

$$I(t) = I_{SS} + I_{EP} \frac{1}{\left(1 + \frac{t}{\tau}\right)^2} \quad (1)$$

The steady-state current I_{SS} is a DC background current thought to be caused by charge injection at the electrodes or by bulk charge generation. The electrophoretic current I_{EP} is a transient current characterized by time constant τ . Knowing τ , the electrophoretic mobility b of the I_{EP} charge carriers is estimated in (2).

$$b \approx \frac{d^2}{\tau V} \quad (2)$$

The number density of the I_{EP} charge carriers is estimated in (3).

$$n \approx \frac{I_{EP}}{q A d} \tau \quad (3)$$

Every parameter in (2) and (3) is known except the charge q on each charge carrier that is assumed to be one electronic charge.

The current through a solution of 1% by weight of OLOA 11000 in dodecane is measured. From (1), the time constant is about 2.1 seconds. The electrophoretic mobility of the inverse micelles of OLOA is estimated using (2) to be $3 \times 10^{-7} \text{ m}^2/\text{VS}$. The number density of charge carriers is estimated using (3) to be $4 \times 10^{+17} \text{ \#/m}^3$.

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I. EXTENDED ABSTRACT

The electrophoretic mobility of charge carriers is key measure of performance characterizing the speed of carriers moving in response to an applied electric field. The motion of charge carriers determines time required to separate DNA, sort biological cells, or form the image of an electronic display. Direct measurement of mobility is tedious and difficult [1]. The speed of individual particles must be detected either optically or by laser dopper anemometry. When many charge carriers are present, measurements of many individual carriers are needed to characterize the variation in mobility.

When investigating the effect of surfactant concentration and applied electric field on mobility, a number of sample solutions must be measured. And, the precise value of mobility is not required. Rather, rank ordering of samples is often sufficient. Presented here is an experimental method for rapidly estimating mobility. The estimates are satisfactory for rank ordering a series of samples from lowest mobility (slowest response) to highest mobility (fastest response).

Reported here are transient current measurements through solutions of OLOA 11000 in dodecane. OLOA 11000 is a surfactant that is miscible in non-polar liquids. At concentrations above the critical micelle concentration (CMC) estimated to be about 0.2% by weight, molecules engage in a dynamic process where groups of 10 to 20 molecules form inverse micelles. These groups of molecules typically surround particles in the liquid forming a stable suspension. This property of OLOA 11000 is very useful. It is used as an ashless dispersant that provides effective sludge and varnish control in gasoline engines and dispersancy for diesel and natural gas engines [2].

The number density of OLOA molecules (molecular weight of about 3000 gm/mole) in a 1% by weight solution in dodecane is about $1.8 \times 10^{+24}$ #/m³. So, the number density of inverse micelles is on the order of $1.8 \times 10^{+23}$ #/m³. While the vast majority of these inverse micelles are electrically neutral, a small number carry net charge and are the charge carriers responsible for the conduction of electrical current.

To estimate mobility, the time constant characterizing the motion of charge carriers must be measured. This is done in the idealized geometry of a parallel plate electrode cell. The cell requires about a small volume of solution; only about 0.5 ml. The active, measurement volume within the cell varies from about 30 μ l to 100 μ l depending on the cell gap. The excess solution fills temporary storage volume.

Analysis presented in this work demonstrates that the time constant characterizing the motion of charge carriers is not an exponential time constant. An exponentially decreasing current would result from solutions where the electrical conductivity is constant. Here, as charge carriers move towards the cell electrodes in response to the applied electric field, the number density of charge carriers in the volume decreases. Consequentially, the electrical conductivity decreases during the process. The decrease in current with time is given by (1).

$$I(t) = I_{SS} + I_{EP} \frac{1}{\left(1 + \frac{t}{\tau}\right)^2} \quad (1)$$

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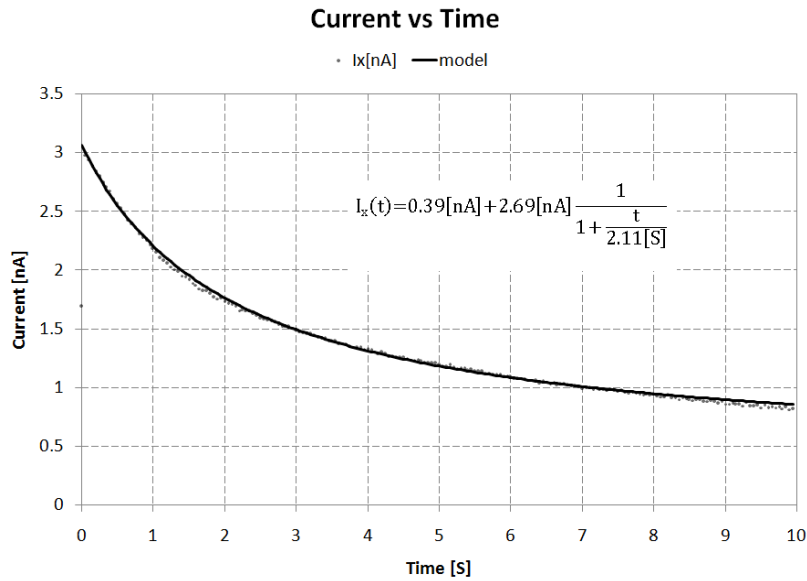


Figure 1: Shown is the transient current measured in a parallel plate test cell filled with a solution of 1% OLOA 11000 in dodecane. The electrode area is $1.45 \times 10^{-4} \text{ m}^2$ and the gap is $565 \text{ }\mu\text{m}$. The time constant t is estimated to be 2.11 s by fitting the data with an empirical model given in (1).

The mobility of charge carriers is given by (2).

$$b \approx \frac{d^2}{\tau V} \quad (2)$$

In some applications, the number density of charge carriers is also of primary importance. The number density of charge carriers is estimated from the initial current by (3).

$$n \approx \frac{I_{EP}}{q A d} \tau \quad (3)$$

II. CONCLUSION

The principle finding of this work is that the time constant characterizing the motion of charge carriers in a 1% by weight solution of OLOA 11000 in dodecane is about 2.2 seconds. The electrophoretic mobility of the inverse micelles of OLOA is estimated using (2) to be $3 \times 10^{-7} \text{ m}^2/\text{VS}$. The number density of charge carriers is estimated using (3) to be $4 \times 10^{+17} \text{ \#/m}^3$. so only about 1 in 10^{+6} inverse micelles carry electrical charge.

REFERENCES

- [1] S. Stotz, "Field Dependence of the Electrophoretic Mobility of particles Suspended in Low-Conductivity Liquids," *J. Colloid and Interface Science*, Vol. 65, No. 1. June 1978, pp 118-130.
- [2] "OLOA 11000 Ashless Dispersant- Succinimide," available: https://www.chevrontexaco.com/products/oronite/products/components_and_chemicals/dispersants.asp