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GENERATION OF ELECTROKINETIC FLOW IN A DOPED NON-POLAR LIQUID

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Extended Abstract

The presence of considerable amounts of free charge dispersed in a liquid is the basis for electrokinetic phenomena which are related to the existence of an electrical double layer (EDL). In polar liquids, the dissociation of electrolytes into ionic species is well understood and numerous electrokinetic phenomena are known; a good overview is given by e.g. Delgado et al. [1]. In nonpolar liquids it is known that electrical charges can exist as well. The presence of these electrical charges is utilized, for example, in colloid science to stabilize particle suspensions [2]. For this purpose, surfactants are added which enhance the zeta potential of the particles in order to prevent their agglomeration. Additionally to the manipulation of surface charges, it is reported that the electrical conductivity of nonpolar liquids essentially increases when surfactant is added and traces of water are present [3]. Such ternary solutions of nonpolar liquid-water-surfactant are known to contain surfactant agglomerations, so-called inverted micelles with a size of several nanometers, detectable for instance by quasielastic lightscattering measurements. Figure 1 sketches the generation and structure of an inverted micelle. In general, surfactants are macromolecules consisting of different functional groups, e.g. a polar “head” and a nonpolar “tail”. Above the critical micelle concentration (cmc), surfactant molecules attach with their polar head at a water droplet forming the inverted micelle. It is assumed that electrical charges are dissolved in the polar core of the inversed micelles enabling opposite charges to be held sufficiently far apart and preventing an agglomeration of different micelles [4].

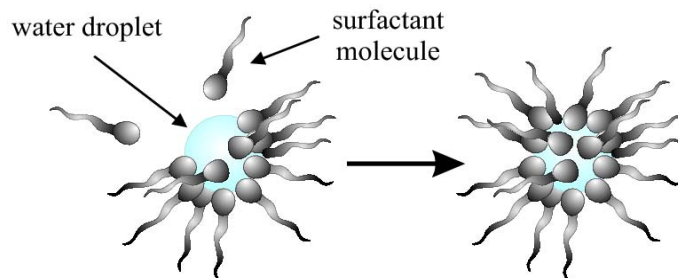


Figure 1: Schematics of the reverse micelle generation.

The capability to generate electrokinetic (electroosmotic) flows in nonpolar liquids gives opportunities for a variety of applications in microfluidics. In this contribution, we shortly describe our respective work which has been recently published in detail elsewhere (cf. [5]). There, we measured the electrical and electrokinetic characteristics of nonpolar liquids containing different concentrations of a surfactant. Solutions of dodecane (anhydrous, >99%, Aldrich) and OLOA 11000 (Chevron Oronite) are prepared. Dodecane is an alkane hydrocarbon with the chemical formula $\text{CH}_3(\text{CH}_2)_{10}\text{CH}_3$; a thick, oily liquid of the paraffin series. The density and viscosity of dodecane are $\rho_D = 0.75 \text{ kg/L}$ and $\mu_D = 1.336 \cdot 10^{-3} \text{ Pas}$, respectively. The conductivities of different mixtures of OLOA 11000 in dodecane are measured by electrical transients. The induced

current densities are proportional to the applied voltage. Hence, the OLOA-dodecane solutions represent an ohmic system. The conductivity does not scale simply with the surfactant concentration, though. It is proposed that different charge generation mechanisms exist depending on the surfactant concentration, and a model which describes the conductivity as a function of the surfactant concentration is presented.

All experiments in this work are performed using the electroosmotic droplet switch (EODS) device which was successfully utilized to measure the zeta potential of porous substrates in contact with aqueous electrolytes (cf. [6]). The idea of the EODS is based on switching between two stable equilibrium states which result when two pinned droplets are coupled by their internal pressure. Inside each droplet, there is a pressure owing to surface tension. (Mechanical) Equilibrium occurs when the pressure difference between the droplets vanishes. That is, when both droplets have the same curvature. The pressure necessary to switch the droplets between their bistable states can be induced by electroosmosis arising at the solid-liquid interface of a porous substrate arranged between the droplets. An approximate correlation for the electrokinetic flow through the substrate is given by

$$\dot{V}_f \approx \pi r_f^2 \frac{\psi}{\chi} \frac{\varepsilon \zeta}{\mu} \frac{\Delta \phi_f}{l_f} \quad (1)$$

Here, r_f , ψ and χ are radius, porosity, and tortuosity of the the circular substrate, respectively; $\Delta \phi_f$ is the average potential drop over the substrate with a thickness l_f ; μ and ε are the viscosity and permittivity of the liquid, respectively. We measure the flow rate through the porous substrate by tracking the volume change of the pinned droplets over the switching time.

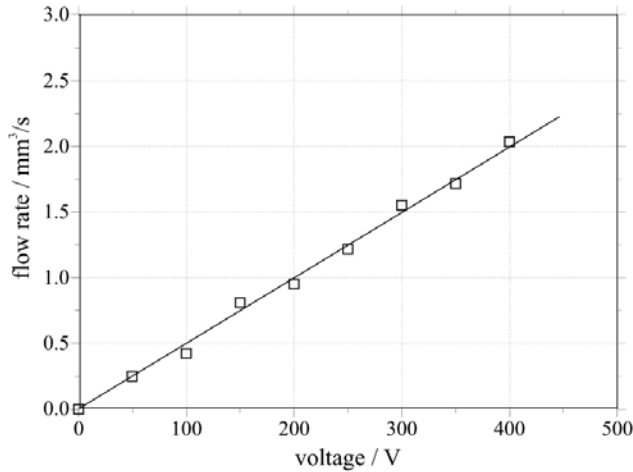


Figure 2: Electrokinetic flow rate of dodecane containing 7.85 mmol/l OLOA 11000 through the porous substrate vs. the applied voltage.

We perform measurements in the EODS device with different surfactant concentrations dissolved in dodecane and several electrical potential differences applied at the electrodes. The electrode voltages induce electric fields within the porous substrate with strengths of 2–40 kV/m. A flow is not detectable when there is no porous substrate installed within the EODS. Likewise, when pure dodecane is filled into the EODS, flow is

not observed either. In contrast, when the EODS is filled with surfactant-dodecane solutions, the application of an electric field induces a flow through the porous substrate. Switching the polarity of the applied voltage results in a change of the flow direction. Figure 2 shows the results of the electrokinetic flow measurements of dodecane containing 7.9 mmol/L OLOA for different applied voltages. We find a linear relationship between the flow rate through the porous substrate and the applied voltage across the electrodes. A carefully conducted comparison to characteristics of electrohydrodynamic (EHD) flows leads to the conclusion that an electrokinetic (electroosmotic) flow is generated (cf. [5]). So far, electrokinetic flows have only been known in polar solutions of electrolytes, since a certain amount of charges is necessary to establish the required electrical double layer.

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