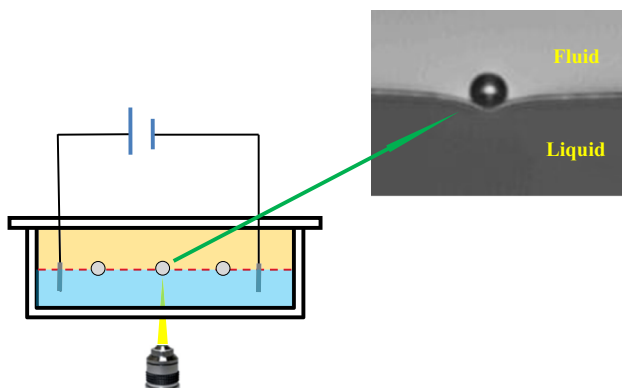


Regular Article

Electrokinetic motion of a spherical polystyrene particle at a liquid–fluid interface

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GRAPHICAL ABSTRACT



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ABSTRACT

Electrokinetic movement of spherical polystyrene particles at different liquid–fluid interfaces was experimentally investigated in this paper. A novel method was developed to place the particles rightly at the interfaces formed in a large plastic container. The velocity was measured by an optical microscope. The experimental results show that the particles (3, 5 and 10 μm in diameter) at the water–air interface, water–dodecane interface and NaCl solution–air interface move in the opposite direction of the applied electric field. The magnitude of the particles' velocity increases linearly with the increase in the applied electric field. Moreover, for particles of the same size, the electrokinetic velocity at the liquid–fluid interfaces is larger than particles' electrophoretic velocity in the bulk liquid phase. Under the same electric field, however, the electrokinetic velocity of smaller particles at the liquid–fluid interfaces is larger than that of larger particles. Such results are attributed to the surface charges at the liquid–fluid interface and the particle–liquid interface.

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1. Introduction

Transporting fluids or moving particles or cells by applying an electric field is a very popular method in microfluidic devices.

The mechanism behind such processes is the interaction of the applied electrical field with the surface charges at the solid wall or on the surfaces of the particles or cells in liquid solutions [1,2]. Electroosmotic flow (EOF) and electrophoretic motion are two main electrokinetic phenomena [3,4] and have been investigated extensively [5–7]. Recently, electrokinetic phenomena at liquid–fluid interfaces have attracted increasing interests due to

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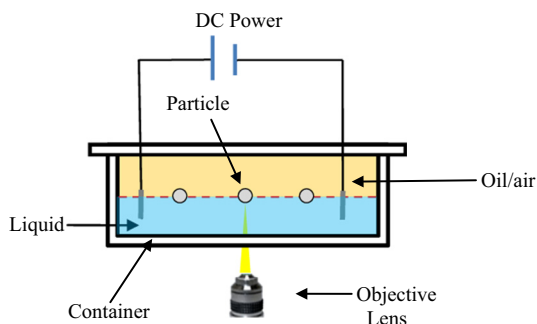


Fig. 1. A schematic diagram of the experimental system.

the rapid development of multiphase microfluidic systems. Different from a solid-liquid interface, the surface charges at the liquid-fluid interface are mobile under an applied electric field. To uncover the underlying mechanisms, several different models were put forward and compared with experimental results [8–10]. Ray et al. [11] numerically investigated the EOF instability of an electrolyte-air interface on a charged rigid surface. They found a new shear-flow mode which can enforce a liquid-air interface to act either as a 'stationary wall' or as 'shearing wall' in or opposite to the direction of EOF of the electrolyte solution, depending on the zeta potential of the liquid-air interface. Gao et al. [9] developed an electric double layer (EDL) model to describe a two-fluid EOF, without considering the interaction of the applied electric field with the mobile interfacial charges. Later, Gao et al. investigated transient two-liquid EOF with the consideration of the interface charges in terms of a new theoretical model (EDL + SC model) [10]. Lee et al. [12,13] investigated the EOF at the liquid-fluid interfaces numerically and experimentally. They found that the electroosmotic velocity at the interface is considerably decreased and the EDL + SC model is the best to explain the experimental phenomena. Additional related studies can be found in other Refs. [14–16].

Besides the liquid flow phenomena involving liquid-fluid interfaces, considerable attentions were also given to the motion of particles trapped at liquid-fluid interfaces which can be used for stabilizing emulsions (Pickering) [17–23], novel material formation [24,25], self-assembled structures [26,27] and anti-reflective

coatings [28–30]. Lee's group [31,32] theoretically studied the electrophoretic motion of a liquid droplet and a solid spherical particle normal to a water-air interface. They found that a water-air interface reduces the droplet/particle mobility when the electric double layer of the droplet/particle touches the interface. They attributed such results to the deformation of electric double layer of the moving droplet/particle. Gao et al. analyzed the translational electrokinetic motion of a particle parallel to a planar liquid-fluid interface. They found that the velocity of the particle's electrokinetic movement increases with the decrease in the separation distance between the particle and the interface [33]. It should be pointed out that the above mentioned studies either focus on the electroosmotic flow of the liquid in the vicinity of the interfaces or the electrokinetic motion of particles near the interfaces. Currently, there are no theoretical or experimental studies of the electrokinetic motion of particles rightly sitting at liquid-fluid interfaces. What are the moving direction and velocity of the particles trapped at different liquid-fluid interfaces? Is there any difference between the electrophoretic mobility of particles at a liquid-fluid interface and that in the bulk liquid? Will the size of particles influence their electrokinetic motion at the interfaces? Fundamental research is required in these regards.

In this paper, electrokinetic motions of spherical polystyrene particles sitting at different liquid-fluid interfaces were studied. A novel method was developed to place particles rightly at the liquid-fluid interfaces formed in a large plastic container. The velocity was measured by an optical microscope with imaging analysis software. While electrokinetic movement of particles near liquid-fluid interfaces was reported previously, this paper for the first time measured the electrokinetic movement of particles attached at the liquid-fluid interfaces and discussed the effects of the surface charges of a liquid-fluid interface on the electrokinetic velocity of particles at the liquid-fluid interfaces. The results presented in this paper can provide a new understanding of the complicated electrokinetic phenomena at liquid-fluid interfaces.

2. Experiments

2.1. Experimental setup and materials

As shown in Fig. 1, the experimental system comprises of a glass container (5 cm × 5 cm × 2 cm, Length × Width × Height) with a

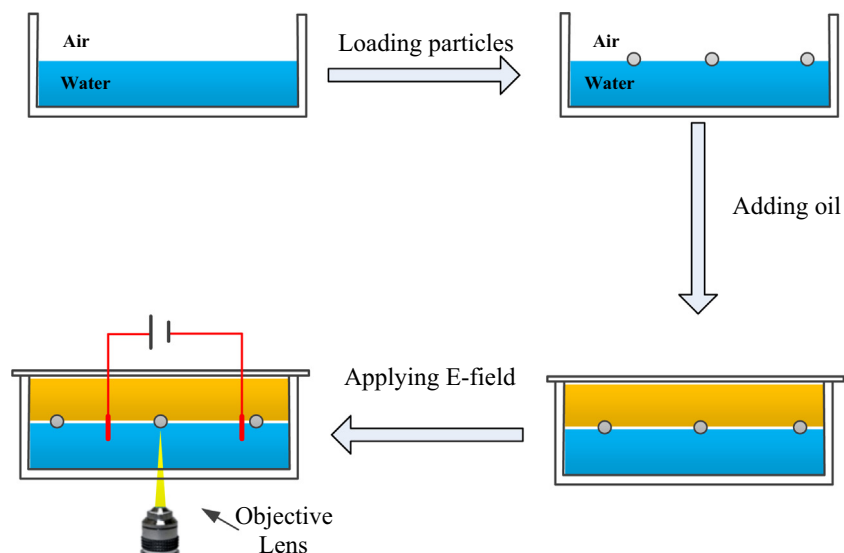


Fig. 2. A schematic of the experimental procedures for depositing particles at water-dodecane interface.

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