Reexamination of Origin of Electric Charge on Migration Particles Used for Electrophoretic Displays

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Abstract

Few reports have presented a comprehensive theoretical analysis of the migration mechanism in electrophoretic display. Theories for aqueous liquids are usually applied to explain the migration mechanism, although electrophoretic displays use non-aqueous liquids. As a result, there are no reasonable guidelines for choosing appropriate materials of particles or liquids for electrophoretic displays. We focus here on the roles of the few ions contained in the liquid used for electrophoretic displays; the role of the ions is essential in determining the migration mechanism in aqueous liquids. We examine the influence of ion density in non-aqueous liquids on the characteristics of electrophoretic migration, and reveal that mobility increases when the density of ions in the liquids is reduced; this result cannot be explained by the conventional theory created for aqueous liquids. Our examination also reveals that migration particles have the same polarities in the liquids as in air. Our conclusion doesn't agree with the conventional explanation of the migration mechanism of electrophoretic displays, which adopts the theory intended for aqueous liquids.

Introduction

The amount of digital information continues to increase with the rapid adoption of the Internet. We can output the information on printed papers or on displays. However, working on displays tends to increase fatigue; we generally prefer to read hardcopies rather than displays. Electronic Paper aims to be an ideal medium on which an increasing amount of digital information can be read comfortably[1)].

This study focuses on the micro-encapsulated electrophoretic display method, which is a promising candidate for Electronic Paper. Benefits of this display method include its high resolution and high contrast.

The structure of a micro-encapsulated electrophoretic system[2)] is shown in Fig. 1. It is rather curious that we have no clear explanation for the electrophoretic behavior used in this display, even though this method is already at the stage of practical use. There are too few study reports dealing with how to prepare appropriate materials for this display method[3)].

In fact, the current theory of the electrophoretic phenomenon was taken from the field of aqueous liquids. This is rather curious given that electrophoretic displays use non-aqueous liquids. The theory for aqueous liquids assumes the existence of many ions in the liquid: these ions form electric double layers, which contribute to the particles' electric surface charge. The theory states that this surface charge is the origin of the force driving the migration of the particles. Fundamentally, this migration theory cannot be applied to non-aqueous liquids, which, ideally, contain no ions. Actually, non-aqueous liquids generally contain very few ions, which are often originated from moisture. Given the extremely large difference in ion concentration between aqueous liquids and non-aqueous liquids, this study examines the feasibility of the applying the theory originated for aqueous liquids to non-aqueous liquids. It determines if the small quantity of ions present in non-aqueous liquids is significant in generating the driving force for migration.

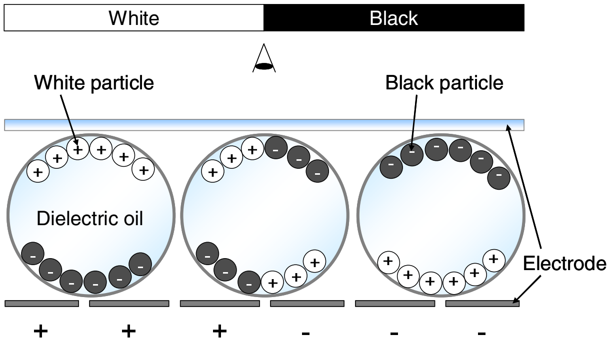

Figure 1. *The structure of micro-encapsulated electrophoretic display*

Experiments

Experiment 1: Influence of Ion density in non-aqueous liquid on electrophoretic migration behavior

Methods

This experiment was carried out in order to evaluate the influence of ion density, in non-aqueous liquids, on mobility.

A non-aqueous liquid (Isoper-G) was processed by using a cation/anion membrane. Figure 2 illustrates the separation process. Five liquids with different ion concentrations were prepared. Table 1 shows their characteristics.

The liquid and particles (nigrosin) were placed in glass cells that had flat ITO electrodes at both sides of the cell: the cell gap was 10 mm, as shown in Fig. 3. Migration behavior of the particles was recorded with a video camera while a certain voltage was applied across the electrodes. Mobilities (μ) were then calculated from the inclination of the linear relation between electric field (E) applied to the cell and the electrophoretic migration speed (v), using the formula, $\mu=v/E$.

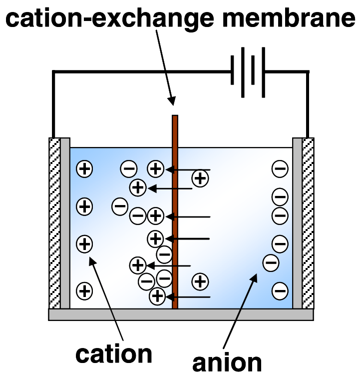

Figure 2. *Procedure of ion exchange*

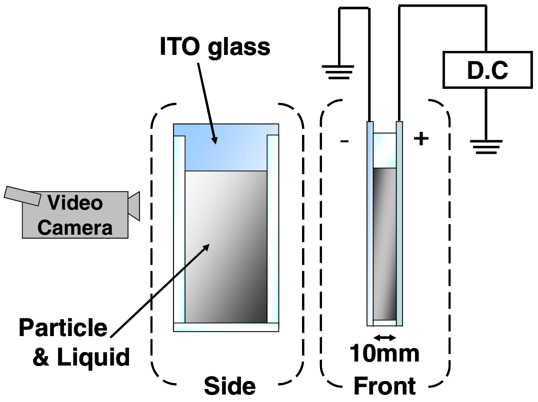

Figure 3. *Test cell structure used for mobility Measurements*

Table 1: Conductivity of each liquid

Liquid	Conductivity (× 10^{-12}S/cm)
Anion increase liquid	13.1
Cation increase liquid	12.4
Base liquid	9.5
Anion decrease liquid	5.6
Cation decrease liquid	5.4

Results

Figure 4 shows measured electrophoretic migration speeds. Mobilities, calculated from the slope of each liquid, are summarized in Table 2[4]. It is shown in Fig. 4 that the mobility decreased as cation density rose. This decrease is not predicted by the conventional theory for aqueous liquids[4]. The conventional theory states that increasing the cation density would increase the electric charge on the particles and thus increase mobility. Our understanding is that the cations were not bound to the particles and their uneven distribution in the liquid weakens the effective electric field in the cell since they form an inverse electric field. This is considered to be the reason why particle mobility fell, contrary to the prediction of the conventional theory[5].

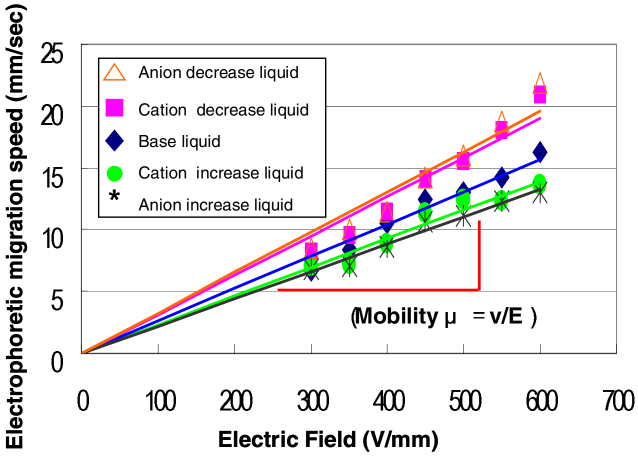

Figure 4. *Electrophoretic migration speeds in various ion densities*

Table 2: Measured mobility for each liquid

Liquid	Mobility(× $10^{-2}mm^2$/V· sec)
Anion increase liquid	2.21
Cation increase liquid	2.32
Base liquid	2.61
Cation decrease liquid	3.16
Anion decrease liquid	3.26

Experiment 2: Confirmation of origin of electric charge on migration particles in electrophoretic display

Methods

The above results suggest that the electric charge of the particles, which contribute to particle movement, does not originate from the ions present in the original liquid[5]. This experiment attempted to discover the process by which the electric charge driving particle migration was established.

Four kinds of particles made from different materials were prepared and their polarities were checked in air and in four liquids. Table 3 lists the particles and liquids used in this experiment. The cell used is shown in Fig. 5.

Polarity was determined from the direction of particle

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migration. The polarity in air was evaluated by the development characteristics for latent charge images, which were prepared on electrostatic printing paper by applying impulse discharges of both polarities.

As for the particles, frictional electrification type toners used for electrophotography, the effects of the frictional electrification process with carrier were also evaluated. Migration speed of the toner particles with and without frictional electrification process was measured. The cell shown in Fig.3 was used for these measurements.

Table 3: Particles and liquids used in evaluating migration behavior

Particle	**Titanium Oxide**
	Carbon
	Toner (+)
	Toner (-)
Liquid	**Xylene**
	Tetrachloroethylene
	Cyclohexane
	Hexane

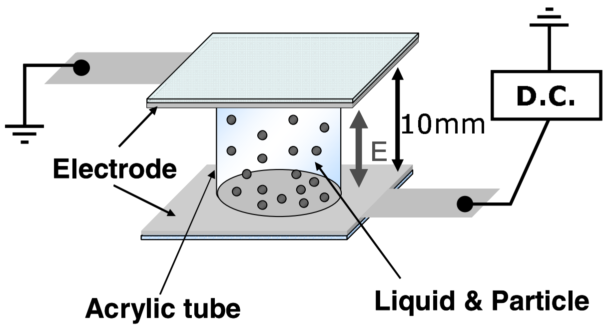

Figure 5. *Test cell used for evaluating particle polarity*

Results and discussion

Table 4 shows the evaluated electrification polarity of each particle in each liquid and in air. Evaluated polarities for each particle were identical in every condition. The application of the tribo-electrification process in air yielded an increase in mobility in the liquids as shown in Fig. 6.

These results indicate that the electric charge obtained in air is a key source of the charge driving migration even in liquids. They indicate that increasing ion concentration didn't yield any increase in mobility, predicated from the experiment in 2.1. (The results of experiment 2.1 show that increasing the ion concentration in liquid actually suppresses particle mobility [6), 7)].)

Table 4: Measured polarities of various particles

Environments \ Particle		Titanium oxide	Carbon	Toner (+)		Toner (-)	
				Without electrification	With frictional electrification	Without electrification	With frictional electrification
In liquid	Xylene	+	+	Incapable of measurement			
	Tetrachloro ethylene	+	+				
	Cyclo hexane	+	+	+	+	-	-
	Hexane	+	+	+	+	-	-
In air		+	+	+	+	-	-

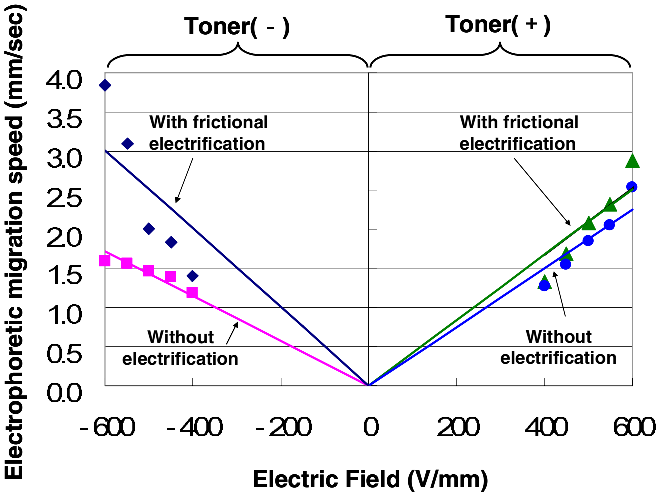

Figure 6. *Dependence of electrophoretic migration speeds on the electrification process for particles in air*

Summary

1) Our experiments have shown that increasing the ion concentration in an electrophoretic liquid decreases the mobility of particles in the liquid.

2) Particles polarity in air and liquids was identical. The increased electric charge by tribo-electrification in air was effective in increasing particle mobility in the liquid.

3) Results (1) and (2) indicate that the increase of ions in non-aqueous liquids does not contribute to the increase in the electric charge of the particles, but acts to suppress mobility. This suggests that it is not appropriate to apply the conventional theory, intended originally for aqueous liquids, to non-aqueous liquids as is commonly allowed.

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Author Biography

Kazuhiro Nakayama was born in 1982. He received his B.S. degree in 2005 from Tokai University. He is expected to receive his M.S. degree from the graduate school of Tokai University in 2007. He is now engaged in a study of Electronic Paper, especially Electrophoretic Displays.

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