Detection of single charging events on optically trapped colloidal particles

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Key Words: Colloid / Optical tweezer / Charge / Electrophoresis

Charged colloids in nonpolar liquids are increasingly important for both practical applications and fundamental research. The working principle of electrophoretic displays, for example, is based on the movement of charged pigment particles in a nonpolar liquid under the influence of an electric field [1]. The importance for fundamental research is mainly a result of the fact that the charge on the particles and the ionic strength of the liquid can be tuned over a wide range by controlling the concentration of added surfactant [2]. Depending on this concentration, the Debye length can be either smaller or larger than the dimensions of the particles or the device, for the same system.

The physical and chemical processes resulting in a charge on colloidal particles in a nonpolar liquid are not well understood. Several hypothesises exist as to the nature of these phenomena [3,4], but in most cases, experiments do not allow to distinguish between them. In this work, we present a new way of looking at charging reactions. Instead of measuring the average (over time and/or many particles) effect of these reactions, we detect the individual events of an increase or decrease of the particle charge with one electron charge. This method may provide information about the charging processes that can not be obtained with existing measurement techniques.

The principle of single charging event detection was first demonstrated by Strubbe et al [5], for a free silica particle in n-dodecane, by optical tracking with a CCD-camera of the movement of the particle in an electric field. Although important as a proof of principle, the practical use of this implementation is limited by the fact that the particle inevitably moves out of focus or out of view as a result of Brownian fluctuations. A particle could therefore not be monitored for more than a few tens of seconds. We overcome this limitation through the use of optical tweezers. An added advantage of this method is that the particle movement can be tracked with a position sensitive detector, which is much faster than a CCD-camera [6].

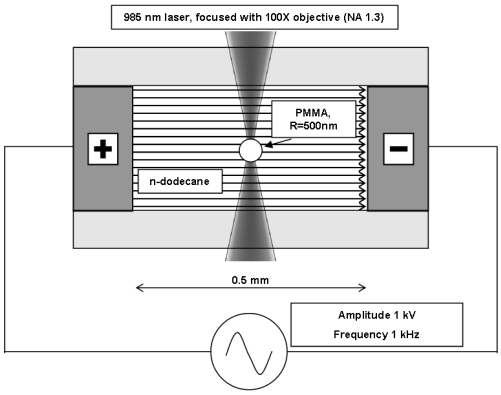

Fig. 1 Schematic overview of an optically trapped particle in an electric field.

The principle of optical tweezers is based on the fact that particles with a higher dielectric constant than the surrounding medium are attracted towards the focus of a tightly focused laser beam. We subject an optically trapped PMMA particle with radius 500 nm in pure n-dodecane (no surfactant) to a sinusoidally varying electric field (figure 1), and measure its movement

around the center of the trap with a position sensitive detector. The charge of the particle can then be obtained from an analysis of this movement.

The accuracy of the charge measurement depends on the dominance of electrophoretic motion over Brownian motion, and is linearly proportional with the amplitude of the electric field and with the square root of the duration of one measurement. Using a high electric field ($2x10^6$ V/m) allowed us to measure the charge accurately enough to distinguish single electrons and fast enough to detect individual changes of an electron charge (figures 2 and 3).

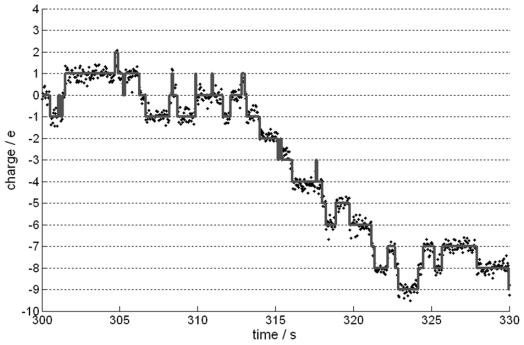

Fig. 2 Charge of a PMMA particle in dodecane in function of time (dots), and the closest multiple of the electron charge (single point fluctuations are discarded). The measurement points are clustered around these multiples, and changes of one electron charge are clearly visible.

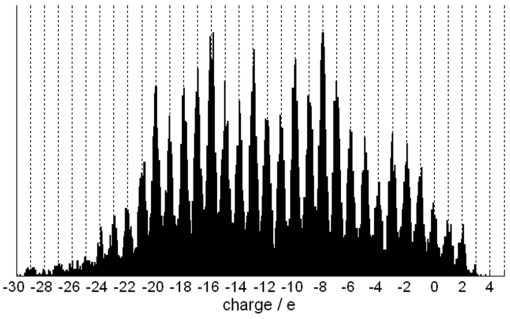

Fig. 3 Charge histogram of a PMMA particle in dodecane, measured during 1000 s. The peaks at equally spaced distances correspond to multiples of the electron charge. The average value of the particle charge during the measurement time is around -12 electron charges.

Because of the optical tweezers, we could also monitor a particle long enough (1000 s) to get useful information about the charging process. As an example, the distribution of the times between consecutive changes of the particle charge with one electron charge is shown in figure 4.

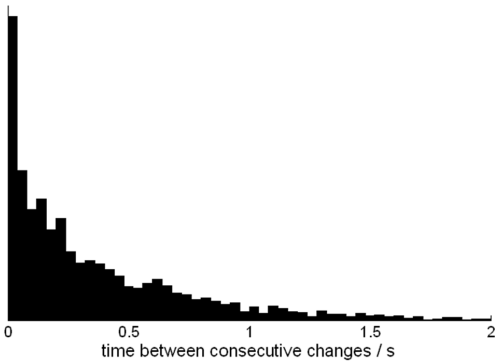

Fig. 4 Histogram of the times between consecutive changes of the particle charge. These times match a Poisson distribution, indicating that the events are independent of each other. The average time between two changes is 0.4 s.

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