

Dielectrophoretic phenomenon and its application in handling particles

CHEM 681 Student Seminar Series

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Theory

As described by Pohl [1], dielectrophoresis (DEP) is the translational motion of neutral matter caused by polarization effects in a nonuniform electric field. To make the dielectrophoretic movement happen, the particle must be dielectric and thus polarizable once the electrical field is applied.

In a conservative field, the force on the body is the negative of the gradient of the potential energy [1]. The potential energy of the particle, U_p , is then

$$U_p = -\mathbf{p} \cdot \mathbf{E}_e = -\alpha v |\mathbf{E}_e|^2,$$

where $\mathbf{p}$ is the dipole moment of a particle, v is the volume of the body, α is the polarizability (dipole moment per unit volume in unit field) and $\mathbf{E}_e$ is the external field.

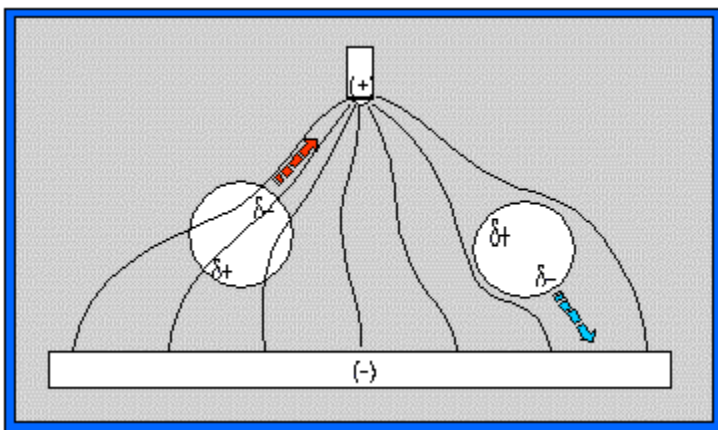


Figure 1. Particles forms net forces when put into a nonuniform electric field (figure taken from <http://www.ibmm.informatics.bangor.ac.uk/pages/science/dep.htm>).

Figure 1 schematically shows the mechanism of dielectrophoretic motion of particles .

Since a dipole experiences a net force in an inhomogeneous external field, particles are

either attracted to regions of high field strength (positive DEP) or repelled from them (negative DEP). Similarly, dielectric particles can be moved in electric fields due to a gradient in the field phase. The time-averaged dielectrophoretic forces, F , acting on a dielectric particle of radius, R , in a time periodic electric field (with radian frequency ω) $E(\mathbf{r},t) = \text{Re}[(E^{\text{re}}(\mathbf{r}) + iE^{\text{im}}(\mathbf{r}))\exp[i\omega t]]$

can be expressed in dipole approximation as

$$\langle F_d \rangle = 2\pi\epsilon R^3 [\text{Re}(f_{\text{CM}})\nabla E_{\text{rms}}^2 + \text{Im}(f_{\text{CM}})\nabla \times E_{\text{im}} \times E_{\text{re}}]$$

where f_{CM} represents the Clausius-Mossotti factor for the particle [6]. For a homogeneous sphere (index p) suspended in a liquid (index l), f_{CM} can be obtained by

$$f_{\text{CM}} = (\epsilon'_p - \epsilon'_l) / (\epsilon'_p + 2\epsilon'_l) \text{ with } \epsilon' = \delta + i\omega\epsilon$$

where δ is the conductivity and ϵ the absolute permittivity of the particle [1]. The sign of the term $\text{Re}(f_{\text{CM}})$ will determine the resulting DEP is a positive one or negative one.

Owing to the inherently high permittivity of water, many particles, macromolecules such as DNA and protein, and biological cells will show negative DEP behavior in a electric field of high frequencies when they are present in aqueous solution [7].

Possible Applications

Pohl and Hawk's work in 1966 appears to be the first successful use of a purely physical means for producing a separation of live and dead cells [2]. Since then dielectrophoresis has been shown to be extremely useful in a wide range of biological applications from cell sorting, cell characterization, and analysis, to the determination that living cells emit radiofrequency at ac fields and attract various foreign particles [3]. The nonuniform electric field effects were found useful in handling almost all types of living cells

including algae, yeasts, bacteria, mammalian blood cells, and the organelles such as sperm, chloroplasts, mitochondria, and plastids [3].

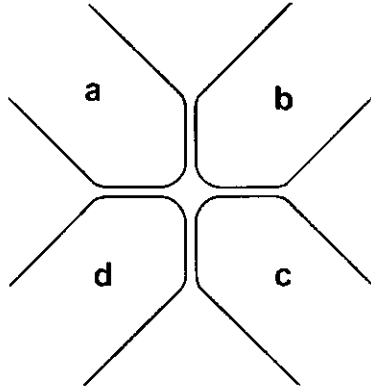


Figure 2. A typical schematic of quadrupole electrode microstructures (figure taken from Ref. 4).

Today's advanced microfabrication technology has been able to offer researchers new opportunities in making microelectrodes for DEP manipulation of smaller particles. Records of the smallest have been broken continuously. According to a recent report [4], the smallest macromolecule that has been manipulated is a virus with a molecular weight of 9 kDa and yet, as small as 97-nm-diameter nanoparticles have been separated by DEP successfully [5-8]. People now believe that ac electrokinetics indeed offers advantages over scanning-probe methods of nanoparticle manipulation in that the equipment used is simple, economic and robust, presenting a touch-free platform relying entirely on the electrostatic interaction between the particle and dynamic electric field [4]. Furthermore, there is theoretical evidence thus the promise that as manufacturing technology further improves, single particles considerably smaller than presently studied using ac electrokinetics may be manipulated [4, 9-12].

In practice, dielectrophoretic manipulation of particles is performed on planar electrode arrays [4]. Like what have been intensively employed in microchip fabrication, these arrays are fabricated on silicon/glass substrates covered with a layer of gold. A

commonly used electrode setup (figure 2, 3) for ac electrokinetics research is a quadrupole arrangement where four electrodes point towards a central region, as firstly designed and fabricated by Huang and Pethig [13]. This kind of design gives us two distinct advantages: 1) electrodes herein can be easily applied to performed dielectrophoresis, electrorotation or both; and 2) there exists a well-defined electric field minimum, which is surrounded a well-defined electric field maxima at the electrode edges [4].

There are two main problems that restricted people's imagination before 80's of using dielectrophoresis to manipulate particles with size of submicron to nanometer range. Firstly, as the size of the particle shrinks, the force caused by dielectrophoresis goes down, making people believe there exists a threshold below which DEP force is not controllable. Second reason is practical; that is, fabrication techniques available at that time are normally crude.

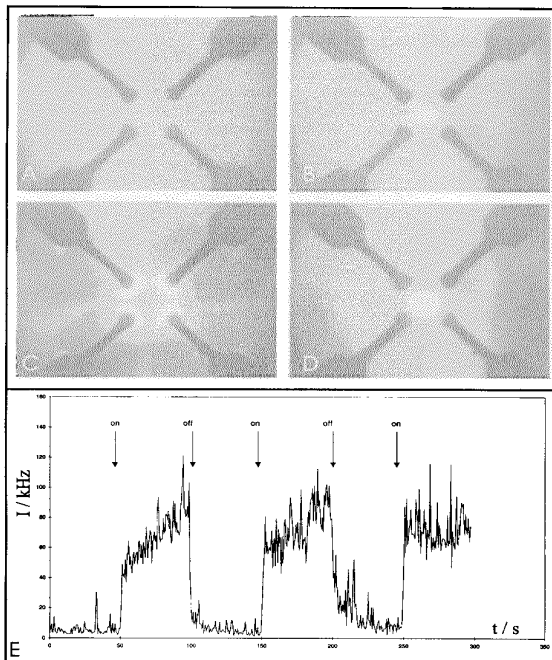


Figure 3. Microphotographs of the quadrupole microelectrodes before and after the electric field is applied. Typical frequency signal is shown in panel E (figure taken from Ref. 7).

Examples

Washizu and coworkers were the first to bring us into the 'nanoworld' of dielectrophoretically manipulating particles [5]. In their work, they used positive DEP to precipitate DNA and proteins as small as 25 kDa. Their results called back the interests of other researchers and thereafter introduced in a host of other innovative designs and applications [9-17]. Here, I will just introduce some recent results on cell characterization through electrorotation [14], cell fractionation [15,16], nanoparticle/macromolecule manipulation [7, 17-19] and liquid actuation [20].

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