Electrical manipulation of particles within a nanopore

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***Abstract*—The electrical field conditions that exist within a conical nanopore, such as used for the electrical sizing of nanoparticles in aqueous suspension, are estimated. In pores that exhibit a large ratio between their radii at the wide and narrow ends, the field is highly concentrated at the narrow end. Modest applied potentials of 0.2 – 0.4V then result in large fields of the order of MV/m which are sufficient to orient, assemble and perhaps deform nanoparticles in the high-field region**

***Index Terms*— Electric field; Dielectrophoresis, Electrophoresis; Nanoparticle.**

I. Introduction

It is well known that electrically polarizable nanoparticles and macromolecules suspended in aqueous solutions can be oriented, assembled and even distorted by means of high electrical fields [1-4]. However, side-issues such as the thermal and electroconvective effects involved have meant that this technique has only seldom been realized, at least where molecules in biological media are involved.

Nanopores, when filled with a conductive solution, permit the electrical detection of nanoparticles and macromolecules such as DNA by means of the resistance increase which occurs when the pore is partially occluded. There is recent interest in using the re-sizeable elastomeric nanopore developed by Izon Science Ltd (formerly Australo) [5] to size, count and characterise bionano particles.

It is significant that the shape of the nanopores produced in Izon's elastomeric membranes is that of a funnel, so that the field is non-uniform. It will be shown from resistance measurements that the field is concentrated in a small percentage of the total volume. The possible consequences, for particles that come into this region, of the high field values will be examined.

II. Modelling

A. Resistance of a conical pore

If a liquid of conductivity σ fills a nanopore of length d (Fig 1) which has the shape of a truncated cone with end planes of radii a and b, then the resistance R between those two end planes is:

$$R = d / ab\pi\sigma \qquad (1)$$

where small contributions from end-effects can be neglected for present purposes.

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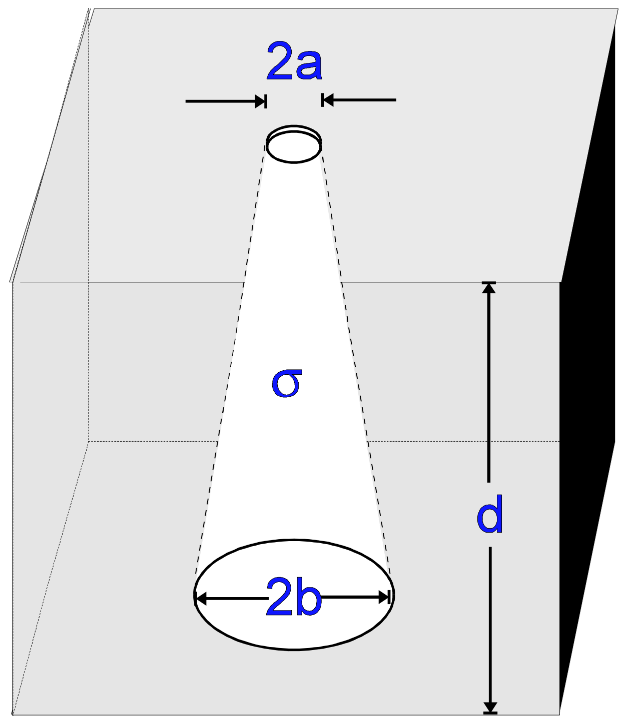

Fig. 1. A conical nanopore in a portion of insulating membrane of thickness d. The nanopore is filled with a liquid of conductivity σ, which also bathes both faces of the membrane. In a particle-measuring application, the membrane would be semi-infinite in extent and contacted by "O"-rings so that the two sides are electrically isolated from each other.

In a pore used for detecting the passage of DNA plasmids [5] an applied bias of 200mV gave rise to a current of 3 nA so that the pore resistance was 67 MΩ. The other parameters of the system were: pore length 250 µm; electrolyte a 1 mole/l solution of KCl of conductivity 11 S/m; larger pore opening 15 µm radius. From (1) it can be deduced that the smaller opening was of 7 nm radius.

However, other examples of the use of this type of nanopore [6] show higher currents of 5-20 nA in response to 0.2 V. Hence the pore resistance was 10 - 40 MΩ, despite the use of a lower electrolyte concentration of 0.1 mole/l (1.3 S/m conductivity). This data implies that the smaller opening is more commonly in the range of 100 - 400 nm radius.

B. Resistance of a small section of the conical pore

A second application of (1) allows the resistance of a restricted length of the pore, starting at the small end, to be calculated. This forms a series circuit with the rest of the pore. In the case of the DNA-plasmid-measuring pore with a total resistance of 67 MΩ, the

TABLE I
RESISTANCE AND FIELD DISTRIBUTION WITHIN A CONICAL NANOPORE

Length(narrow section)	50nm	100 nm	200 nm	1000 nm
R(narrow)	20.3 MΩ	31.2 MΩ	42.7 MΩ	60.6 MΩ
R(remainder)	47.3 MΩ	36.4 MΩ	24.9 MΩ	7.0 MΩ
Fraction R in narrower	30.0 %	46 .2 %	63.2 %	89.6 %
Field strength @ 400mV	2.4 MV/m	1.85 MV/m	1.26 MV/m	0.36 MV/m

percentage of the total applied voltage that is dropped over various short lengths starting at the small end can be calculated (Table 1).

It follows that moderate voltages applied across the membrane will develop extreme fields in the constriction. Assuming this to be of 100nm length, then a common particle-sizing voltage of 0.4V will generate a field of 1.85 MV/m, whereas 50 nm length would imply 2.4 MV/m.

III. APPLICATIONS

Field values in the low MV/m range are capable of a number of effects such as [1-3]:

- Stretching of long polyelectrolytes: eg DNA;
- Collection of polarizable nanoparticles such as viruses and some protein molecules by dielectrophoresis;
- Exclusion from the pore of weakly-polarizable molecules;

In addition, because these effects all depend on electrical polarizabilities that are themselves frequency-dependent, it should be possible to switch between them by use of alternating fields rather than only DC.

IV. CONCLUSION

Examination of the data on conical nanopores in aqueous systems indicates that very high fields suitable for the manipulation of nanoparticles can be achieved within them.

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REFERENCES

[1] M.Washizu, S. Suzuki, O. Kurosawa, T. Nishizaki and T. Shinohara, “Molecular dielectrophoresis of biopolymers”, IEEE Trans. Ind. Appl., vol. 30, pp. 835-843, 1994.
[2] A. Castellanos, A. Ramos, A. González, N.G. Green and H. Morgan, “Electrohydrodynamics and dielectrophoresis in microsystems: scaling laws” J. Phys. D, Vol. 36, pp. 2584-2597, 2003.
[3] M. Washizu, “Biological applications of electrostatic surface field effects,” *Journal of Electrostatics*, vol. 63 pp. 795–802, 2005.
[4] W.M. Arnold, “Particle patterning using fluidics and electric fields,” *IEEE Trans. Diel. Electr. Insul.*, vol. 15, pp. 144, 2008.
[5] S. J. Sowerby, M. F. Broom, G. B. Petersen, “Dynamically resizable nanometre-scale apertures for molecular sensing,” *Sensors and Actuators* vol. B 123, pp. 325-330, 2007.
[6] G. R. Willmott and P. W. Moore, “Reversible mechanical actuation of elastomeric nanopores,” *Nanotechnology* vol. 19 Art. 475504 (9pp) , 2008.