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REMARKS ON THE FIELD DISTRIBUTION IN FOUR ELECTRODE CHAMBERS FOR ELECTROROTATIONAL MEASUREMENTS

J. GIMSA, R. GLASER, G. FUHR
Department of Biology, Humboldt University of Berlin, Berlin

By means of electrorotation the dielectric properties of cells or other dielectric particles can be investigated. To measure electrorotation usually four-electrode-chambers are employed. Field distribution in these chambers was studied. Recommendations of electrode shapes for electrorotational measurements are made. The special case of only one driven electrode for dielectrophoretic measurements or for adjusting cells in the chamber was considered too.

1. Introduction

By means of electrorotation the dielectric properties of cells or other dielectric particles can be investigated. This requires to measure the rotational behavior of cells or other dielectric particles in rotating electric fields as a function of external field frequency /5/. The prerequisite for the generation of a rotating electric field vector within the chamber are at least 3 electrodes. In general the number of phase-shifted driving signals for the measuring chamber is equal to the electrode number. Usually four-electrode-chambers are used. So four signals with a progressive 90°-phase-shift are needed. These signals may have different wave forms, sinusoidal or square-topped. In the following different fields are considered generated in four-electrode-chambers.

The practical performance of the measuring chamber largely depends on the field distribution inside. So for electrorotational investigations a large area of homogeneous field distribution with a continuously rotating field vector is required for obtaining comparable results at different points inside the chamber. To minimize convective flow and dielectrophoretic cell collection at the electrode surfaces one has to avoid strong field inhomogeneities. Reduction of the electrode surfaces or isolation of the connecting wires reduces the current and thus the heat production.

For dielectrophoretic manipulations or measurements a continuously inhomogeneous field having only one definite point of high field strength is needed. For this purpose it is useful to know how the field distribution is in the case of only one electrode driven.

2. Materials and method

The measurements presented here were performed under enlarged model conditions. Model electrodes were built from aluminium foil. They were put in a water filled trough. The distance between two opposite electrodes was 10 cm. Equipotential lines within the measuring chamber were measured with the help of a thin electrode connected with a high impedance voltage measuring instrument. In dependence on the considered driving signal one, two or three electrodes were switched on to one or the other output of a 6 V, 50 Hz transformer. In Fig. 1 three different circuits are shown. The signs (+), (−) and (0) indicate that the related electrode is switched on to one or the other output signal or to ground.

	(−)			(−)			(−)	
(−)		(−)	(−)		(+)	(0)		(0)
	(+)			(+)			(+)	
a)			b)			c)		

FIG. 1

Scheme a) in Fig. 1 represents the case of only one driven electrode. This is the case for dielectrophoretic measurements or dielectrophoretic adjustment of cells. On the other hand a) can be taken to judge the field form for electrorotation for the case of a chamber driven by square-topped signals with a key-ratio of 1:3. Scheme b) in Fig. 1 serves to judge field shape in the case of a key-ratio of 1:1 for electrorotation. In connection with scheme c), b) also serves to judge sinusoidal fields. Case c) appears in the case of sinusoidal driving signals.

3. Results and discussion

The areas marked by the inner squares in Fig. 2 contain 49% of the area of the chamber. For the judgement of the field form in sinusoidal driven chambers the field determined in case b) and c) was used. The driving voltage for the model electrodes used in these measurements was the same for case b) and c). This means that for the judgement of a field produced by sinusoidal driving signals the voltage for case b) was too high in comparison with case c). For this reason the field strength in case b) was corrected by a factor of $0.5*\sqrt{2}$. The result was compared with the field strength in case c). The latter was assumed to be 1. Tab. 1 shows the results:

TAB. 1
Amplification factors for the field strength in case of sinusoidal driving signals for $\alpha=n*\pi/2+\pi/4$ compared with $\alpha=n*\pi/2$
(α- angle of the field vector in [rad], n- integer)

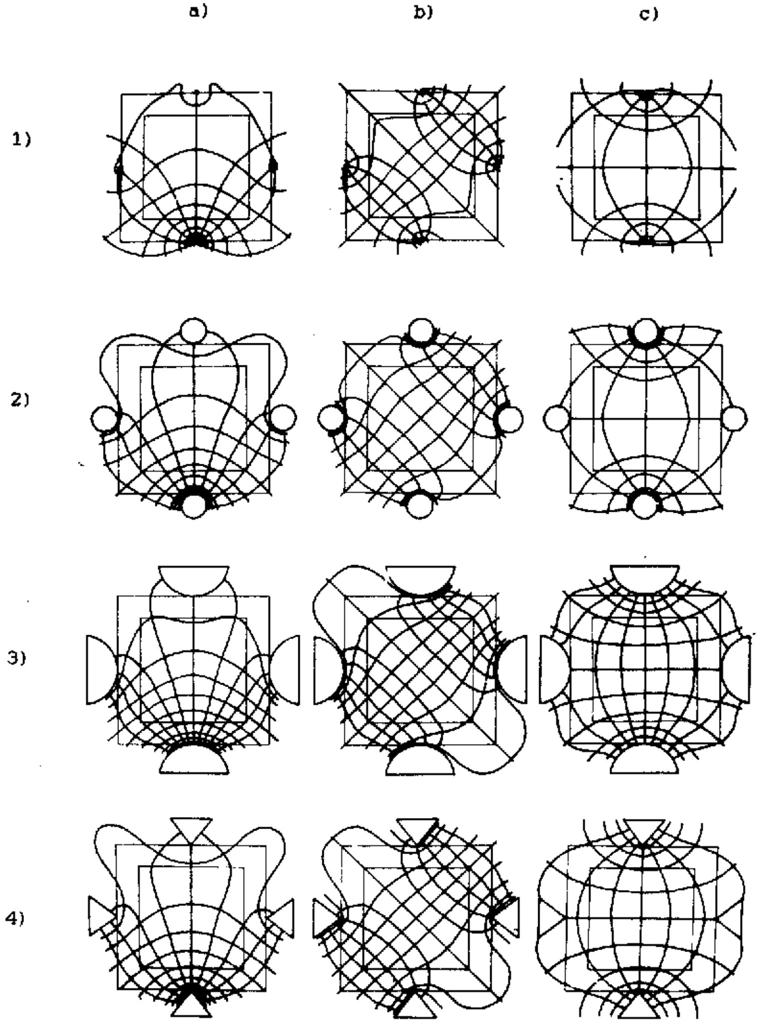
electrode-shape	1	2	3	4	5	6	7	8
ratio	1.31	1.03	0.92	0.99	1.17	1.01	1.04	1.08

Factors >1 indicate a decreasing field strength when the field vector in Fig. 2 is horizontally or vertically oriented and vice versa. These distortions cannot appear in the case of square-topped pulses with a key ratio of 1:1. In this case the field vector jumps within every cycle four times by an angle of 90°. The criterion of a suitable electrode shape in this case is constant field strength and rotation of field lines by 90° in a large area of the chamber when the field vector jumps by 90°. These requirements are realized by the idealized electrode shape 7. Practical chambers can be compared to case 8. Unfortunately, in this case the field is strongly elliptical in the surrounding of the concave electrode surface.

Another criterion for an optimal electrode shape is to avoid areas with a very inhomogeneous field, in order to avoid dielectrophoresis during electrorotation measurements. If one liked to adjust cells within the chamber with the help of dielectrophoresis by driving only one electrode the field in case a) should have only one definite point of high field strength.

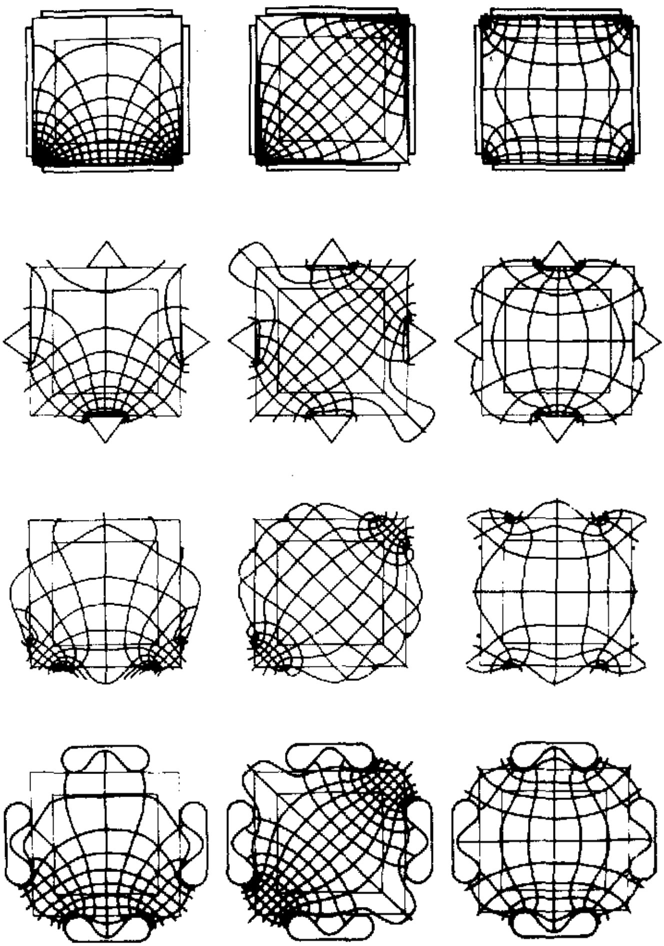
Taking these considerations into account the electrodes of shape 2, 4 and 6 are recommended. Experimental data of the rotation of one and the same cell at different places within a chamber are described in /2/.

FIG. 2



a) b) c)

5)
6)
7)
8)



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Dr. J. GIMSA, Department of Biology, Humboldt University of Berlin, Invalidenstr. 42, DDR-1040 Berlin, GDR