A TECHNIQUE FOR MEASURING REAL VOLUME CHARGES IN WAX ELECTRETS

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A technique has been developed for measuring real charges inside wax electrets. The measuring apparatus is basically a Faraday container suspended from a balance. An electret whose charge distribution is to be measured is positioned above the Faraday container, and thin layers of the electret are removed by shaving with a special knife. As the shavings drop into the Faraday container, the real charges on the shavings are measured by the electrometer connected to the container, while the mass of the shavings is measured by the balance. Since the mass density of the wax is a constant, the density of real charges within the electret can be calculated directly.

INTRODUCTION

Although electrets have been studied for many years, the nature of the electret effect is not yet well understood. This is partly due to the fact that no detailed information is available on the location and magnitudes of the electric charges inside the electrets. In the often cited works of Thiessen et al.[1], for example, the authors attempted to obtain such information by cutting carnauba wax electrets. In actuality, they measured not the real internal charges of the electrets but rather, the effective surface charges (the sum of real charges and polarization charges) on the successively exposed surfaces of the electrets. The newer, thermal depolarization, method[2] provides a way for obtaining certain information on the internal charges but does not reveal their exact location. We have attempted therefore to develop a reliable and direct technique for determining the distribution of charges within electrets. This paper describes the technique which we found to be particularly effective for studying wax electrets.[3,4] The technique is based on removing (shaving off) thin layers of an electret without altering the magnitudes of the original charges in the layers. The real charges on the shavings are measured by an electrometer connected to a Faraday container that receives the shavings and the mass of the shavings is measured at the same time by a balance. Since the mass density of the electret material is a constant, the density of the real charges within each layer of the electret can then be easily calculated, and a histogram of the real charge density as a function of layer depth can be constructed.

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CHARGE MEASURING APPARATUS

The charge measuring apparatus is shown in Fig.1. The Faraday container is a cylindrical aluminum cup 7.5cm inside diameter and 7.5cm high. The upper end of the container is made in the form of a collecting funnel 14cm in diameter. The Faraday container is suspended by two insulating rods hung from an Ohaus magnetically damped balance accurate to ± 0.01g, and the container is electrically connected to a Keithley 610B electrometer by means of a short length of 25μ diameter copper wire and a coaxial cable. The Faraday container and collecting funnel are surrounded by a grounded metal screen to shield them from external electric fields. The top section of the screen has openings through which the shavings can fall unhindered into the container.

An electret whose charge distribution is to be measured is placed on a special holder and positioned above the Faraday container. The holder (Fig.1) is essentially a shallow Plexiglas cup with a metallic bottom. This cup supports the electret, and the metallic bottom shields the lower surface of the electret.

Layers of the electret are removed by shaving with a special knife made by mounting a 0.4cm portion of the tip of a steel hobby blade (X-acto blade No.11) into a 1/2 inch diameter Plexiglas handle. The knife is electrically floating, has a very low capacitance (about $0.1\mu\mu$f), and can store a maximum charge of about 5×10^{-10}coulomb.

In designing this knife, special care was taken to prevent the undesired electrification of the electret material that could possibly be created during shaving. Several types of knives were tested for their ability to produce shavings with a minimum of charge deposition. The testing arrangement and the various knives are shown in Fig.2. These knives are: a dielectric knife made from glass, an electrically floating metal knife with an insulating handle, a grounded metal knife, and a metal knife to which a voltage is applied. Thin layers of wax blanks and of electrets were shaved with each knife, and the charges on the shavings as well as those on the shaved surfaces were measured. It was determined that the metal knives deposited the smallest amounts of charge. However, the grounded metal knife and the metal knife to which a voltage was applied were discarded because a corona discharge originated from them when they were exposed to a strong electric field (as when cutting an electret). Various designs for the electrically floating metal knife were then tested (Fig.3) by performing shaving operations in the presence of an electric field equal to or surpassing the field actually present when shaving a strong electret. The field was produced by connecting the metal bottom of the sample holder to a high voltage source (Fig.3). A 'high capacitance' knife (about $35\mu\mu$f), a 'low capacitance' knife (about $1\mu\mu$f), and a 'very low capacitance' knife (about $0.1\mu\mu$f) were tested in this way. The very low capacitance knife performed best. The charge deposited with this knife on electret shavings was two orders of magnitude smaller than the largest true charge of the shavings.

CHARGE MEASURING TECHNIQUE

The general procedure for determining the real charge distribution inside wax electrets is as follows. An electret whose charge distribution is to be determined is placed on a holder and positioned above the Faraday container (Fig.1). A square area, approximately 2.8cm on a side, is marked on the upper surface of the electret and a thin layer of electret material is removed from this area by shaving with the very low capacitance knife described above. As the electret shavings fall through the top metal screen into the Faraday container, their real charge is registered by the electrometer connected to the container, and their mass is registered by the balance. Any shavings that stick to the electret surfaces or the knife are gently blown off by an air stream from a rubber bulb. After the shaving of a layer has been completed, the charges remaining on the knife are measured by touching the knife blade to the terminal of a separate electrometer. The electret is then inverted on the holder, and a similar layer is shaved from the corresponding square area of the opposite side (bottom surface). Successive layers are removed in alternation from the two sides until all the electret material corresponding to the marked off area has been completely removed and a square hole has been cut through the electret. The layers are normally about 0.25mm thick at the electret surface and increase in thickness to about 1mm at the midplane. For each layer the charge per unit mass is calculated by dividing the charge of the removed electret material plus the charge of the knife by the mass of the removed material.

A typical data sheet used for recording the data obtained from the above operations is shown in Table 1. The data are for our Electret No. 56 formed from a mixture of 45% carnauba wax, 45% colophonium, and 10% white beeswax. The electret was prepared by melting the wax mixture for 1.5 hours at 120°C and then allowing the melt to solidify in a forming electric field of 7.87 kV/cm for 20 minutes. The electret reversed polarity in 2 days and was 2.6 years old when its internal charge distribution was investigated. Just before shaving, the electret exhibited effective surface charges of 15×10^{-10}coulomb/cm^2 on the top surface and -15×10^{-10}coulomb/cm^2 on the bottom surface. The electret was 13mm thick, and altogether twelve layers were used to shave completely through its entire thickness. The entries in the data sheet shown in Table 1 are: the layer number, the sequence of layer removal, the charge on the electret material collected from each layer, the balance reading before and after each layer is removed, the mass of the material in each layer, and, finally, the charge-per-mass ratio computed for each layer.

From data shown in Table 1 the relative thickness of an individual layer and the charge per unit volume in this layer were calculated. The results are shown in Table 2. The relative thickness of a given layer was calculated by dividing the mass of that layer by the total mass of all 12 layers. For example, the topmost layer (layer 1) had a mass of 0.18g and the total mass of all layers was 5.83g. Hence the relative thickness of this layer was 0.18g divided by 5.83g or 3.1% of the total electret thickness. The real charge per unit volume turned out to be numerically equal to the charge per unit mass since the density of the electret material was 1 g/cm^3. The charge per unit volume was finally plotted as a histogram (Fig.4) representing charge per unit volume as a function of relative distance, x/L, where x is the distance (depth) into the electret measured from the top surface, and L is the thickness of the electret. As one can see from Fig.4, the density of real charge in the interior of the electret is very substantial and exhibits a very peculiar dependence on depth. There are strong accumulations of charges near the surfaces, and there are two secondary accumulations deeper into the volume of the electret. These secondary accumulations contain charges whose polarity is opposite to those near the surfaces. In the case of the Electret No. 56, the charge density near each surface was about 10^{-7}coulomb/cm^3, and the maximum charge density in the secondary accumulations was 10^{-8}coulomb/cm^3. It is instructive to compare the charge distribution in an electret (Fig.4) with the charge distribution in a neutral wax blank (Fig.5) where the charge density was found at all depths to be only 10^{-9} coulomb/cm^3.

Using the above technique we have obtained well reproducible data for the real charge density distribution inside approximately 100 electrets. These data will be reported elsewhere. However, we would like to mention here that the distribution of real charges shown in Fig.4 is characteristic for all carnauba wax electrets that we investigated, and that this distribution is essentially independent of the forming electric field, magnitudes of effective surface charges, and age. In particular, this charge distribution does not reverse polarity when the effective surface charge of an electret reverses its polarity and is the same for both heteroelectrets and homoelectrets. Even the electrets which are 'dead' (effective surface charge has become zero) exhibit essentially the same strong real volume charge distribution as that shown in Fig.4.

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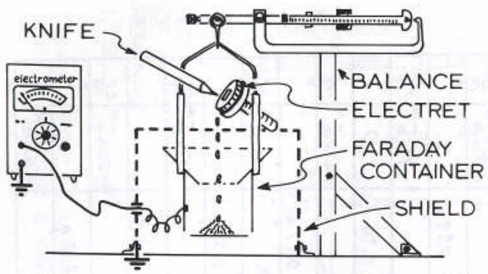

Fig.1. Apparatus for measuring real space charges inside electrets.

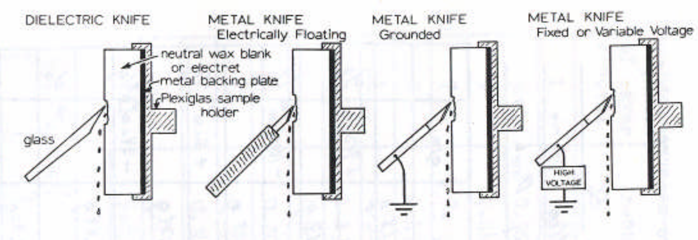

Fig.2. Arrangement for testing knives for their ability to produce shavings with a minimum of charge deposition.

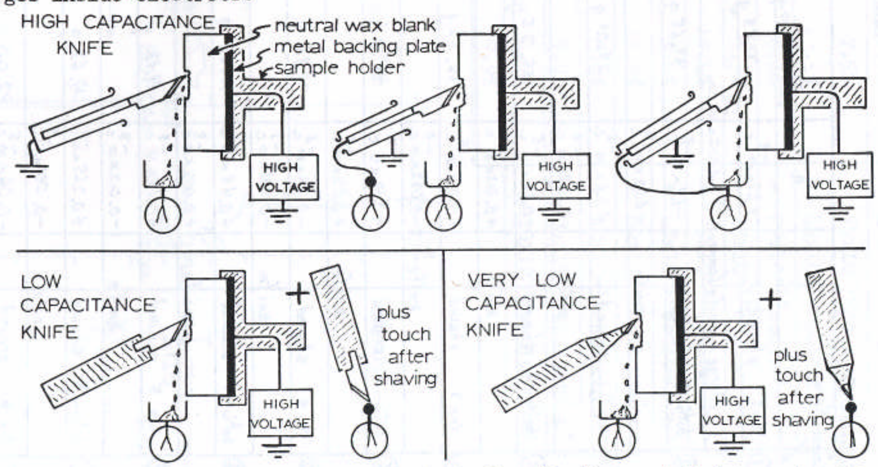

Fig.3. Arrangement for testing electrically floating metal knives in the presence of strong electric fields. The very low capacitance knife performed best.

Table 1. Typical data sheet for real charge measurements.

Knife Very low capacitance - Floating

Technique Shaved top & bottom in alternation toward the middle.

Electret No. 56

Type 7.87 kV/cm - 20 min.

Date Thursday - March 11, 1971

Sequence of Layer Removal	q	balance start 37.30 g	m	q/m	
① top 1 shaved	$+1.7 \times 10^{-8}$ c.	37.48 g.	0.18 g		
charge on knife (correction)	-0.002×10^{-8} c			$+943 \times 10^{-10}$	c/g
② bottom 1 shaved	-1.7×10^{-8} c	37.65 g.	0.17 g		
knife	-0.02×10^{-8} c			-1010×10^{-10}	c/g
③ top 2 shaved	$+0.1 \times 10^{-8}$ c	38.04 g	0.39 g		
knife	-0.038×10^{-8} c			$+16 \times 10^{-10}$	c/g
④ bottom 2 shaved	-0.13×10^{-8} c	38.38 g	0.34 g		
knife	$+0.013 \times 10^{-8}$ c			-34×10^{-10}	c/g
⑤ top 3 shaved	-0.3×10^{-8} c	38.82 g	0.44 g		
knife	-0.032×10^{-8} c			-75×10^{-10}	c/g
⑥ bottom 3 shaved	$+0.12 \times 10^{-8}$ c	39.17 g.	0.35 g		
knife	$+0.02 \times 10^{-8}$ c			$+40 \times 10^{-10}$	c/g
⑦ top 4 shaved	-0.33×10^{-8} c	39.96 g	0.79 g		
knife	-0.021×10^{-8} c			-44×10^{-10}	c/g
⑧ bottom 4 shaved	$+0.48 \times 10^{-8}$ c	40.66 g	0.70 g		
knife	$+0.002 \times 10^{-8}$ c			$+69 \times 10^{-10}$	c/g
⑨ top 5 shaved	-0.15×10^{-8} c	41.13 g	0.47 g		
knife	-0.012×10^{-8} c			-29×10^{-10}	c/g
⑩ bottom 5 shaved	$+0.265 \times 10^{-8}$ c	41.69 g	0.56 g		
knife	-0.001×10^{-8} c			$+47 \times 10^{-10}$	c/g
⑪ top 6 shaved	-0.06×10^{-8} c	42.00 g	0.31 g		
knife	-0.0075×10^{-8} c			-22×10^{-10}	c/g
⑫ bottom 6 shaved	$+0.05 \times 10^{-8}$ c	43.13 g	1.13 g		
knife	$+0.001 \times 10^{-8}$ c			$+5 \times 10^{-10}$	c/g

Table 2. Typical data analysis for real charge measurements (for data taken from Table 1).

sequence of layer removal	mass	% of the total electret thickness	charge/volume
1	0.18g	3.1%	+ 943x10^{-10}coulomb/cm^3
3	0.39g	6.7%	+ 16x10^{-10}coulomb/cm^3
5	0.44g	7.5%	- 75x10^{-10}coulomb/cm^3
7	0.79g	13.5%	- 44x10^{-10}coulomb/cm^3
9	0.47g	8.1%	- 29x10^{-10}coulomb/cm^3
11	0.31g	5.3%	- 22x10^{-10}coulomb/cm^3
12	1.13g	19.4%	+ 5x10^{-10}coulomb/cm^3
10	0.56g	9.6%	+ 47x10^{-10}coulomb/cm^3
8	0.70g	12.0%	+ 69x10^{-10}coulomb/cm^3
6	0.35g	6.0%	+ 40x10^{-10}coulomb/cm^3
4	0.34g	5.8%	- 34x10^{-10}coulomb/cm^3
2	0.17g	2.9%	-1010x10^{-10}coulomb/cm^3
Total	5.83g	99.9%	

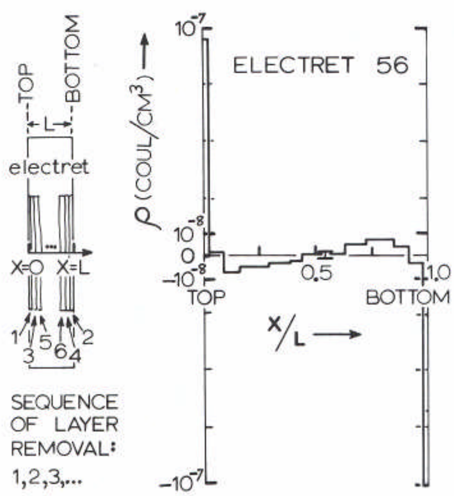

Fig.4. Order of layer removal(left),and typical data for a wax electret(right).

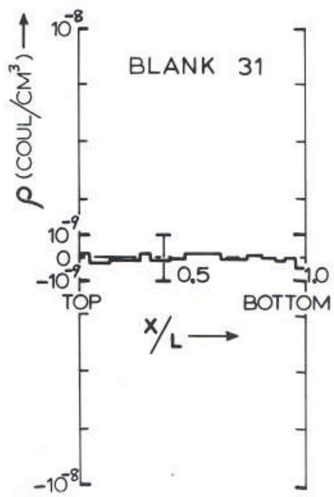

Fig.5. Typical data for a neutral wax blank.