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Dependence of Electret Charge on Shielding Conditions

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Abstract

The present paper investigates the dependence of electret charge on shielding conditions and compares the results with the Gubkin theory. The electret material is a mixture of carnauba wax, colophonium, and beeswax.

GUBKIN [1] derives an expression for the electret effective surface charge (real charge plus fictitious polarization charge), assuming ohmic conduction of real charge and the spontaneous decay of remanent ("frozen in") polarization. The effective surface charge, σ_e, is

$$\sigma_e = \frac{\alpha}{(\alpha-\beta)} P_{ro}(e^{-\alpha t} - e^{-\beta t}) + \sigma_{eo}e^{-\beta t} \qquad (1)$$

where t is the time measured from t=o at the end of electret formation, P_{ro} is the remanent polarization at the time t = o, σ_{eo} is the effective surface charge at the time t=o, and α is a remanent polarization decay parameter ($\alpha = \frac{1}{\tau}$, τ is the electret lifetime and is assumed to be more than 10 years). The parameter β can be written as [1]

$$\beta = \frac{\gamma d/L}{\epsilon_o(1+\epsilon d/L)}$$

where γ is the electret conductivity, ϵ_o is the permittivity of free space, ϵ is the static dielectric constant, L is the thickness of the electret, and d is the total (top and bottom) air gap between the electret surfaces and the shorted metal storage shields.

The theoretical dependence of the effective surface charge, Eq. (1), on the parameter β, Eq. (2), may be investigated by varying the distance d, the shielding conditions of the electret. A large change ($\approx 10^6$) in d may be conveniently accomplished by first using "nearly perfect" shielding, when the metal storage shields are firmly adhering to the electret wax surfaces ($d \approx 10^{-10}$m, atomic dimensions), and then using "good" shielding, when the electret is tightly wrapped with the metal shield ($d \approx 10^{-4}$m). The effective surface charge versus time curve for an electret undergoing this change in shielding conditions is shown in Figure 1. The modification of shielding takes place at a time before the ordinary reversal time of the electret. The theoretical prediction derived from the Gubkin theory indicates (Figure 1) a slow decrease in the magnitude of the effective surface charge under "nearly perfect" shielding conditions, and then a rapid reversal of the charge governed by the new shielding conditions.

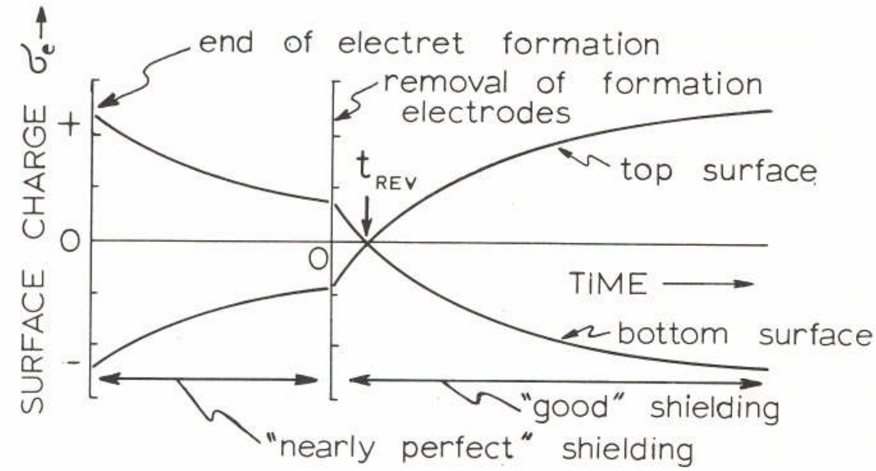

FIGURE 1. Theoretical curves for dependence of effective surface charge on shielding conditions.

Experiment

Thirty-five disk-shaped (7 cm diameter and 1.27 cm thick) thermoelectrets were prepared under nearly identical conditions from a mixture of 45 per cent carnauba wax, 45 per cent colophonium, and 10 per cent white beeswax (this gave $\epsilon = 2.5$ and $\gamma \approx 10^{-15}$ amp/volt m). The wax mixture was melted for 1.5 hr at 120-125° C and poured into a plexiglass mold for formation. A formation electric field of 7,900 v/cm was applied to aluminum foil formation electrodes placed above and below the wax melt and the mold. After a 20-min formation period the solidified wax (now an electret) was removed from the mold with the formation electrodes intact, adhering firmly to the top and bottom wax surfaces.

In a normal electret-making procedure [2] the formation electrodes would be immediately removed (peeled off), the electret effective surface charge would be measured by induction, and the electret would be tightly wrapped in an aluminum foil storage shield. However, for the present work, immediately after formation the formation electrodes (still adhering to the electret) were shorted and left intact on different electrets for periods of ¼ hour, ½ hour, 1 hour, 1 day, 1 week, 1 month, or 3 months. At the end of this period the electrodes were removed and the electret was measured by induction and then tightly wrapped in an aluminum foil storage shield. Subsequently, the electret surface charge was measured each hour for several hours, each day for one week, each week for one month, and each month for almost one year (at this writing).

Results and Discussion

The effective surface charge versus time curves for three typical electrets are shown in Figure 2. Electret No. 73 (Figure 2, top) was stored for one day without removing the formation electrodes ("nearly perfect" shielding). No surface charge measurements were made during this time in order to maintain the shielding. At the end of this period the formation electrodes were removed and the electret was tightly wrapped in a metal foil storage shield ("good" shielding). Induction measurements were made during the "good" shielding period. This electret exhibited a reversal time

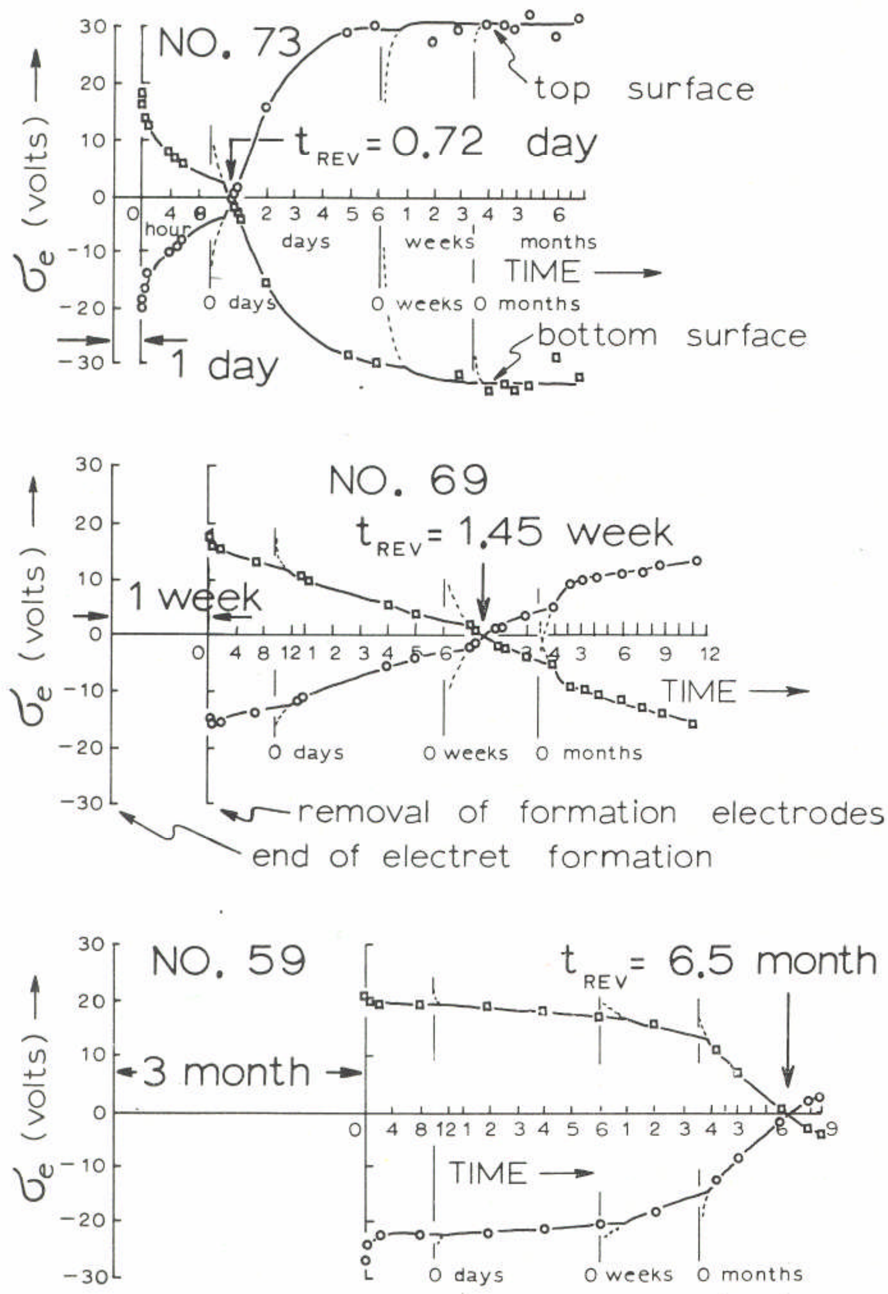

FIGURE 2. Experimental curves for dependence of effective surface charge on shielding (10 volts corresponds to 4.6×10^{-6} amp sec/m²).

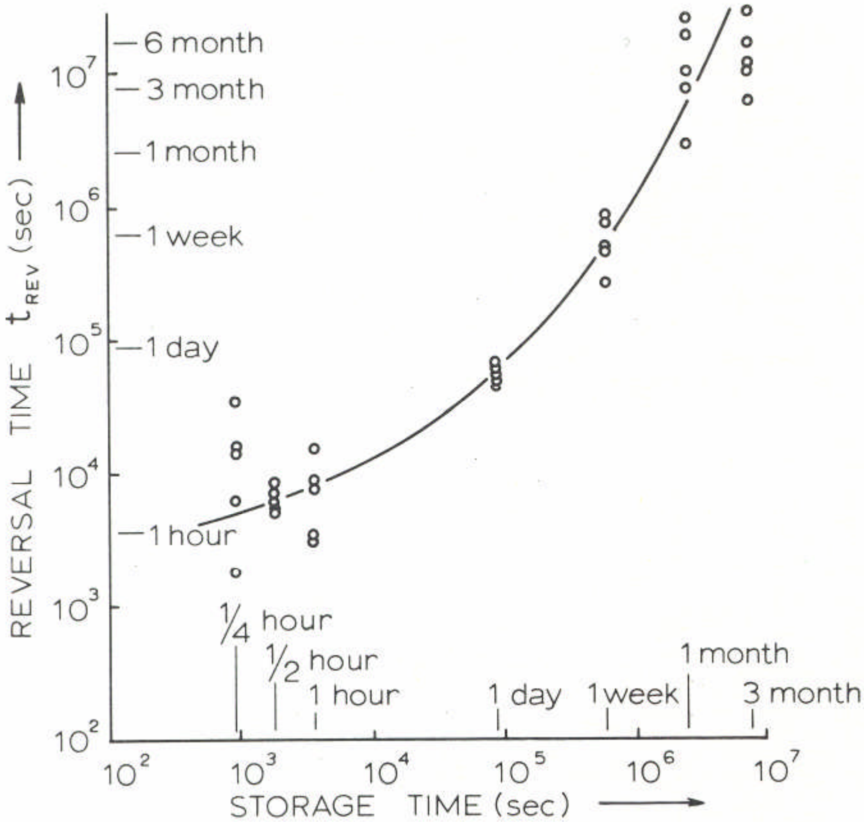

FIGURE 3. Dependence of electret reversal time on storage under "nearly perfect" shielding conditions. The reversal time is measured from $t = o$ at the beginning of "good" shielding conditions.

of $t_{REV} = 0.72$ days (measured from $t = o$ at the instant of electrode removal). Electret No. 69 (Figure 2, center) was stored for one week with formation electrodes intact and exhibited a reversal time of $t_{REV} = 1.45$ weeks. Electret No. 59 (Figure 2, bottom) was stored for three months with formation electrodes intact and exhibited a reversal time of $t_{REV} = 6.5$ months.

Reversal time data for all thirty-five electrets are shown in Figure 3. In contradiction to the theory (compare Figures 1 and 2), a strong dependence of the reversal time upon the period of storage of the electret before the removal of the formation electrodes is clearly shown.

The effective surface charge immediately after removal of the formation electrodes (end of "nearly perfect" shielding and start of "good" shielding) is shown in Figure 4. This initial charge, within the normal variation of charge for identical electrets, is observed to be essentially constant for all electrets, regardless of the period of storage with formation electrodes intact. Hence, the electret apparently must be "activated" for reversal by the removal of the formation electrodes. These results are not predicted by the theory (compare Figure 1 with 2 and 4).

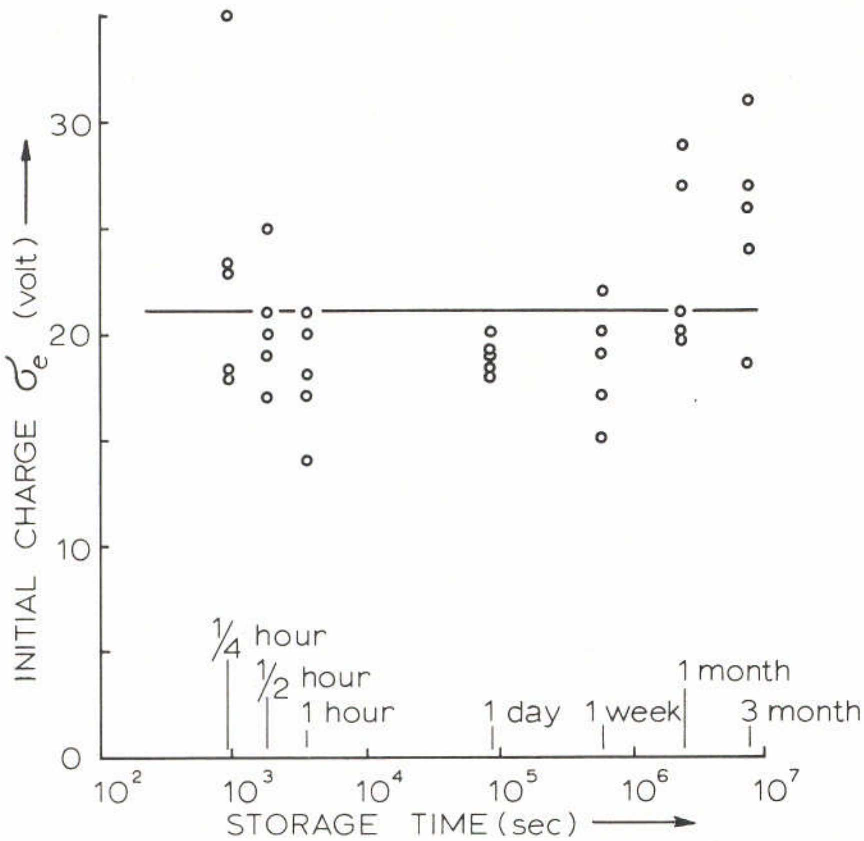

FIGURE 4. Dependence of effective surface charge at the beginning of "good" shielding conditions on storage conditions under "nearly perfect" shielding (10 volts corresponds to 4.6×10^{-6} amp sec/m^2).

Summary

It was found that: (1) electrets must be "activated" by removal of their formation electrodes, (2) the initial surface charge on electrets is independent of the storage time preceding the activation, and (3) the storage time of the electret in the unactivated state is a strong factor determining the reversal time after the activation. These results suggest that Gubkin electret theory is incomplete and that a further theoretical analysis is needed for elucidating the nature of the electret effect.

LITERATURE CITED

1. Gubkin, A. N. 1957. The phenomenological theory of electrets. Soviet Phys., Solid State **27**: 1813-1824.
2. Jefimenko, Oleg, and David K. Walker. 1967. External field and stability of carnauba wax electrets. Proc. W. Va. Acad. Sci. **39**: 392-394.