REMARKS ON THE ARTICLE BY COOPER AND GROSSART, "TIME DELAYS IN INTERNAL ELECTRIC BREAKDOWN OF SOLID DIELECTRICS"[1]

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IN the breakdown of the ionic crystals NaCl, KCl, and KBr under 1/5000 microsecond pulses, Cooper and Grossart[1] obtained anomalously large delay times for the discharge, of the order of 10^{-6} to 10^{-5} seconds. In our opinion, this result followed from deficiencies in the method of investigation. In the first place, a test made by the full-wave method (repeating the voltage pulses with increasing amplitudes) may lead to an incomplete breakdown if the field is not sufficiently uniform.[2] In this case, there would be a distortion of the field within the dielectric. In addition, when a 1/5000 microsecond pulse is used, and especially when several such pulses are repeated, the voltage is applied to the dielectric for a considerable time, which may lead to the introduction of various secondary factors, such as heating effects, etc.,[3] which complicate the interpretation of the results.

In determining the delay time for discharges in ionic crystals it is sounder to make the test by means of individual rectangular voltage pulses with amplitudes exceeding the breakdown voltage by, say, 10, 20, 30%, and so on. Experiments which we have carried out in this way on NaCl samples 0.12 mm thick, in a uniform field at 20% over-voltage, gave time delays of the order of 4 to 5×10^{-8} seconds. Experiments with repeated rectangular voltage pulses (rise time of the order of 3×10^{-8} sec), of uniform amplitude somewhat below the breakdown value, showed that the effect of each successive pulse was to lower the electric strength, and that the breakdown took place, not at the first pulse, but at the n-th, where n has been found to range from 2 to 81.

In the article cited, the authors do not give the values of electric strength for the dielectrics they studied, nor do they show how they measured the time delays from the oscillograms and the pulse repetition rate, which limits the value of their paper.

[1] R. Cooper and D. T. Grossart, Proc. Phys. Soc. 69, 1351 (1956).
[2] A. Walter and L. Inge, J. Tech Phys. (U.S.S.R.) 1, 389 (1931).
[3] F. Lehmhaus, Arch. Elektr. 32, 281 (1938).

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THE n-ELECTRON GREEN'S FUNCTION IN THE BLOCH-NORDSIECK APPROXIMATION

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ON the basis of the results of Schwinger[1] one can write for the n-electron Green's function G_n in the Bloch-Nordsieck[2] approximation, i.e., after replacing the matrices γ^μ by c-numbers, the following equation:

$$\left\{iu^\mu \partial/\partial x_1^\mu - m + \sqrt{4\pi} e u^\mu A_\mu(x_1) + i\sqrt{4\pi} e u^\mu \int D_{\mu\nu}(x_1, \xi)\frac{\delta}{\delta A_\nu(\xi)} d\xi\right\} G_n(x_1, \ldots, x_n; y_1, \ldots, y_n | A)$$
$$= -\sum_P (-1)^l \delta(x_1 - y_j) G_{n-1}(x_2, \ldots, x_n; y_{j+1}, \ldots, y_n, y_1, \ldots, y_{l-1} | A), \quad (1)$$

where the summation is taken over all possible cyclic permutations of the arguments $y_1, \ldots, y_n$, and ℓ is the number of interchanges necessary to go from $y_j \ldots y_n y_1 \ldots y_{j-1}$ to $y_1 \ldots y_n$.

We seek the solution of Eq. (1) in the form

$$G_n(x_1, \ldots, x_n;\ y_1, \ldots, y_n \mid A) = -\sum_P (-1)^l [G_1(x_1, y_j \mid A)\, G_{n-1}(x_2, \ldots, x_n;\ y_{j+1}, \ldots, y_n, y_1, \ldots, y_{j-1} \mid A)$$

$$+ G_{1n}(x_1, \ldots, x_n;\ y_j, \ldots, y_n, y_1, \ldots, y_{j-1} \mid A)]. \qquad (2)$$

The equation for G_{1n} in the momentum representation can be solved exactly by a method used previously.[3] We get as the result

$$G_{1n}(p_1, \ldots, p_{2n-1} \mid A) = -\sqrt{4\pi}\frac{eu^{\mu_1}}{(2\pi)^2}\int_0^\infty d\nu e^{-\varepsilon\nu} \exp\left\{-i\left[m - \sum_{i=1}^{2n-1}(up_i)\right]\nu + f(\nu)\right\} \exp\left\{-\sqrt{4\pi}\frac{eu^{\mu}}{(2\pi)^2}\int \frac{e^{-i(up)\nu} - 1}{(up)} A_\mu(p)\,dp\right\}$$

$$\times \int D_{\mu_1\nu_1}(k)\left\{G_1(p_2 \mid A)\left[\frac{\delta G_{n-1}(p_3, \ldots, p_{2n-1} \mid A)}{\delta A_{\nu_1}(k)}\right]_{A \to T_x A}\right\}_{A \to A^{T_\nu}} \exp\left\{i\left(k + p_2 - \sum_{i=1}^{2n-1} p_i\right)x\right\} dx\,dk. \qquad (3)$$

It follows that the probability for the emission of n low-energy photons is given by the Poisson formula

$$w_n = e^{-W}\frac{W^n}{n!}, \quad W = \frac{2e^2}{\pi}\ln\frac{E_2}{E_1}, \qquad (4)$$

where the energy of the photons lies between E_1 and E_2.

[1] J. Schwinger, Proc. Nat. Acad. Sci. **37**, 452 (1951).

[2] F. Bloch and A. Nordsieck, Phys. Rev. **52**, 54 (1937).

[3] R. V. Tevikian, J. Exptl. Theoret. Phys. (U.S.S.R.) **32**, 1573 (1957), Soviet Phys. JETP **5**, 1282 (1957).

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ON THE SPEED OF PROPAGATION OF ELECTROMAGNETIC WAVES AT AUDIO FREQUENCIES

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THE speed of electromagnetic waves has been investigated experimentally in various researches, over a frequency range approximately from 10^{15} cps (optical waves) to 10^6 or 10^5 cps (so-called medium radio waves). Recently we have determined the speed of electromagnetic waves under natural conditions at lower, audio frequencies, namely from about 3×10^4 to 10^3 cps; in addition, the investigations are about to be extended down to frequencies of some tens of cycles per second.

The method used in our work was that of complete harmonic analysis of photo-oscillograms of individual atmospheric events $E(t, r)$, taken at various distances from their sources (thunderstorm discharges).[1,2] The distances r from the sources were determined by means of three direction-finders. The method consists in the following.

The spectral density of the signal $E(t, r)$ can be written in the form