symbolically in the form

$$S=1+(i/\hbar)\{L'\}+(i/\hbar)^2\{L'D_+L'\}+(i/\hbar)^3\{L'D_+L'D_+L'\}+\cdots \quad (2)$$

in non-local field theory as well as in local field theory, where L' is an invariant operator characterizing the interaction which can be expressed as a sum of products of non-local and local field quantities. In the particular case of the interaction between local fields, the matrix elements of L' reduce to the form

$$(n', x'|L'|n'', x'')=(n'|L'(x')|n'')\prod_{\mu=1}^{4}\delta(x_\mu'-x_\mu''), \quad (3)$$

where $(n'|L'(x')|n'')$ is the matrix element for the Lagrangian density for the interaction in the usual theory. D_+ is an invariant displacement operator with the matrix elements

$$(n', x'|D_+|n'', x'')=1,\ \tfrac{1}{2},\ \text{and } 0, \quad (4)$$

according as $x'-x''$ is a future-like vector, a space-like vector, and a past-like vector respectively. We can show very generally that the matrix S as defined by (2) fulfills all requirements for the S-matrix. Firstly, it is obviously relativistically invariant. Secondly, one can prove that it is unitary. Thirdly, the matrix element $(n'|S|n'')$ is different from zero only if the final and initial states, which are characterized by n' and n'' respectively, have the same total energy and momentum.[2]

As for the finiteness of the matrix S, it is not easy to draw a general conclusion. However, we can show that, for example, the self-energy of a spinor particle interacting with the non-local scalar field is finite due to the appearance of the form factor, as far as the third term of S in (2) is concerned. Further investigations are needed in order to settle the question of convergence in non-local field theory.

Detailed accounts will be published at a later date.

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* On leave of absence from Kyoto University, Kyoto, Japan.

[1] H. Yukawa, Phys. Rev. **76**, 300 (1949); **76**, 1731 (1949); **77**, 219 (1950).

[2] We mean by the total energy and momentum the sums of energies and momenta respectively of the translational motion of the existing particles.

Photon Pulses from Point-to-Plane Corona

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An RCA 5819 photo-multiplier and a millimicrosecond oscilloscope have been used to study the photon pulses occurring at corona onset in air at atmospheric pressure, by use of a point-to-plane gap. Pulses of more than ten volts amplitude are obtained directly from the photo-multiplier, from single corona events which cannot be individually observed either visually or photographically. The method should be valuable for other gas discharge processes that have a similar low average, but high intrinsic, light output. It has already been used to study discharges of high average brightness such as long sparks[1] and pulsed discharges.[2]

Figure 1 shows the photon pulses obtained with 1-mm radius of curvature point and 5-cm gap. Pulses from the photo-multiplier were passed through an amplifier with pass band 100 kc to 100 Mc per second and through a coaxial line which delayed them relative to the triggering of the sweep. The photographs are a superposition of several sweeps, as can be seen in the lower picture where all the pulses do not coincide. Single sweeps were observed visually.

Studies of the induced pulses produced at the plane electrode by the corona[3] have indicated that these are due to electron motion near the point. This motion is quite slow compared to the rate of propagation of the corona, so that little of the corona process is revealed. The photon pulses do not suffer from this limitation, and give quite distinct and characteristic pulses for positive and negative point polarity.

The *positive* pre-onset streamer pulse shows a slow initial rise which may be due to the multiplication process that builds up the initial space charge necessary for the streamer to propagate. On about every tenth pulse this slow rise is replaced by a slight "bump," and the main rise of the pulse is delayed about two trace-widths. Each pulse shows a well-defined plateau, which gives the impression of two overlapping peaks. Pulse duration at 30 percent maximum amplitude is about 6×10^{-8} second. Observations with test pulses of from 3 to 8×10^{-8} second duration, inserted at the photo-multiplier anode, indicate that the plateau does not arise in the amplifier. It may be due to the nature of the decay of excitation in a single streamer channel, or again, perhaps it is possible for two successive pulses of excitation to occur in the same channel, even with a time separation as short as 3×10^{-8} second.

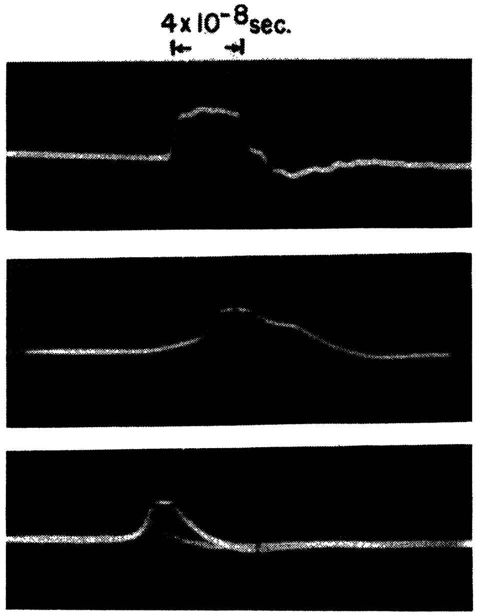

Fig. 1. Upper: Test pulse from discharge of 0.02 microsecond delay line. Middle: Photon pulse from positive point pre-onset streamer. Lower: Photon pulse from negative point "Trichel" pulse. All pulses traversed the same amplifier system.

The *negative* "Trichel" pulse shows only a slight indication of the initial multiplication process mentioned above. It rises abruptly at a rate about the same as the fast rise of the positive pulse, and decays smoothly after a duration at 30 percent maximum amplitude of about 3.5×10^{-8} second. Such a short simple pulse is surprising. The negative point corona in air has the appearance of a complete miniature glow discharge, and one might expect the process of building up the space charge formations needed to account for this structure[4] to give rise to a longer and more complex pulse.

In preliminary interpretation of the present results, it has been assumed that excitation of the gas is proportional to ionization, and that the decay of the excited states is rapid compared to the duration of the photon pulse. Further experiments with different gases, pressures, and electrode arrangements should make possible an explanation of the pulse shapes observed, and give new information of the corona processes involved.

The writer is grateful to Dr. C. Hendee of Northwestern University for suggesting the use of a photo-multiplier in the present problem. He is indebted to the Electronics Branch, Chalk River Laboratory, and especially to Mr. G. J. R. MacLusky, for loan of the oscilloscope, amplifiers and pulse generator, and for helpful advice.

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[1] R. F. Saxe and J. M. Meek, Nature **162**, 263 (1948).

[2] W. S. Huxford and H. N. Olsen, Pittsburg Conference on Gaseous Electronics (November, 1949).

[3] W. N. English and A. W. Love (to be published).

[4] L. B. Loeb, J. App. Phys. **19**, 882 (1948); Phys. Rev. **71**, 712 (1947).

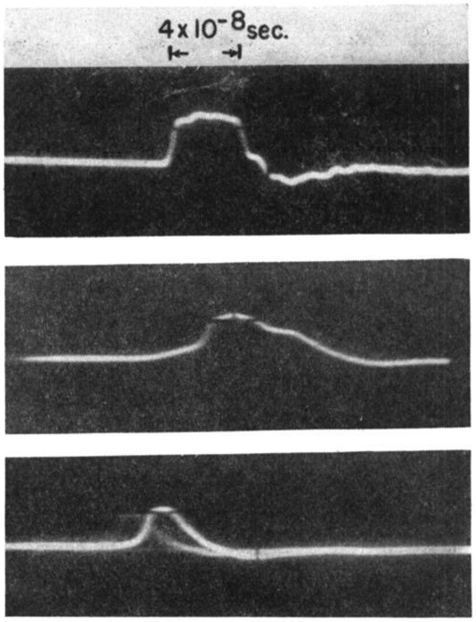

Fig. 1. Upper: Test pulse from discharge of 0.02 microsecond delay line. Middle: Photon pulse from positive point pre-onset streamer. Lower: Photon pulse from negative point "Trichel" pulse. All pulses traversed the same amplifier system.