Streamer Breakdown and Sparking Thresholds

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THE studies of Raether[1] with Wilson cloud chambers and of the writer's students[2] with positive corona have established the reality of the streamer breakdown mechanism of sparks beyond the shadow of a doubt. All sparks showing bright, narrow channels, straight, crooked, or branched, extending down to pressures so low that diffusion yields broad fuzzy channels or glow, unquestionably involve as an important element of the mechanism the positive and negative streamer mechanisms as postulated by Meek and the writer[3] and by Raether.[1]

The streamer mechanism was invoked initially, among other reasons, to account for the formative time lags of the order of 10^{-7} sec observed in slightly overvolted gaps.[3] These could not well be accounted for by the classical secondary Townsend mechanisms. Relatively recently, Gaenger[4] and Fisher[5] and his collaborators attempted to locate the lower pressure and gap length values at which, in uniform fields, transition of the streamer mechanism to the diffuse Townsend spark occurred. They found that down to conditions where the spark appears as a diffuse glow, the breakdown is consistently of the streamer type. Fisher and his collaborators further found that as the applied overvoltage across the plane parallel plate gaps was decreased to a few tenths of a percent in air and N_2, the *formative time lag of sparking rose rapidly from 10^{-7} to 10^{-4} sec* and longer. The curve between overvoltage and time lag was independent of triggering illumination within limits, was independent of pressure, but varied in proportion to gap length. Analogous but more erratic data were observed in O_2. In argon the formative lag was much greater than in air and could be reduced to microseconds only by overvoltages of the order of 100 percent. In argon and O_2 the overvoltage time lag curves were pressure dependent. Such long time lags are incompatible with a sparking mechanism in which the *threshold is set by streamer formation* as originally proposed by Meek[3] and the writer and Raether.[1]

The theory for the temporal growth of a Townsend discharge developed by von Engel and Steenbeck[6] has been elaborated by Bartholomeyczyk[7] and investigated by von Gugelberg[8] in terms of the various secondary γ-mechanisms. The theory and data on γ fix the threshold for a Townsend discharge as $\gamma \exp(\alpha d)=1$ for a uniform field gap of length d with α the first Townsend coefficient. Above this threshold positive ions accumulate in the gap through a diffusive self-sustaining discharge of low order. It has independently been shown by von Engel and Steenbeck[9] and by Varney, White, Loeb, and Posin,[10] that if the X/p values are such that they lie below the point of inflection of the $[(\alpha/p)-(X/p)]$ curve, the space charge accumulations will enhance the development of the distortion leading to a spark. Near the threshold of the Townsend discharge the space charge build-up takes long time intervals as shown by Schade[11] and von Gugelberg[8] in conformity with theory. The time of build-up rapidly decreases the greater the overvoltage. In fact, Kachickas and Fisher have calculated the formative time lags using Schade's approximation to von Engel and Steenbeck's theory assuming $\gamma \exp(\alpha d)=1$. The crude theory qualitatively predicted the course of the observed variations of the overvoltage-time lag curves for air and argon remarkably well.

It must thus be concluded that with low values of γ as in air and especially with low values of α and high values of γ as in argon, the Townsend threshold for a space charge build-up sets in at values of X/p and of potentials V *below* those which would initiate streamer formation. Streamer formation requires values of avalanches, $\exp(\alpha d)$, of the order of 10^7 electrons or more. Thus, *spark discharges in uniform fields set in at thresholds for low order Townsend discharges* by creating space charge field distortions. These distortions increase to the point where avalanches reach streamer-forming proportions in midgap, thus yielding sparks as streamer-type breakdown. As overvoltages increase, the temporal rate of space charge production is increased, and the streamer-forming avalanches are produced in progressively shorter time intervals. In air or O_2 the low values of γ require high potentials to give the correspondingly large values of $\exp(\alpha d)$ for Townsend thresholds. Hence, only slight overvoltages are needed in air so that Meek's streamer criterion nearly holds. In argon and other inert gases appreciable values of α set in at such low values of X/p and α is so small, while γ is large, that the Townsend thresholds fall far below streamer thresholds. Thus, Meek's streamer theory cannot apply to such gases.

The physicist must, therefore, reconcile himself to the paradoxical situation of a streamer breakdown mechanism for spark in uniform fields with *a threshold which is set by the conventional Townsend criterion* and *not* by that of *Meek and the writer and of Raether.* If this is done, practically all of the difficulties of the past are reconciled in a single consistent sparking theory.

It must be emphasized that the conditions cited apply to uniform field breakdown. In the intense highly distorted fields near positive points and wires, streamers can and do form as postulated by the writer, Meek, and Raether, and ultimately lead to breakdown. Thresholds for such discharges are set directly by streamer theory and are entirely gas dependent.[12]

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A Note on the Calculation of the Fermi Function in the Theory of Beta-Decay*

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IN view of recent advances in experimental techniques of beta-ray spectroscopy, the accuracy of the calculation of the Fermi function has been investigated by several authors.[1] In fact, it can be calculated as accurately as desired without much effort.

According to Konopinski's formulation[2] of the theory of beta-decay, the number of beta-particles emitted in the momentum range p to $p+dp$ is given by the relation

$$Ndp=CF(z, W)p^2(W_0-W)^2dp \tag{1}$$

where $F(z, W)$ is the Fermi function given by

$$F(z, W)=\frac{4(2pR)^{2s-2}e^{\pi\delta}|\Gamma(s+i\delta)|^2}{|\Gamma(2s+1)|^2}\cdot\frac{1+s}{2},$$

and

$$\delta=\alpha 2W/p. \tag{2}$$

TABLE I. Comparison of the approximations to the Fermi function.

	S^{35}		$Cu^{64}(\beta^-)$		RaE		
p	$(F/F_K)^{\frac{1}{2}}$	$(F/F_B)^{\frac{1}{2}}$	$(F/F_K)^{\frac{1}{2}}$	$(F/F_B)^{\frac{1}{2}}$	$(F/F_K)^{\frac{1}{2}}$	$(F/F_B)^{\frac{1}{2}}$	$(F/F_F)^{\frac{1}{2}}$
0.2	1.0094	0.9957	1.0209	0.9869	0.2967	0.8524	1.797
0.4	1.0059	0.9952	1.0144	0.9860	0.2927	0.8561	1.764
0.6	1.0034	0.9950	1.0077	0.9852	0.2867	0.8595	1.745
0.8	1.0013	0.9949	1.0021	0.9848	0.2799	0.8620	1.737
1.2	0.9984	0.9949	0.9934	0.9845	0.2666	0.8650	1.738
1.6	0.9964	0.9949	0.9869	0.9843	0.2549	0.8659	1.745
2.4	0.9933	0.9948	0.9775	0.9842	0.2371	0.8668	1.757
3.2	0.9912	0.9948	0.9707	0.9841	0.2242	0.8670	1.759
4.0	0.9896	0.9948	0.9655	0.9841	0.2145	0.8672	1.755
4.8	0.9882	0.9948	0.9613	0.9841	0.2067	0.8673	1.744