AN EXPERIMENTAL TEST OF THE STREAMER BREAKDOWN CRITERION*

By M. C. Cavenor†

The filamentary spark channel, resulting from the electrical breakdown of a gas, generally forms in one of two ways. At voltages close to the minimum breakdown potential the spark channel has been shown to develop from the constriction of the diffuse glow discharge formed from the superposition of many generations of electron avalanches (Cavenor and Meyer 1969). At large overvoltages, however, single avalanches have been observed to develop into luminous conducting filaments, called streamers, which completely bridge the electrode gap within the transit time of the initial avalanche (Wagner 1966).

The criterion proposed for the occurrence of this streamer mode of development is that the charge carrier number in the initial avalanche should attain a value of some 10^9 ions and electrons and that the electrons be concentrated within the diffusion radius of the avalanche. Under such conditions it is suggested that enhancement of the electric field by the space charge, in the vicinity of the avalanche, is sufficient to allow gas ionizing radiation to extend the ionized region simultaneously towards both electrodes (Raether 1964). For avalanches initiated by single photoelectrons the amplification of the avalanche, $\exp \alpha d$, must therefore be 10^9 and thus αd, the product of the primary ionization coefficient and the gap length, must be of the order of 20 ion pairs.

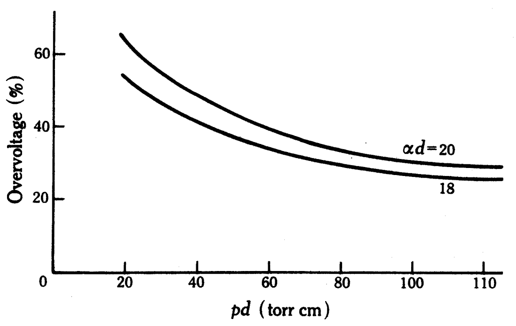

Fig. 1.—Overvoltage required to establish the conditions $\alpha d = 18$ and 20 as a function of pd.

For the case of hydrogen, with a given value of pd it is possible to compute, from values of α/p versus E/p and experimentally determined breakdown voltages, the percentage overvoltage required to establish the condition $\alpha d = 20$. This information is given in Figure 1 where the corresponding curve for $\alpha d = 18$ is added to show

* Manuscript received June 16, 1970.

† Department of Physics, University of New England, Armidale, N.S.W.; present address: Department of Chemical Engineering, Imperial College, London S.W.7, England.

the weak dependence of αd on overvoltage. At $pd \sim 100$ torr cm the condition should be satisfied for relatively low values of percentage overvoltage ($\sim 25\%$). An investigation was undertaken therefore to establish optical evidence for a transition to the streamer-type breakdown as the percentage overvoltage is increased.

The apparatus used for producing spark discharges in hydrogen at atmospheric pressure and for obtaining shutter photographs of their development at low overvoltages has been described previously (Cavenor and Meyer 1969). In order to produce the spark discharges at large overvoltages, a rectangular voltage pulse was applied to the spark chamber by means of a triggered spark gap. The hydrogen discharge was initiated by the ultraviolet light from a trigger spark in air at atmospheric pressure which illuminated the entire cathode surface for a period of 100 nsec.

With increasing overvoltage, the previously reported characteristic two steps in the discharge current pulse progressively disappeared being replaced by the single stepped pulses shown in Figure 2. The converter closing time for each frame of the shutter photographs is indicated by the correspondingly numbered mark on the accompanying current oscillogram. These shutter photographs, which were all obtained at an overvoltage of 100% at $pd = 100$ torr cm, show two modes of development. The upper sequence of photographs shows a development identical to that observed at low percentage overvoltage (type 1 development) but in which a number of similar discharges occurred simultaneously at various places on the cathode. Such parallel development only occurred during the diffuse and constricted glow phases as the voltage collapse associated with the arc formation effectively arrested all but the most developed channel.

In the type 2 development several diffuse glows again formed over various regions of the cathode, these however being followed within 5 nsec by a bright spot or a number of spots at the cathode surface without the prior formation of a constricted glow column. The luminosity at the cathode then extended towards the anode until the electrode gap was bridged by the most advanced filament. At 60% overvoltage only 1 in 20 of all discharges had the type 2 development, but this increased to equal probability with type 1 at 100% overvoltage and finally became the sole mode of development at overvoltages in excess of 150%. Furthermore, the overall voltage across the diffuse discharge in both the type 1 and type 2 developments remained constant for overvoltages from 0 to 100% even though there was a threefold increase in discharge current.

The important observation from all the shutter photographs is that even at the highest values of overvoltage a diffuse glow discharge is formed initially, characterized by a Faraday dark space indicating a high cathode fall field. Thus, although the macroscopic electric field conditions are such that a sufficiently high ($> 10^9$) charge carrier amplification could be achieved in a single avalanche, other factors influence the situation in favour of a multiple avalanche growth and streamers are not therefore observed. The evidence suggests that, within a time comparable to the transit time of the primary electron avalanches, many such avalanches have been released from a wide area of the cathode, both by the unfocused trigger light source and by photons from the primary avalanches. Under such conditions it is most unlikely that localized field enhancement leading to streamer development will ever occur, and in fact no evidence of a streamer development has been recorded.

Satisfying macroscopic field conditions to ensure amplification appropriate to the relation $\exp \alpha d = 10^9$ is therefore not sufficient to produce a streamer mode of breakdown. It is significant that various precautions have been observed in the past in order to facilitate the study of streamers. These include the use of short

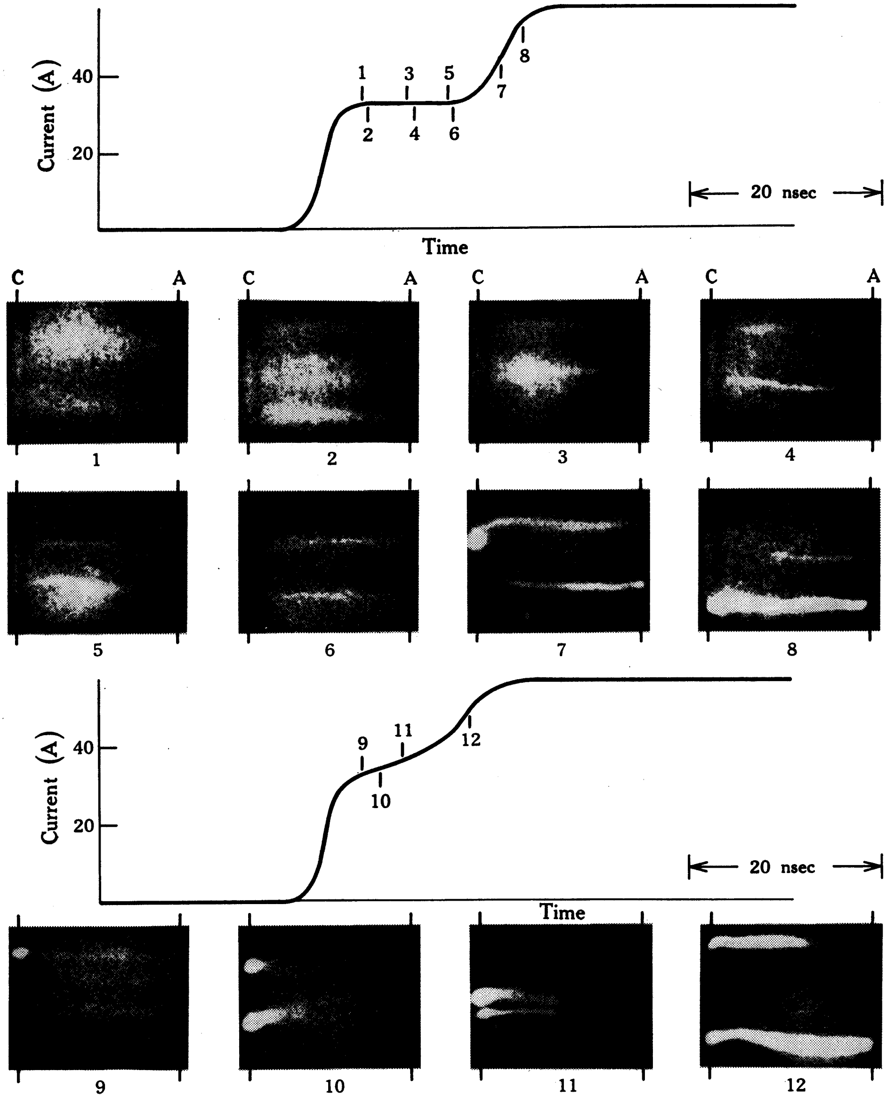

Fig. 2.—Shutter photographs of a discharge in hydrogen at 500 torr and 100% overvoltage ($d = 2$ mm, $V = 5 \cdot 8$ kV).

duration focused light sources together with gas and cathode material combinations having extremely low γ-photon yields, or alternatively cathode point to plane geometry. The present work suggests that only when these specific controls are placed on the experimental conditions is there any likelihood of a streamer being formed at all.

Acknowledgments

This work has been undertaken with support from the Australian Institute for Nuclear Science and Engineering and the Electrical Research Board. The author is pleased to acknowledge a number of helpful discussions with Professor S. C. Haydon.

References

Cavenor, M. C., and Meyer, J. (1969).—*Aust. J. Phys.* **22**, 155.
Raether, H. (1964).—"Electron Avalanches and Breakdown in Gases." (Butterworth: London.)
Wagner, K. G. (1966).—*Z. Phys.* **189**, 465.