FIRING CHARACTERISTICS OF HALOGEN-QUENCHED GEIGER-MÜLLER COUNTERS

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Abstract

A few discharge parameters of the low voltage halogen-quenched counters are presented and contrasted with those of the conventional argon-alcohol counters. The discrepancies which are mainly quantitative are easily understood if photons are considered to liberate secondary electrons from the cathode unlike the photoionization in the other counters. No new mechanism of either metastable formation or resonance radiation finds support from the time correlations of the individual avalanches. The greater attenuation length of the radiation, seemingly due to far less absorption, explains adequately the ineffectiveness of beads, the larger output pulse and the greater probability of discharge spread. The formative time lag in the pulse build up and the greater ascent of the leading edge manifest themselves due to the 'transit lag' of electrons in these low fields. The velocity of discharge spread compares favourably with the values in case of externally quenched counters.

1. Introduction

Soon after Liebsons' (1947) discovery of the successful rôle of halogens as quenching admixtures, Present (1947) showed that the use of halogens was consistent with the theory of Geiger counter operation which had previously been worked out by him in collaboration with Korff (1944). Later followed a host of publications which delineated clearly the advantages of these low voltage tubes such as low working potential, an almost indefinite operating life, immunity from damage arising from heavy discharges, temperature independence (−50° to +60°C.) and above all large output pulse. Whereas these unambiguous advantages over the conventional counter sufficed as an incentive for their development, one cannot be oblivious of their glaring defects of longer build up times rendering them unsuitable for coincidence work and non-uniform efficiency over the cross-section in addition to the constructional difficulties arising from the chemical clean up of halogens during electrical discharges.

The gas discharge mechanism of these counters is still only imperfectly understood and the information available appears to be too sketchy to decide the secondary mechanisms of pulse build up satisfactorily. The knowledge of secondary processes will provide a clue for eliminating the above-mentioned limitations of these otherwise versatile tubes.

Van Zoonen (1953) conjectured that there is no real delay but only a very slow multiplication giving the impression of a delay, the secondary mechanism being the ionization of halogen molecules by metastable rare gas atoms, the latter being formed by resonance radiation. In a later article the same author (1954) concluded that the photo-effect at the cathode does not play a part in the multiplication process. Moreover, when one of the two identical counting systems in the same bent-glass envelope discharges, the other is nearly always ignited by resonance photons of the first discharge, with a delay of the order of some microseconds. The study of the additional discharge parameters, which constitute this paper, was undertaken to assess the validity of the above conclusions.

2. CONSTRUCTION OF COUNTERS

The comprehensive procedure of counter construction as outlined by Croissette and Yarwood (1951) was taken advantage of. To be saved of the encumbrances of freeing bromine of dissolved air and water vapour, the gas was prepared by heating cupric bromide (anhydrous) and further dried by making it stand over calcium chloride and phosphorus pentoxide. This method proved quite dependable as bromine is needed only in relatively smaller quantities.

All the counters employed, whose specifications are listed in Table I, are of maze type for facility of construction. The purity of gases is of extreme importance, as even a small contamination had such a deleterious effect on counter operation so as to completely jeopardize its correct working.

The counter bodies and the relevant parts of the filling system were soaked by bromine at a pressure of about 1·5 cm. Hg for a couple of hours. This precaution renders the counter and glass system completely incapable of further absorption of the small amount of bromine introduced. No lowering of threshold was noticed in a sealed-in construction. The small pressure of halogen was measured with a travelling microscope of least count 0·02 mm.; its flow was controlled by a spiral of glass tubing with constrictions. The control was both slow and precise.

3. DISCHARGE SPREAD PROBABILITY

In order to find the range of photons generated in the discharge, a discharge parameter α, called discharge spread probability, which is defined as

$$\alpha = \frac{\text{Number of coincidences in } A \text{ and } B}{\text{Impulses in } A + \text{Impulses in } B - \text{Coincidences in } A \text{ and } B}$$

was measured as a function of overvoltage and distance. Obviously this is a quantitative measure of the degree of mutual ignition of two counters. This is accomplished by employing a multicathode single anode counter, by initiating the discharges in one extreme cathode and detecting the same discharge in the next cathode, keeping the intervening space dead by keeping the cathodes at the wire potential. This procedure establishes definitely that whatever passes across the dead space of few cm. are photons, which escape absorption by the gas filling. Each of the cathodes (2 cm. long) was further delimited by two guard cathodes of 3 mm. on either side. The results obtained for the counter Br_1 are plotted in Figs. 1 and 2. The larger values of α ($\sim$95%) as compared to those in case of argon-alcohol counters ($\sim$0·5%) directly point out to the far less absorption of the radiation generated in the discharge.

4. ATTENUATION LENGTH OF THE PHOTONS

For the quantitative understanding of the discharge mechanism the knowledge of the attenuation length of the photons generated in the discharge is absolutely essential. The ultraviolet content of the discharge is characterized by an exponential absorption coefficient μ, depending upon nature and pressure of the gas filling. A split cathode counter Br_2 filled with 20 cm. argon and 1·6 mm. bromine of the externally coated type was employed in the measurement (Fig. 3). Each of the cathodes was defined by guard cathodes of 3 mm. on either side. The discharge probability was measured as a function of distance, between the centres of the first and last active cathodes.

Taking into account the pressure dependence of μ, it can be written that

$$\mu = \mu_0 p / p_0$$

TABLE I

All counters are of maze type

Notation	Cylindrical radius	Wire diameter	Length	PRESSURE			Purpose for which employed
				Neon	Argon	Bromine	
Br_1	9 mm.	3 mil.	19 cm.	25 cm.	2 mm.	0·4 mm.	Discharge spread probability
Br_2	10 mm.	3 mil.	34 cm.	—	20 cm.	1·6 mm.	Attenuation length of photons
Br_3	16 mm.	3 mil.	64 cm.	—	35 cm.	3 mm.	Discharge spread velocity
Br_4	10 mm.	3 mil.	34 cm.	—	20 cm.	1 mm.	Formative time lag in build up
Br_5	10 mm.	3 mil.	34 cm.	—	25 cm.	1 mm.	Ascent time of the leading edge

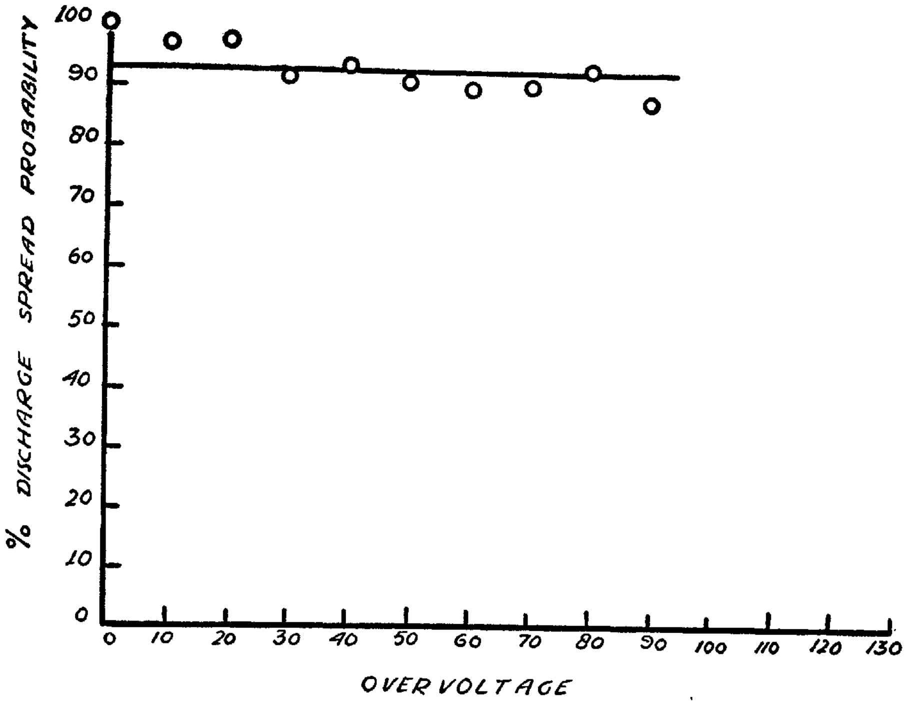

FIG. 1. Discharge spread probability versus overvoltage for a distance of 2·7 cm. between the middles of active cathodes for counter Br_1.

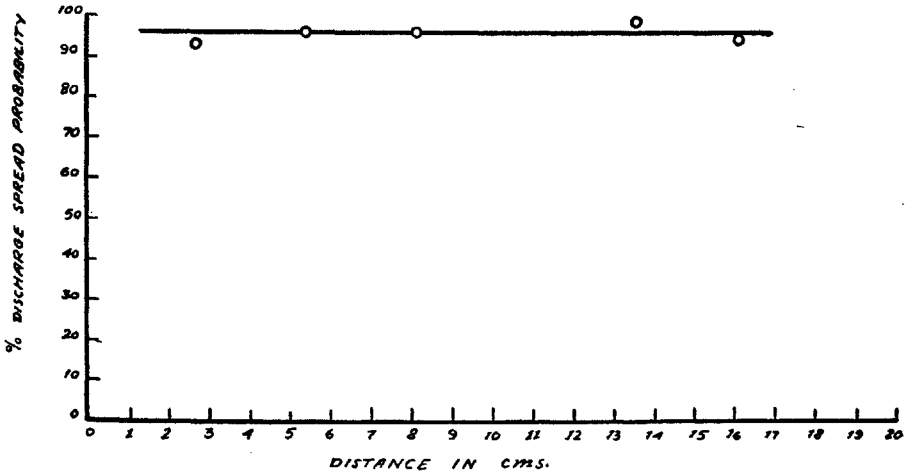

FIG. 2. Discharge spread probability versus distance in cm. between the middles of active cathodes for counter Br_1.

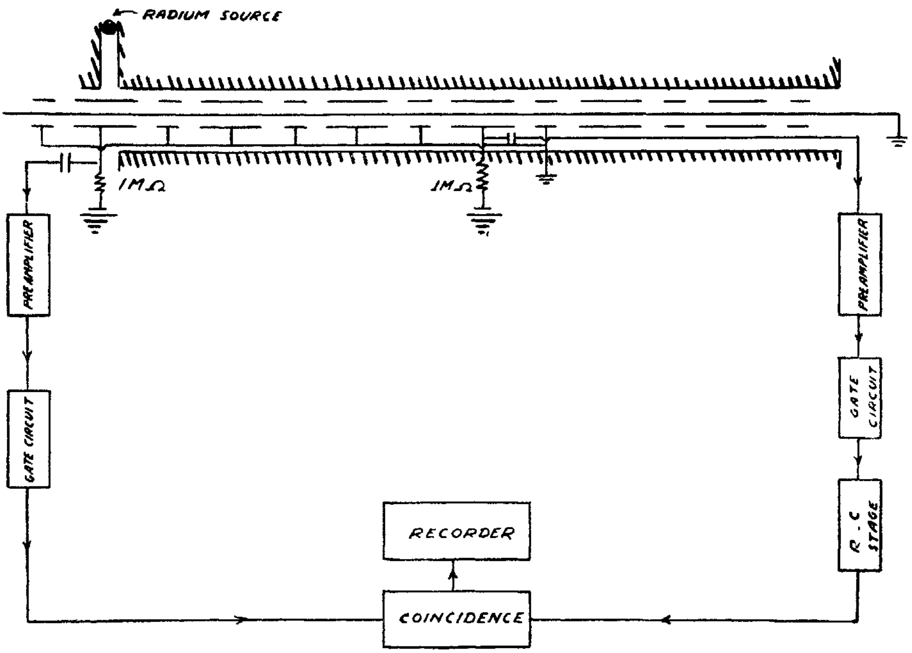

FIG. 3. Block diagram of the experimental set-up for attenuation length of photons.

where p is the actual pressure of halogen and p_0 the normal atmospheric pressure. Let N photons be released in the first cathode discharge resulting from deexcitation. The number reaching the next active cathode at a distance x is

$$N' = Ne^{-\mu_0 \cdot p/p_0 \cdot x} \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (1)$$

Let γ denote the Townsends' second coefficient; then the discharge spread probability α becomes

$$\alpha = \frac{N}{\gamma} e^{-\mu_0 \cdot p/p_0 \cdot x} \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (2)$$

Fig. 4 is a plot of α vs. x at a fixed voltage. Taking any two points x_1 and x_2 and substituting it in (2)

$$\mu_0 = \frac{p \, . \, ln \frac{\alpha_1}{\alpha_2}}{p(x_2 - x_1)} \text{ cm.}^{-1} \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (3)$$

The above relation gives

$$\mu_0 = 190 \text{ cm.}^{-1} \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (4)$$

This numerical value means that in a counter containing 0·2 mm. Hg of bromine, the number of photons sink down to 1/e of their original value, after 20 cm. of distance. This explains very clearly the ineffectiveness of glass beads as reported by Zoonen and Prast (1952) and Egan (1956). Since the multiplication occurs at greater distances, the comparatively greater charge released per discharge is understandable.

The striking difference of the attenuation length of photons in halogen counters as contrasted to that in argon-alcohol counters ($\sim$ 1 mm. Alder *et al.*,

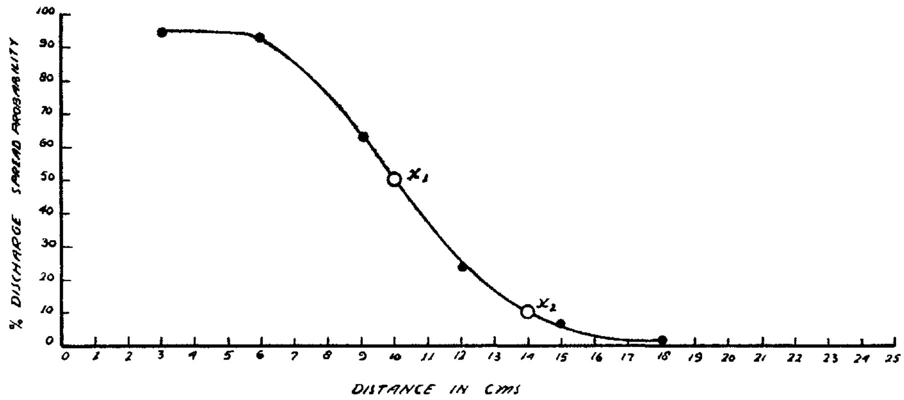

FIG. 4. Discharge spread probability versus distance for counter Br_2.

1947) is not surprising since the absorption of the active photons in halogen-quenched counters is much less than in other types, as much less halogen vapour is present.

5. PROPAGATION PARALLEL TO THE WIRE

Spreading of discharge in Geiger-Müller counters is generally described as occurring through a succession of elementary processes where photons of a primary avalanche release electrons either out of the cathode (in non self-quenching counters), or out of the filling gas as in self-quenching counters. These secondary electrons initiate the necessary new avalanches which further contribute to the stepwise discharge spread. The duration of an elementary process is sum of the time intervals involved in the production and migration of photons and transit time of the secondary electrons. Now with gas mixtures commonly used in counters, for example 9 cm. argon plus 1 cm. alcohol vapour, each elementary process of discharge step averages around 1 mm. in length, which is followed by a deexcitation time of around 10^{-8} second. The new electron formed by the absorption of the quantum and resulting photoionization of the organic molecule then originates a new Townsend avalanche. The distance for the electron from the point of formation to the wire, being 1 mm. or less, and being in a region where the field is high, 10^3 or more volts/cm., it requires time of the order of 10^{-9} second. Thus the velocity of spread may be as much as 10^6 to 10^7 cm. per second, which fact is borne out by experimental evidence.

A highly differentiated pulse from the Geiger counter shows two peaks, each marking the arrival of the 'burning' length at either end of the counter. The burning length is that part of the counter wire where great avalanche activity exists. Halogen counters offer an altogether different case as axial photon movements of few cm. are not different from reality, as reflected in the far greater attenuation length. The discharge does not get quenched before it propagates further unlike the conventional counters. This is supported by the oscillograms which do not show any peaks on high differentiation and any change in pattern on irradiating different places of the counter.

A counter Br_3 was split into two counters of 4 cm. and 60 cm. lengths by graphitizing the corresponding lengths of the cathodes. The rise time of the pulses from the photographs is taken with a synchroscope. The arrangement of apparatus is shown in Fig. 5. In the case of smaller counter, the pulse rise contains the formative time lag (§ 6), the time of formation of the initial avalanche whereas the pulse in case of longer counter contains in addition the time for the discharge

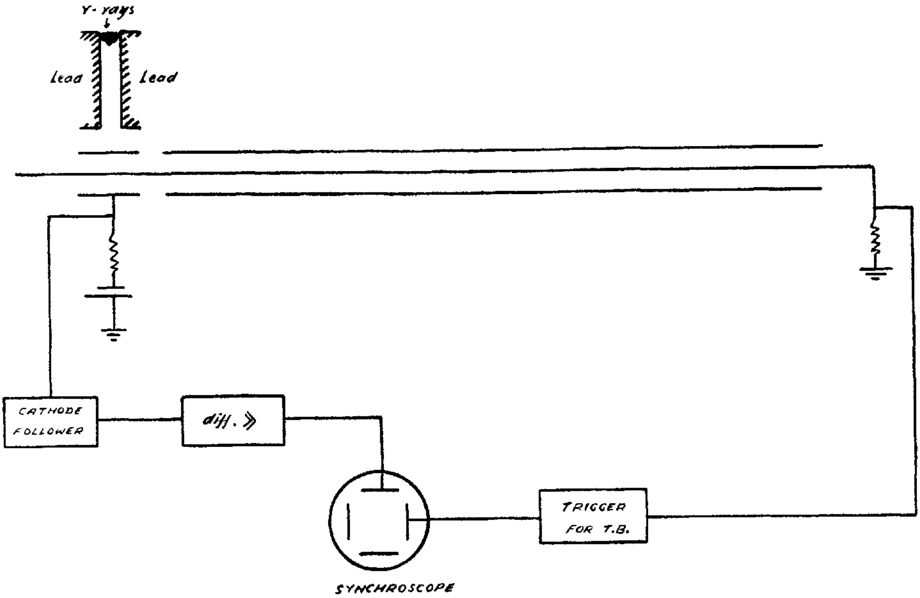

FIG. 5. Diagram for experimental set-up for measuring the velocity of propagation of the discharge parallel to the wire. T.B. is the time base for the Dumont synchroscope 329-A.

to propagate down the length of the cylinder. The difference in rise times of the two pulses (Figs. 6 (*a*) and 6 (*b*)) therefore yields the spreading time, and combined with the cylinder length, also the spreading velocity. The results of the measurement are plotted in Fig. 7, which compare favourably with the values of discharge velocity in case of non-self-quenching counters (Balakrishnan and Craggs, 1950). It is also comparable with the spread velocity of visible light flashes in bromine-quenched counters as measured by the delayed coincidence method, using photo-multiplier tube as light detector. It had values of the order of 10^8 cm. sec. even in the counting region (Fumio Yamasaki and Masaharu Okano, 1954). This shows that faint flashes are coincident with the ionizing discharges.

6. FORMATIVE TIME LAG IN PULSE FORMATION AND THE PHOTON TRANSIT TIME

Formative time lags between the passage of the primary ionizing particle and the consequent development of the output pulse were first pointed out to be the limiting factor for the multifarious usage of halogen counters by Laosemore and Sharpe as early as 1951. This study was incorporated by Van Zoonen (1953) who measured times of the order of 10^{-5} to 10^{-6} seconds for a change in the wire potential of 15 mV. Van Zoonen (1953) interpreted this observed delay as only a very slow multiplication giving the impression of a delay. The secondary mechanism was assumed to be ionization of halogen molecules by metastable rare gas atoms which are known to be excited either by electron impacts or resonance radiation.

In order to assess the validity of this conjecture, a counter Br_4 filled with 20 cm. argon and 1 mm. bromine was employed, where metastable action is unimportant. The technique for observing the build up lag consisted of a triple cosmic ray coincidence telescope, the extreme counters of which were argon ether filled. The counter under investigation was placed with its axis parallel and

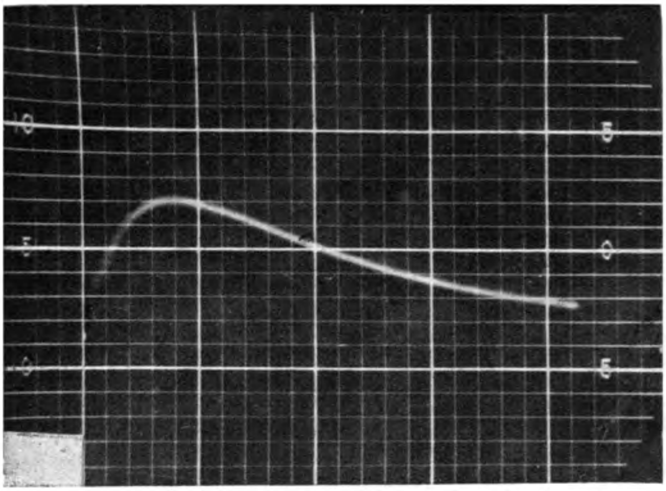

FIG. 6 (*a*). γ pulse in counter Br_3 from the cathode of 4 cm. length for spread velocity measurements. Overvoltage = 180 *V*, Marker = 0·2 microsec.

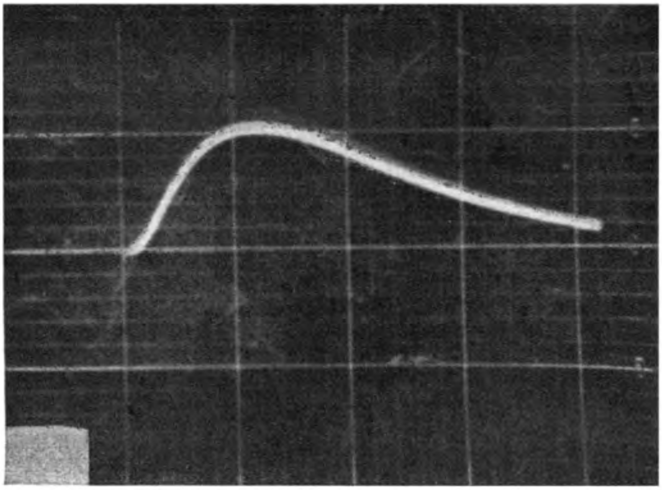

FIG. 6 (*b*). γ pulse in counter Br_3 from the cathode of 64 cm. length. Overvoltage = 180 *V*, Marker (small), 0·2 microsec. The difference in rise times gives the spreading time.

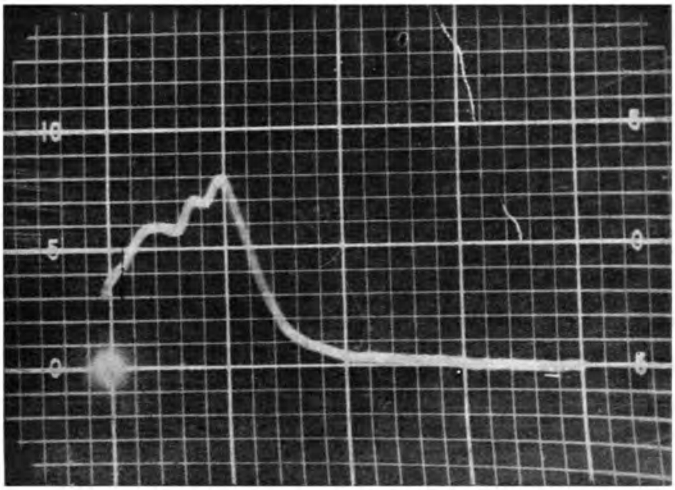

Fig. 12. Pulse at Geiger threshold. Gas filling: argon 20 cm., bromine 3 mm. Voltage = 840 V, RC = 0·32 microsec., Markers (small) = 2 microsec.

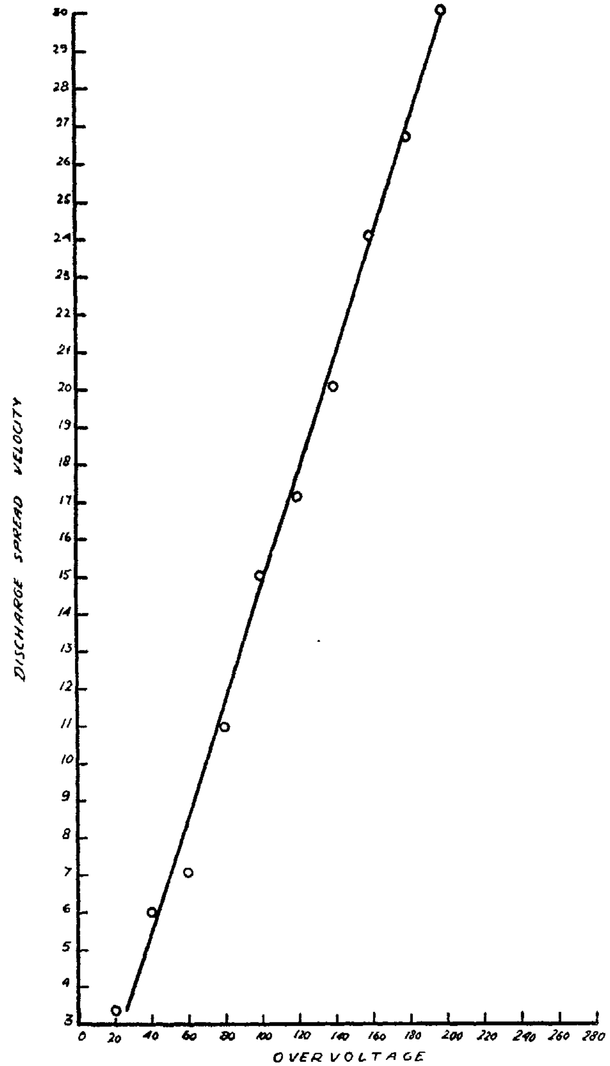

FIG. 7. Discharge spread velocity versus overvoltage for the counter Br_3.

vertically in between the other counters. The uncertainty in firing for the extreme counters is known to be of the order of 0·25 microsecond (Laufer, 1950). A coincidence circuit ($3{\cdot}5\times10^{-8}$ sec.) (Mandeville and Scherb, 1948), delivered the coincidence pulse of the extreme counters which triggered the sweep of the 329-A Dumont oscilloscope. The pulse from the bromine counter was displayed along the time base and photographed. A time scale was already preset so as to conveniently observe the pulse. The arrangement is sketched in Fig. 8.

The delay τ in microseconds versus the voltage applied gives a log-log fit. The delay denoted is the most probable one as adjudged visually otherwise it follows a distribution. The results are plotted in Fig. 9.

The same counter Br_4 is used for the measurement of the photon transit time across a dead space of 30 cm. by the synchroscope method, as it is expected to

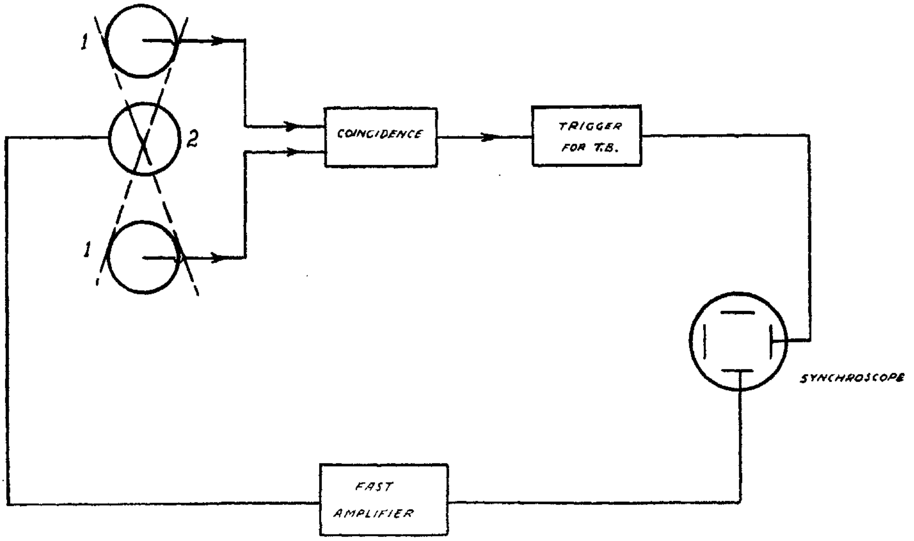

FIG. 8. Arrangement for measuring the formative time lag in the build up of pulse. 1—argon-petroleum ether filled counter; 2—halogen counter under investigation.

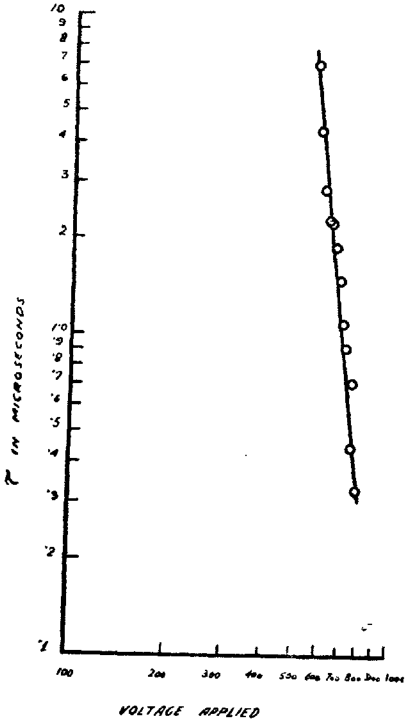

FIG. 9. Formative time lag in pulse build up versus voltage applied for the counter Br_4.

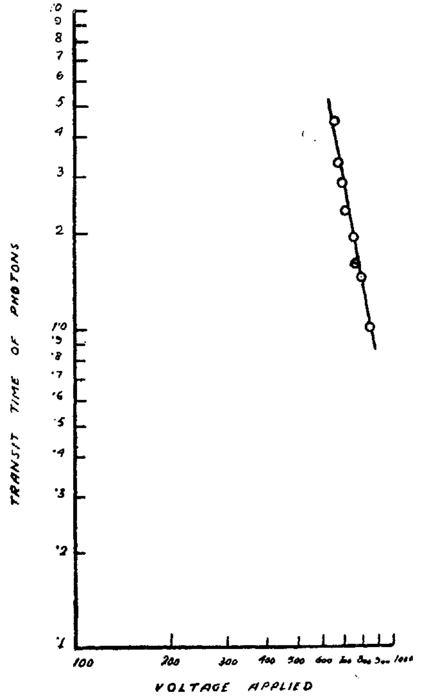

FIG. 10. Photon transit time across a dead space of 30 cm. versus voltage applied for the counter Br_4. The counter threshold shows a rise in threshold when the space intervening the true cathodes is earthed, which is due to circuit loading. Still the results are comparable at corresponding over-voltages.

yield decisive clue as to the carriers of discharge. The photon transit time versus voltage applied gives a linear log-log fit (Fig. 10) and the values correspond to those of the pulse build up. This clearly points out the rôle of photons as carriers, since the diffusion of metastables being a slow and diffuse process will require far greater time of transit.

7. TIME OF ASCENT OF THE LEADING EDGE OF THE PULSE

The pulse in the Geiger zone is contributed almost totally by the outward motion of the positive ions left by the space charge, the motion of the electrons having contributed little to the pulse since they were formed too close to the wire. The basic mechanism is the same as in the case of a proportional counter but for a finite time needed for the discharge to spread the length of the counter, but in halogen counters the spread velocity is relatively unimportant in determining pulse shape, since it is too high.

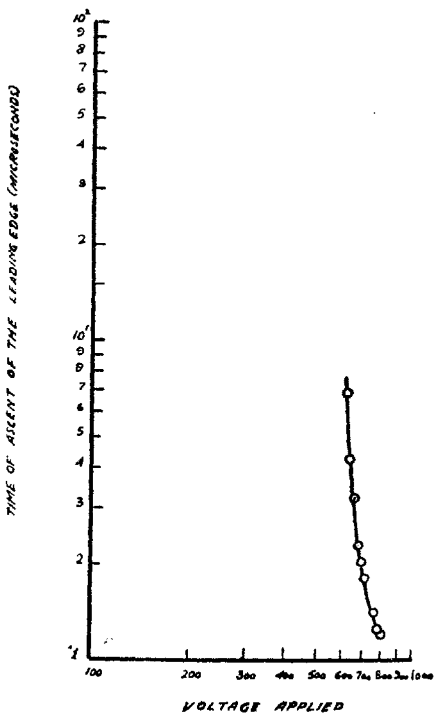

FIG. 11. Time of leading edge of the pulse in counter Br_5 as displayed on the synchroscope.

The time of ascent of the leading edge of the pulse in case of a counter Br_5 filled with 25 cm. of argon and 1 mm. of bromine was measured from patterns displayed on the oscilloscope. The values of the ascent times versus voltage applied are plotted in Fig. 11. The values seem comparable with the formative time lag for the build up of the pulse. Its value of a microsecond as compared to 10^{-7} second in case of argon-alcohol counters points out to the slower multiplication of the pulse.

8. Discussion: Secondary Mechanisms

The mechanism of delay in build up can only be decided from the secondary mechanisms which are operative in discharge between a positive wire and a cylinder. The incoming ionizing particle creates n electrons and ions near the outer cathode cylinder. Under the applied field the fine linear cloud crosses to the anode in a transit time τ_e. On its way each electron produces an avalanche of $M = \exp \int_b^a \alpha \, dr$ electrons where α is the first Townsend coefficient, r is the radial distance and a and b the radii of anode and cathode respectively. The electrons are pulled towards the anode and the space charge of positive ions is left by the avalanche in the vicinity of the anode. It is the outward motion of this positive ion sheath which induces a current flow from ground to cathode leading to an initial sharp pulse on the oscilloscope. This is the primary and triggering mechanism. The positive ions drift to the cathode in a time τ_i leading to a decline of the current pulse to zero on arrival. The avalanche of electrons, ions and excited molecules may result in any of the secondary mechanisms.

Positive ions on arrival at the cathode liberate electrons by virtue of their potential energy with a chance γ_i per ion. This mechanism is characterized by a succession of one or more secondary pulses following the primary one spaced τ_e and τ_i where τ_e and τ_i are the transit times of electron and ion respectively. As this total time ranges around 10^{-4} seconds and no such time correlation between individual events is evident (Fig. 12), this mechanism no longer remains plausible.

Secondary liberation by diffusion of metastable configurations to the cathode will be too slow and diffuse to be sharply well defined as borne out by the photograph. The possibility of negative ion formation by attachment of electrons to molecules is also ruled out altogether as it will lead to irregular delayed pulses between τ_e and τ_i in time.

Photons of sufficient energy which reach the cathode without resonance absorption liberate photo-electrons and this process is characterized by one or more secondary pulses spaced τ_e, or about a few microseconds at these low fields.

The presence of resonance radiation which suffers emission and re-emission through steps of a tenth of a mm. till emitted finally has been reported in rare gases (Dorgelo *et al.*, 1926). Holstein (1951) developed a theory of this process according to which the duration of this imprisonment process should be of the order of 10^{-5} to 10^{-4} seconds and must depend upon the diameter of the encasement. Alpert *et al.* (1949) found the time of decay of the resonance line 2537 Å in Hg vapour at densities around 10^{15} molecules per c.c. to be of the order of 10^{-4} second, a thousand times greater than the natural lifetime of an excited 6^3P_1 atom. Greater densities of gas concentration increase the decay time. This process does not seem to occur as it requires longer times.

The ascent time of the leading edge coincides with the formative time lag in the pulse build up at the corresponding overvoltages. Moreover, the separation between individual avalanches being also comparable at threshold, it points to the inevitable conclusion that it is the photoelectric emission which plays the rôle of secondary mechanism for discharge spread. The build up time is the true 'transit lag' due to the low mobility of electrons at these comparatively lower fields. No new mechanism need be invoked to explain these obvious disparities of behaviour of a low voltage halogen tube from the conventional one.

9. Conclusions

It is about a ten times greater pressure of alcohol than of the halogen which introduces these discrepancies of behaviour. The far less absorption of photons due to less amount of halogen gives rise to a longer mean free path (§ 4) which consequently explains the ineffectiveness of beads, larger output pulse and far greater discharge spread probability (§ 3). The propagation along the wire proceeds by liberation of electrons from the cathode and these greater discharge spread velocities are comprehensible (§ 5) as also consistent with the values reported in externally quenched counters. The formative time lags in the build up of pulse (§ 6) which range around a microsecond is due to the transit lag of the primary electrons whereas the longer ascent time of the leading edge of the pulse (§ 7) is due to the triggering mechanism which proceeds slowly.

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