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THE DISCHARGE MECHANISM OF SELF-QUENCHING G-M COUNTERS

by

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ABSTRACT

A split counter arrangement was used to investigate the absorption coefficient of the radiation which causes the discharge to spread along the wire of a counter after the triggering of a pulse. The counters used were filled with various pressures of methylene bromide and argon, and with ethyl alcohol and argon. The results indicated that the vapor dissipates electron energies, thereby reducing the number of photons produced during the discharge. It was also observed that the absorption coefficient was a function of the argon alone, from which it was concluded that photo-ionization of the argon was responsible for spreading the discharge along the wire. This behavior was also observed with helium and neon in combination with alcohol or methylene bromide.

THE DISCHARGE MECHANISM OF SELF-QUENCHING G-M COUNTERS

THE COUNTER

The Geiger-Mueller counter usually consists of a cylindrical cathode with a co-axial anode enclosed in a glass envelope and filled with a suitable gas (Figure 1). If a voltage of the order of 1000 volts is applied to the tube, the creation of a charged particle within the gas volume of the counter generates a series of electron avalanches in rapid succession and gives rise to a detectable voltage pulse in the anode or cathode circuit. This pulse may be amplified by conventional pulse amplifiers and made to actuate an impulse register or electrical counting system. The number of counts is proportional to the intensity of radiation when the tube is operated so that it returns to its initial state before the arrival of the next burst of primary ionization.

THE DISCHARGE MECHANISM

Counter operation may be divided into several categories depending on the field strengths, gas pressure, and type of gas. Figure 2 shows the amplification due to a constant source of radiation, as a function of the applied voltage in the circuit. In the first region the tube acts as an ionization chamber, where the output charge flowing through the resistor R is equal to the initial ionization produced by the incident radiation. The second region is called the proportional region. Here ionization processes start in the gas itself, and the output current is proportional to the initial ionization, but of greater magnitude.

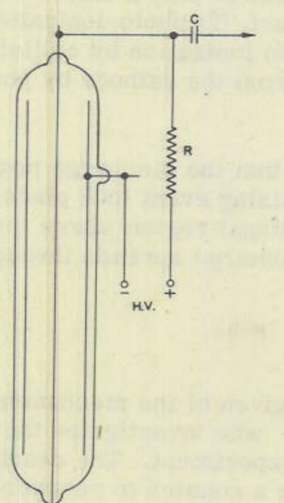

Fig. 1. Typical Geiger Counter

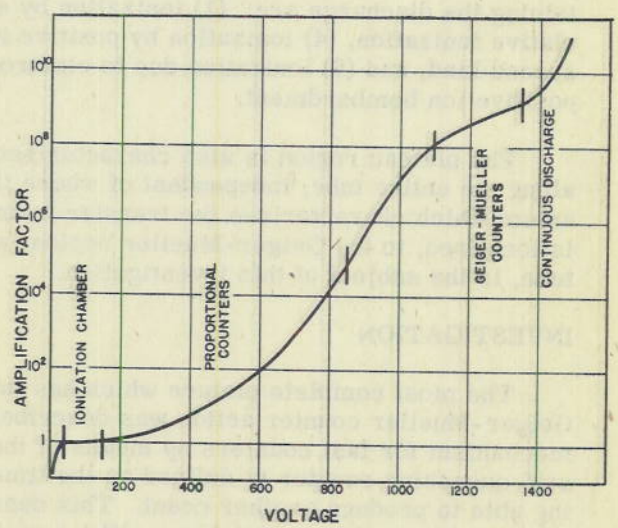

Fig. 2. Amplification Factor in a Tube Counter as a Function of Applied Voltage

For alpha particles the upper limit of the proportional amplification is about 10^4, and about 10^7 for beta particles. The next region is the Geiger-Mueller region, which is characterized by pulse size independent of the magnitude of the initial ionizing event. This region usually contains a plateau, a region wherein the number of counts does not vary much with change in voltage. The last region is a region where the counting rate increases rapidly due to spurious effects, and the tube tends to go over into a self-sustained corona discharge

A further distinction is made according to the types of filler gas used. A counter operating in the Geiger-Mueller, or plateau region, has its discharge halted, or quenched, in "slow" counters, by the combined effects of the resistance in series with the anode or cathode, and by positive ion space charge. The resistance and counter capacity act to hold the voltage on the wire below threshold until the tube is de-ionized. In "fast" counters, first investigated by Trost, [1], the primary quenching agent consists of the ion cloud formed near the anode, which lowers the field of the tube to the point where the discharge may no longer continue (See Reference 2, 3, and 4). The major difference in action between the fast counter and the slow counter is assumed by Montgomery and Montgomery [2] to result from the fact that in the fast counter there are no secondary electrons emitted from the cathode after the discharge. Such secondaries would regenerate new avalanches and tend to maintain the discharge. The suppression of secondary emission in a fast counter is accomplished by the addition of a trace of organic vapor. Without the organic vapor present in fast counters, it is supposed that secondary electrons produced at the cathode prolong the discharge until a statistical fluctuation in secondary emission and space charge combine to break off the discharge.

The advantage of the fast counter over that of the pure gas counter is its greater resolving power. A fast counter is capable of counting thousands of ionizations per second, whereas, with the use of special circuits, the slow counter is limited to several hundred counts per second.

In the plateau region, the ionization processes assumed to play a major role in maintaining the discharge are: (1) ionization by electron impact, (2) photo-ionization, (3) cumulative ionization, (4) ionization by positive ion impact, (5) ionization by collisions of the second kind, and (6) ionization due to electrons emitted from the cathode by photons or positive ion bombardment.

The plateau region is also characterized by the fact that the discharge now spreads along the entire tube, independent of where the initial ionizing event took place. The mechanism which characterizes the transfer from the proportional region where the discharge is localized, to the Geiger-Mueller region, where the discharge spreads throughout the tube, is the subject of this investigation.

INVESTIGATION

The most complete picture which has thus far been given of the mechanism of fast Geiger-Mueller counter action was described by Stever[3] who investigated the discharge mechanism for fast counters by means of the deadtime experiment. The deadtime of a self-quenching counter is defined as the time it takes for a counter to recover before being able to produce another count. This deadtime is usually about 100 microseconds, and may be observed on a suitable oscilloscope of the self-synchronizing type, when many pulses are superimposed. Stever attempted to develop a theory which would explain the appearance of the pulses in the deadtime experiment with emphasis placed on (1) the rapid breakdown time of less than 10 microseconds, (2) the deadtime, and (3) the building up in pulse size from the end of the deadtime period to the point where pulses recover to the initial size. In developing his theory, he assumed that the discharge had spread through the tube, after which the space charge developed around the wire in the form of a positive ion sheath, reducing the field at the wire and quenching the discharge. The space charge was then drawn to the cathode by the action of the electric field, till a point was reached where a counting field was once more established at the wire. The counter could then respond once more to ionization and yield a counting pulse, though of lower magnitude, because of the space charge still remaining within the tube. As the space charge moved out towards the cathode, the ionizations which occurred subsequent to the initial discharge became larger and larger, until, when the ion sheath had reached the cathode walls, the field was completely established at the wire, and full sized pulses appeared once more. The recovery time was calculated theoretically and shown to be equal to

$$t_r = \frac{(b^2 - R^2)(p/p_0)\log b/a}{2KV} \tag{1}$$

where a and b are the wire and cathode radii respectively, R is the critical distance to which the sheath must move before a counting field is once more established at the wire, K is the mobility at atmospheric pressure, p/p_0 is the ratio of the pressure in the counter to atmospheric pressure, and V is the effective potential across the counter, including the effects of space-charge. Also, according to the theory, R may be approximated by

$$R = be^{-\frac{Vu}{2q}} \tag{2}$$

where V_u is the difference between the operating voltage and threshold, called the overvoltage, and q is the positive ion space-charge per unit length. The experimental verification of these formulae established the validity of the theory. One further observation made by Stever, to be discussed shortly, was that the discharge was localized in the region around the wire. Korff and Present [4] extended Stever's hypotheses by suggesting that the polyatomic gas served to (1) quench ultraviolet photons, and (2) quench secondary emission by positive ions reaching the cathode, an hypothesis included in the earlier work of Montgomery and Montgomery [2]. The quenching of ultraviolet photons in the initial avalanche was assumed to be due to photodecomposition of the polyatomic gas by the photons emitted from the excited monatomic gas. The polyatomic molecules used in counters have a lower ionization potential than the pure gas composing the remainder of the filler. Since the positive ions make about 10^5 collisions in crossing the counter, the electron transfer probability from the vapor to the monatomic gas is so high that the sheath reaching the cathode wall is composed almost entirely of polyatomic ions. On the basis of work done by Oliphant and Moon (See Reference 5, 6) and Massey [7], Korff and Present indicated that secondary emission from the cathode wall was very much less likely by a polyatomic ion than a monatomic ion. Previously, Rose and Korff [8] had pointed out that there would be some quenching of the production of photons in the inelastic collisions of electrons with methane molecules, in proportional counters, dissipating the energy of the electrons by rotational and vibrational excitation of the molecule. However, Korff and Present [4] believed that this was not the most important factor, since the greatest multiplication takes place in the high field region near the wire where the electrons gain enough energy in one free path to excite or ionize the monatomic gas.

Spatz [9] showed that during use, the pressure within the counter increased due to decomposition of the organic vapor. Accordingly, counters have operating lifetimes limited by this decomposition.

The object of this investigation was to study through controlled conditions, the mechanism for the spread of the discharge along the length of the wire, when the Geiger-Mueller counting region had been reached. The processes of the discharge in the counter tube may be broken down into three phases. The first phase is the ionization chamber and proportional counting region where the pulse size is proportional to the number of initial ionizing events. The main factor here in producing the discharge is the ionization by electron impact, leading to the formation of a Townsend Avalanche[8]. The second stage of the discharge, the Geiger-Mueller region is characterized by the spread of the discharge along the length of the tube by a process previously shown to be photoelectric in nature [10,11]. This process is supposed to depend on the excitation of certain spectral lines of the gas at a given field strength corresponding to the threshold voltage[12]. This region is also characterized by the self-quenching process resulting from the reduction of the field at the anode by the ion sheath [2,3]. The third phase is that of the continuous corona discharge in which the field strength is such that the discharge is not quenched [13].

Several experiments have been conducted to determine the mechanism for the spread of the discharge. Greiner's experiments [11] on slow counters came closest to the intent of this investigation. Greiner used two counters facing each other, in a common envelope. The anodes were separated at a fixed distance of about 1 centimeter. He then measured the number of counts that originated in one counter and spread across to the other, at different pressures. By means of these measurements he was able to deduce absorption coefficients for different gases. That the discharge was caused by photon absorption was proven by the use of celluloid films, the thinnest (20 $m\mu$) of which allowed the discharge to propagate. The most plausible explanation for the discharge spread across the foil was photoemission in the second counter. In another experiment, when insulating beads of different thicknesses and diameters were placed on the anode, it was found that the discharge was localized between the beads[14] In still another experiment conducted by Ramsey, two adjacent slow counters were triggered coincidentally when the discharge was initiated in one of the counters [15], but discharged randomly when a self-quenching gas mixture was used. A similar type of experiment was performed by Curran and Strothers [16] The arrangement in both experiments were such as to minimize the possibility that the discharge was being initiated by any mechanism other than photons. A further set of interesting experiments were performed by Stever [3] following experiments by Prof. Brode of the University of California. Stever performed experiments with divided cylinders and beads on wires. In one most suggestive experiment, a glass bead on a wire served to stop the discharge spread at low values of E/p, but did not hinder the discharge at large values of E/p, where E is the field strength and p is the pressure. This was interpreted to mean that the radius corresponding to the critical value of E/p was pushed out till the bead was well enclosed within it, and the discharge could then spread. This ruled out localization of the discharge at the surface of the wire, and indicated a mechanism in the gas at the critical value of E/p. In another paper Stever[17] used the divided counter as a counter telescope where separate ionizing events were necessary in each segment to cause the segment to count. Other localization effects have been studied by investigators who used divided cathode cylinders with different voltages on each segment [18] The effectiveness of insulating beads in stopping the discharge from spreading was attributed by Wilkening and Kanne[14] to a combination of reduction of field intensity through accumulation of charge on the insulators as well as to photon absorption by the vapor. Their results were interpreted to mean that the photon absorption in the gas is complete within a few electron mean free paths.

THEORETICAL DETERMINATION OF ABSORPTION COEFFICIENT AND NUMBER OF PHOTONS

In order to measure the absorption coefficient for the discharge process a double counter arrangement was used. One of the counters could be moved along its axis with respect to the other, in the same glass enclosure (Figure 3). The electronic circuits were so designed that a count could be kept of all discharges which spread from one counter to the other. Assuming an absorption to take place, the probability of discharge spread will be a function of the total amount of intervening gas, or what amounts to the same thing, the probability of spread will depend on the constitution of the gas mixture, the distance between the counters, and the pressure. Since the charge per unit length of a counter is a constant, those discharges which spread across the intervening tap, appear as pulses twice the size of those which develop in one of the counters (Figure 4).

The ratio of the number of large (double-sized) pulses to total pulses determines, w the probability for spread of the discharge. In subsequent paragraphs it will be shown how this measurement can determine both the absorption coefficient, μ , and the total number of photo-ionizations per unit length of the wire responsible for the spread of the discharge. Knowing the number of ions per unit length per discharge, it then becomes possible to determine the kumber of photo-ionizations produced per ion in the discharge.

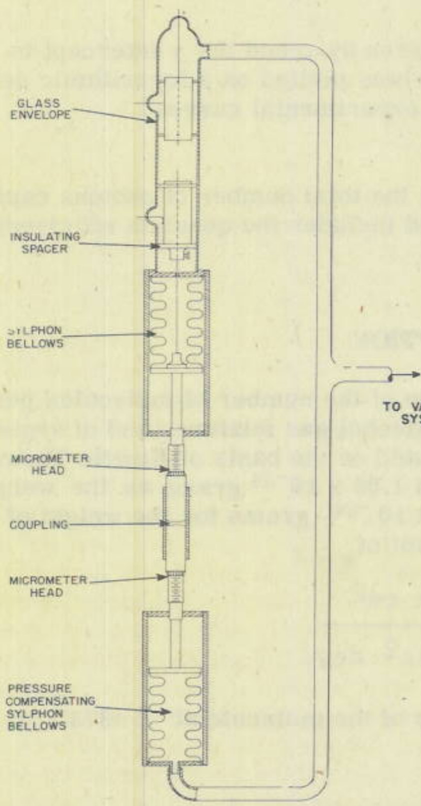

Fig. 3. The Movable Double Counter

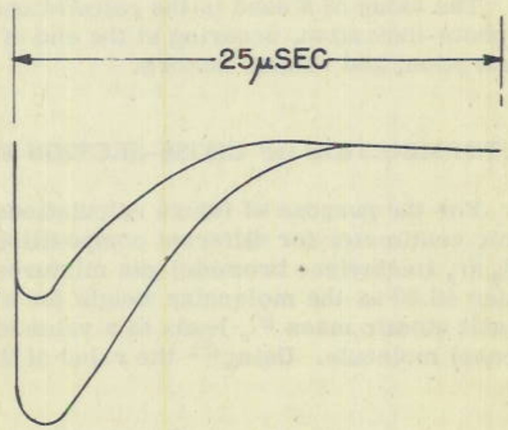

Fig. 4. Appearance of Single and Double Sized Pulses from Split Counters

The absorption coefficient may be determined in the following manner: If $e^{-\mu x}$ is the probability that a quantum appearing at the end of one counter wire will traverse a distance, x then, $1-e^{-ux}$ is the probability that a quantum will not pass through that distance. The probability that all of N quanta will be absorbed is $(1-e^{-ux})^N$ It follows, therefore, that

$$w = 1 - (1 - e^{-\mu x})^N$$

where w is the probability that one or more will not be absorbed, and N represents number of effective photons, or those producing counts.

If the value of x is large, eauation (3) may be simplified to (3)

$$w = 1 - e^{-Ne^{-\mu x}} \tag{4}$$

is the probability for a discharge to occur at large distances of x. If the logarithm of equation (4) is taken, there results:

$$\log\left[- \log(1 - w) \right] = \log N - \mu x. \tag{5}$$

This is the equation of a straight line whose slope is given by $-\mu$ and the y intercept is given by log N. To determine μ, the logarithm of $(1-w)$ was plotted on a logarithmic scale as a function of x, and the slope determined from the experimental curves.

The value of N used in the calculations represents the total number of photons capable of photo-ionization, occuring at the end of the wire, and includes the quantum efficiency, absorption, and related factors.

DETERMINATION OF CROSS-SECTION FOR ABSORPTION

For the purpose of future calculations, a tabulation of the number of molecules per cubic centimeter for different compositions of argon-alcohol gas mixtures and of argon - CH_2Br_2 (methylene bromide) gas mixtures, was computed on the basis of Kinetic Theory. Using 46.07 as the molecular weight for alcohol [19] and 1.66 x 10^{-24} grams as the weight of unit atomic mass [20], leads to a value of m = 76.48 x 10^{-24} grams for the weight of an alcohol molecule. Using [21] the value of the gas constant of

$$R = 1.372 \times 10^{-16} \frac{gm\ cm^2}{sec^2\ deg.}$$

there may be obtained a value of $\overline{C}$, the mean velocity of the molecule at $T = 373°K$, from,

$$\overline{C} = \frac{1}{1.086}\sqrt{\frac{3RT}{m}} \tag{6}$$

Substituting this value in the viscosity formula

$$K = 0.499 \frac{m \overline{C}}{\sigma^2 \pi \sqrt{2}} \tag{7}$$

where K is the viscosity and σ is the effective molecular diameter of alcohol, gives a value for σ of 5.73 x 10^{-8} cm where the value of K was taken as 108 x 10^{-6} poises[22].

Knowing the value of Sutherland's constant for alcohol[21], C = 525, and using Sutherland's formula

$$\sigma^2 = \sigma_\infty^2 \left(1 + \frac{C}{T}\right) \tag{8}$$

the molecular cross-section at 20° C, is σ = 6.16x10^{-8}cm. Using Jeans[21] values for Argon of σ = 3.66 x 10^{-8}cm at 0° C and C = 169.9, the cross-section of the Argon atom is found to be 3.59 x 10^{-8} centimeters. The number of molecules per unit volume at 1-centimeter pressure and at 20° C is given by

$$n = \frac{p}{p_{std}} \cdot \frac{T_{std}}{T} \cdot \frac{N_1}{m} \cdot \rho_{std} \tag{9}$$

where p is the pressure, the subscript "std" meaning at standard conditions, N_1 = 6.023 x 10^{23} being Avogadro's number, and ρ_{std} being the density at standard conditions. The density of Argon[23] is 1.7837 grams per liter at 0° C and 760 mm pressure, and the density of alcohol vapor[24] is 0.00164 at 78.3° C and atmospheric pressure. This leads to a value of 32.5 x 10^{16} for the number of argon atoms per cubic centimeter at 20° C and 1-centimeter pressure and 34 x 10^{16} for alcohol vapor.

For methylene bromide, CH_2Br_2, of molecular weight 173.86, no information was available on either density or viscosity of the vapor. An approximate value for the viscosity of 200 x 10^{-6} poises was assumed which is about the order of magnitude of the viscosity of similar molecules. From equations (6) and (7) a value of 5.5 x 10^{-8} cm is obtained for the effective molecular diameter. The density of the vapor is determined from the fact that 22.4 liters of a gas at standard conditions (atmospheric pressure and 0° C) contain one mole of the gas (6.023 x 10^{23} molecules). This gives a value of 3.3 x 10^{17} molecules per cubic centimeter at 1-cm pressure and 20° C. From the data given, Table I was computed for the electron free paths in different percentages of vapor and gas at 10 centimeters total pressure.

The cross-section for photon absorption is defined by

$$\mu = N\pi\left(\frac{\sigma}{2}\right)^2 \tag{10}$$

where μ is the absorption coefficient (cm^{-1}), N is the number of molecules per cubic centimeter, and σ is the effective atomic cross-section. This was used to calculate the cross-sections for absorption from the experimental measurements.

TABLE I

Electron Free Paths in Vapor-Gas Mixtures
20° C and 10 cm Total Pressure

Argon Partial Pressure (cm of Hg)	Electron Free Path in Alcohol-Argon (cm)	Electron Free Path in Methylene Bromide - Argon (cm)
10	30.7×10^{-5}	30.7×10^{-5}
9	26.2	26.9
8	22.9	23.9
7	20.4	21.5
6	18.3	19.5
5	16.6	17.9
4	15.2	16.5
3	14.1	15.4
2	13.1	14.3
1	12.2	13.1
0	11.4	12.6

DESCRIPTION OF EQUIPMENT

The moveable split counter was constructed of brass cylinders (Figure 3) 5-cm long and 2.07-cm diameter, mounted in a pyrex glass envelope with tungsten seals. The anodes were 0.031-inch diameter tungsten wire, one of which was sealed directly to the pyrex envelope, and the other attached to a sylphon bellows and micrometer screw arrangement moving in a vacuum-tight brass housing to minimize side motion of the wire. The bottom cathode was moveable through the same bellows. The brass housing was sealed to the pyrex envelope with a minimum of de Khotinsky Cement. It was found necessary to provide another sylphon bellows system, operating by means of a coupling shaft to the counter, so that the pressure was maintained constant, i.e., when the bellows in the counter was compressed, the compensating bellows expanded. The glass envelope was cleaned with chromic acid and thoroughly rinsed with distilled water, and the metal parts were cleaned in a caustic solution before assembly. The tungsten wires were mechanically polished, and the ends carefully rounded. The ends of the wires extended 0.150 inches beyond the associated cathode cylinders, the criterion for this distance being determined in the following manner: After each wire had been mechanically polished and rounded, it was inserted in a counter on the sylphon system in such a manner that the end of the wires could be moved along the axis out beyond the cylinder by about 1/2 inch, or withdrawn into the cylinder by about 1/4 inch. The field at the end of the wire was considerably higher inside the cylinder than it was outside the cylinder. In operation as a counter, the field at the tip of the wire determined the threshold when the wire was within the cylinder, but the concentric field along the wire determined the threshold when the end of the wire extended well beyond the cylinder. Therefore, in order to insure a uniform field along the entire length of the wire, the threshold voltage was plotted for each wire as a function of its distance from the end of the cylinder, and that distance beyond which the threshold did not change, was chosen as the minimum distance which gave uniform field along the entire length of the wire.

It was observed during initial experimentation that the counter glass wall charged up in the region between the counters, and affected the field at the ends of the wires. In order to eliminate this disturbance and to provide a constant potential surface an Aquadag coating was applied to the outside of the glass and grounded to the cathode through 200 volts positive with respect to the cathode. The positive voltage effectively prevented the accumulation of positive ions on the walls of the tube. Spurious effects of this nature produced large numbers of counts in the absorption measurements, made at small cathode separations. Whether or not these counts were due to phenomena associated with leakage from the glass envelope or related effects on the electric field at the wire could not be ascertained. More of this will be discussed in the section on measurement of the increase of production of photons.

To eliminate spurious effects in the determination of charge per pulse, the presence of occasional point discharges and errors in resetting the micrometers, measurements of plateau, charge per pulse, photon production, and derived quantities were made on a counter tube of the same general dimensions as the moveable counter tube, except that a fixed distance between cathodes of 1.4 centimeters was employed, and the inner wires were continuous through the tube.

Figure 5 shows the measuring circuits associated with counting the pulses for absorption measurements. The output pulse voltage across resistance R is fed through a condenser to a cathode follower circuit consisting of a type 954 pentode acorn tube, with plate and screen tied together. A low valve of grid leak (10,000 Ohms) is used in conjunction with a $50\mu\mu f$ coupling condenser to differentiate the pulses, thereby accentuating changes in pulse shape. The purpose of the cathode follower was to isolate the counter

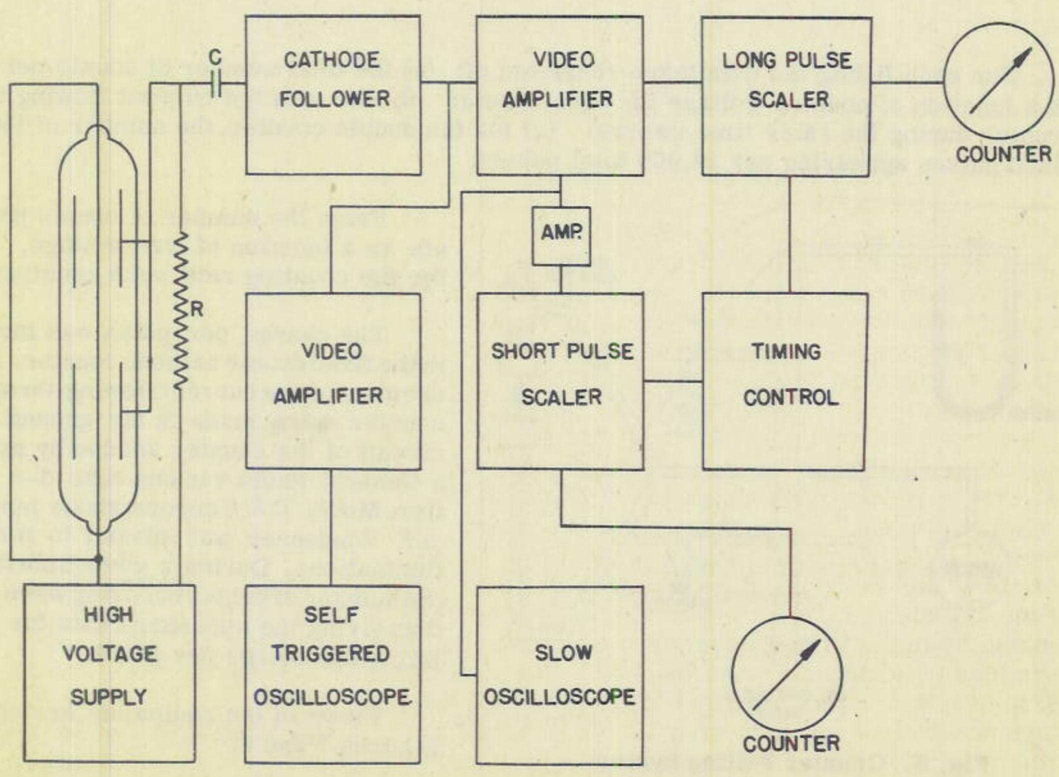

Fig. 5. Schematic of Double Counter Analyzing Equipment

tube from external circuits by virtue of the high input impedance typical of cathode followers, in addition to providing a low-impedance output for the input circuits of the two video amplifiers. One of the video amplifiers was used to amplify the signals which were fed to a self-triggered oscilloscope with sweep times of 5, 25, 100 and 500 microseconds. This served as a monitoring oscilloscope to indicate the shape and characteristics of the Geiger-counter pulses. The band pass of the video amplifier was roughly 100 cycles per second to 4 megacycles per second. The other amplifier output was connected to a commercial type oscilloscope and to the input circuits of two scaler units. The oscilloscope was used to monitor the scaler inputs. The scalers were conventional Eccles-Jordon type scale of two multivibrators, 1 output pulse to every 16 input pulses. Mechanical-impulse recorders were connected to the thyratron used as output tube from each scaler. One of the scalers was supplied with an additional amplifier tube with adjustable gain, so that all pulses would register. The gain of the video amplifier was adjusted simultaneously so that only the large pulses, those which propagated across the gap, could register on one of the recorders. A mechanical timing control was connected to the scalers, so that the total number of large pulses, as well as the total number of pulses, could be recorded in the same time interval on the other recorder.

Figure 6 shows the filling system used for the counters. The procedure used for filling the counters was standardized in the following manner: For methylene bromide vapor, the mechanical gage was used, allowing the vapor pressure to reach 2.5 centimeters, then closing the vapor stopcock and admitting argon from a flask of spectroscopic argon until the total pressure gave the desired percentage. After a day of diffusion, the system was pumped down to the pressure used for the tests. For alcohol vapor, the same method was used but an oil monometer was used to indicate vapor pressure.

For each filling the data taken consisted of: (a) the total number of counts per minute as a function of counter voltage for each counter (b) the average current flowing to the counter during the same time interval (c) for the double counter, the number of double-sized pulses appearing per 16,000 total pulses.

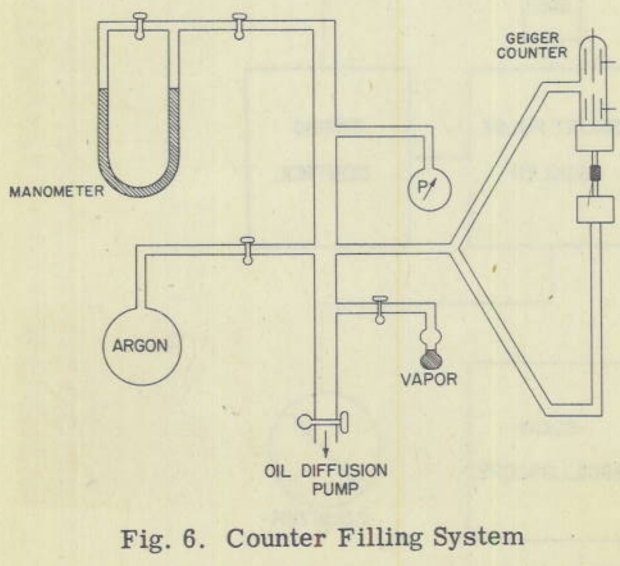

Fig. 6. Counter Filling System

From the number of counts per minute as a function of overvoltage, curves for the counting rate were constructed.

The charge per pulse was measured in the fixed double cathode counter. Measurement of the current flowing through the counter were made in the ground return circuit of the counter anodes by means of a General Radio vacuum tube d-c amplifier, Model 715 A across whose input a 20 μf condenser was placed to minimize fluctuations. During a given time interval the number of pulses occuring were counted thus giving the necessary data for calculating the charge per pulse.

Views of the equipment are shown in Figures 7 and 8.

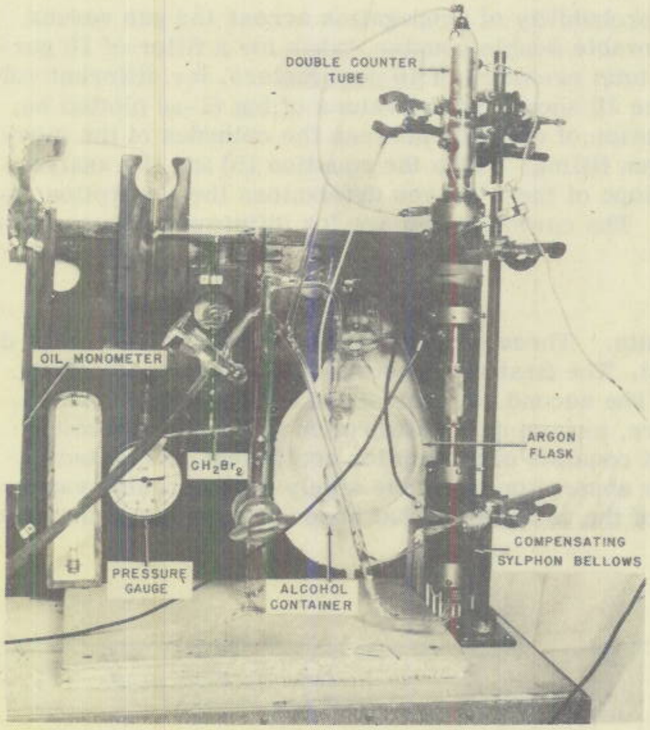

Fig. 7. View of Vacuum System and Movable Counter

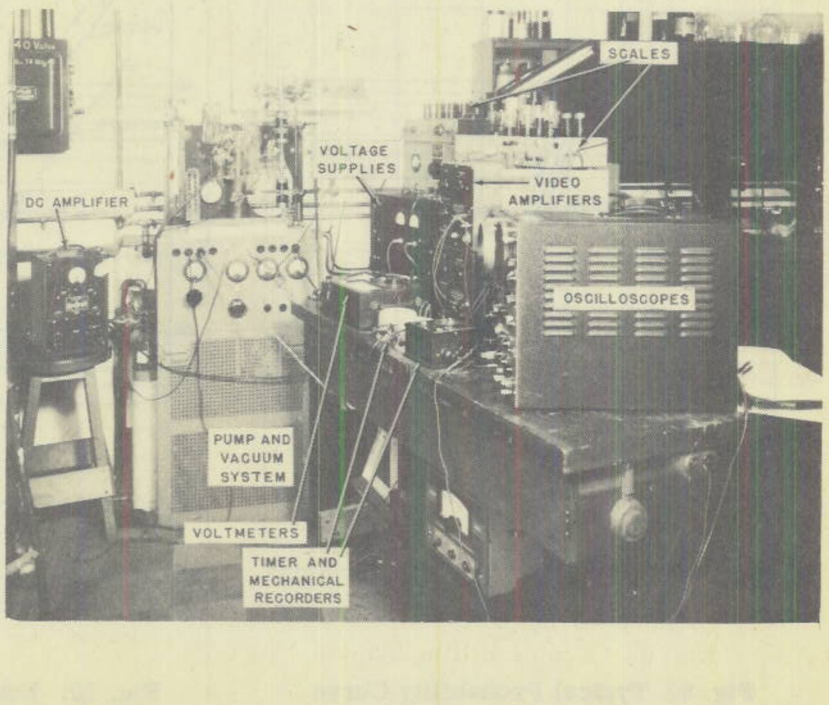

Fig. 8. View of Entire Equipment

ANALYSIS OF DATA

Figure 9 shows a typical curve of probability of propagation across the gas versus distance between the cathodes of the movable double counter, taken for a filler of 10 percent CH_2Br_2 and 90 percent argon at a total pressure of 10 centimeters, for different voltages between anode and cathode. Figure 10 shows typical values of log (1-w) plotted on semi-logarithmic graph paper as a function of distance between the cathodes of the movable counter system for an alcohol-argon filling. From the equation (5) and the analysis following it, it is easily seen that the slope of these curves determines the absorption coefficient for the spreading mechanism. The curves shown are for different voltages in the Geiger-Mueller region.

Table II is compiled from the results. Three sets of absorption coefficients were determined from the curves and tabulated. The first set consists of measurements of the slope taken directly from the curves. The second set consists of absorption coefficient, corrected to one-centimeter of pressure, assuming the absorption to be due only to the amount of argon present. The third set consists of absorption coefficient, corrected to one-centimeter pressure, assuming the absorption to be due solely to the organic vapor. The data are overwhelmingly in favor of the assumption that absorption is due to the argon alone.

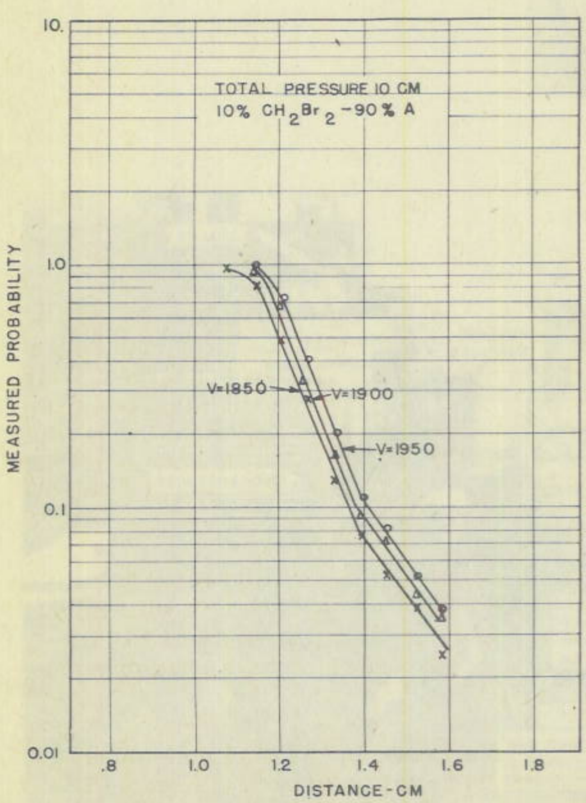

Fig. 9. Typical Probability Curve

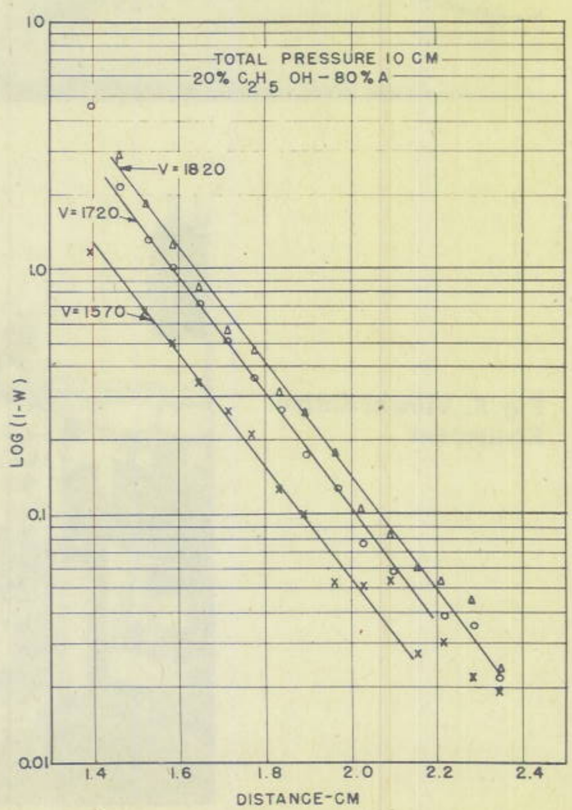

Fig. 10. Log (1-w) Absorption Curve

TABLE II

MEASURED ABSORPTION COEFFICIENTS

Pressure	Vapor Filler		From Curves		Corrected Values for 1-cm Argon		Coefficients Assuming Vapor Absorption for 1-cm Vapor	
(cm of Hg)	Vapor	(%)	μ_1	μ_2	μ_{1A}	μ_{2A}	μ_{1B}	μ_{2B}
5	CH_2Br_2	10	7.0		1.25		14	
5	CH_2Br_2	20	5.2		1.73		5.2	
10	CH_2Br_2	4	13.5	5.8	1.41	0.6	33.7	15
10	CH_2Br_2	10	11.5	6.4	1.28	0.71	11.5	6.4
10	CH_2Br_2	20	12.1	5.5	1.51	0.68	6.1	2.8
20	CH_2Br_2	10	23		1.28		11.5	
10	C_2H_5OH	5		3.83*				
10	C_2H_5OH	10		5.8		0.64		5.8
10	C_2H_5OH	20		5.4		0.67		2.7
10	C_2H_5OH	30		5.8		0.83		1.6
20	C_2H_5OH	5		3.5*				

*Low percentage of alcohol encourages spurious effects on walls of counter and does not permit accurate measurements.

Weighted Average of $\mu_{1A} = 1.35$; $\mu_{2A} = 0.65$

The following conclusions may be drawn from these data:

1. The absorption is constant, depending only on the amount of argon present.

2. There are two different absorption constants which indicate two different types of photons. At various percentages of CH_2Br_2 at 10-centimeter total pressures both coefficients show clearly. In alcohol-argon mixtures only one coefficient was observed, from which it is concluded that the separation used during measurements is such that one of the photons has been almost completely absorbed when the separation is sufficient for readings to be taken. The larger value of the absorption coefficient is probably characteristic of the higher energy photon because this coefficient appeared more prominently as the voltage was increased.

3. From the shapes of the curves and their intersections with the log $(1-w)$ axis, it appears that the number of effective photons increases with voltage, which is what might be expected. As will be shown later, the function of the filler vapor seems to be to inhibit the production of photons in the discharge rather than absorb them, as had previously been thought.

The corrected values of μ shown in Table II were obtained by dividing the values of μ_1 and μ_2 obtained from the curves by the associated partial pressures of argon. The weighted values were obtained by estimating the accuracy of each set of readings, assigning relative weighting factors to each, and averaging the results. When alcohol was used as a filler, as mentioned earlier, the spurious effects due to charging of the glass walls or to phenomena attributed to the field between the cathodes, caused triggering action from one tube to the other. The poor results obtained with the five-percent alcohol mixtures are in accord with results of Wilkening and Kanne[14] who found that counters made with less than five-percent alcohol showed almost no localization effects.

The absorption measurements were repeated with fillings of neon-methylene bromide and helium-methylene bromide. The results with these mixtures verified the conclusions that the absorption coefficient is a function of the rare gas alone. For a ten-percent methylene bromide-argon mixture at 10-centimeter pressure, the coefficient of absorption was 0.93 per centimeter, corresponding to a coefficient of 0.1 per centimeter for neon at a pressure of one centimeter of mercury. For helium, the coefficient was so small that accurate determination of the slope was not feasible.

It can be assumed that the various errors involved in counting, filling to the correct pressure, and measurement of slope, are sufficient to account for the minor variations observed in both the absorption coefficients listed in Table II. Figure 11 depicts one type of error in counting rate that affects the results for large vapor percentages. These drawings were made for small values of over-voltage, about 10 volts. The production of photons, as will be explained later, was so inhibited, that many of the pulses did not develop properly and did not permit a clear discrimination between single counter pulses and those which originated in one tube and spread to the other. That the geometrical arrangement did not introduce appreciable error in the measurements may be concluded from the fact that the curves in general show the same slope in spite of the different distances used, and that the slopes of the 5-, 10-, and 20-centimeter total pressure, absorption curves yielded the same values of the absorption coefficient.

Measurements made on methylene bromide were based on a counting rate of about 20 per second, and a total count of about 10,000 counts, in order to minimize errors due to resolving time and to limit the standard deviation of counts per second to about one percent. Measurements made on the alcohol counters were not as accurate and, in general, were conducted only as a control experiment to support the results obtained with methylene bromide.

After considering all possible sources of error it is quite evident from the results that the absorption coefficient is not a function of the amount of vapor present.

Using formula (10), and inserting a value of $\mu = 1.35/cm$ for one absorption coefficient, and $\mu = 0.65/cm$ for the other absorption coefficient, the resulting values for the atomic cross-section of argon for the two types of photons are

$$\sigma_{1.35} = 0.23 \times 10^{-8}\ cm$$

and

$$\sigma_{.65} = 0.16 \times 10^{-8}\ cm$$

PHOTON INCREASE MEASUREMENTS

Equation (4) demonstrates that the experiment is well suited for the determination of N, the number of photons causing a photoelectric effect in the gas, if cathode phenomena are omitted. Equation (4), rewritten

$$\log (1-w) = -AN \qquad (11)$$

indicates that for a fixed separation between counter cathodes, e^{-ux} is a constant, A, and

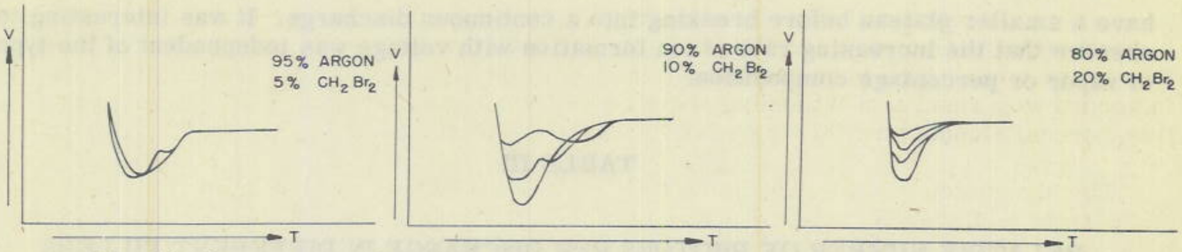

Fig. 11. Appearance of Pulses at Low Overvoltages for Different Gas-Vapor Pressures at Total of 10 Centimeters

log (1-w) is directly proportional to the number of effective photoelectrons. Accordingly probability measurements were made on the double counter with fixed separation of 1.4-centimeters as the voltage was increased throughout the plateau region. Included with every run were measurements made of the average current flowing through one of the counters and the plateau. Preliminary investigations showed that both counters were sufficiently alike to provide similar curves for plateau and charge per pulse, as derived from the average current readings. Typical results are shown graphically in Figure 12. The data in Table III clearly show the effect of the vapor on the number of photons available to propagate the discharge. Here again, as for the absorption measurements, more accurate data were taken with the methylene bromide. The ionization data were obtained by measuring the average current flowing through the counter while the counts were being recorded, and converted to ions per centimeter per discharge by dividing the charge per count obtained on one counter by 5.5 centimeters, 0.5-centimeters allowance being made for end effects. In the data, the separation of the counters is such that only the μ = .65/cm type of photon is involved. It may be seen that more photons were produced in alcohol-argon mixtures than in equivalent proportions of methylene bromide-argon mixtures. If the transition from the proportional region to the plateau region depends on the number of photons available for propagating the discharge, then the results indicate that alcohol-argon counters should have lower thresholds, which is in agreement with observation. This was also borne out by the greater slope of photon increase in alcohol-argon counters. This greater increase of slope presumably also has a bearing on the fact that alcohol-argon counters

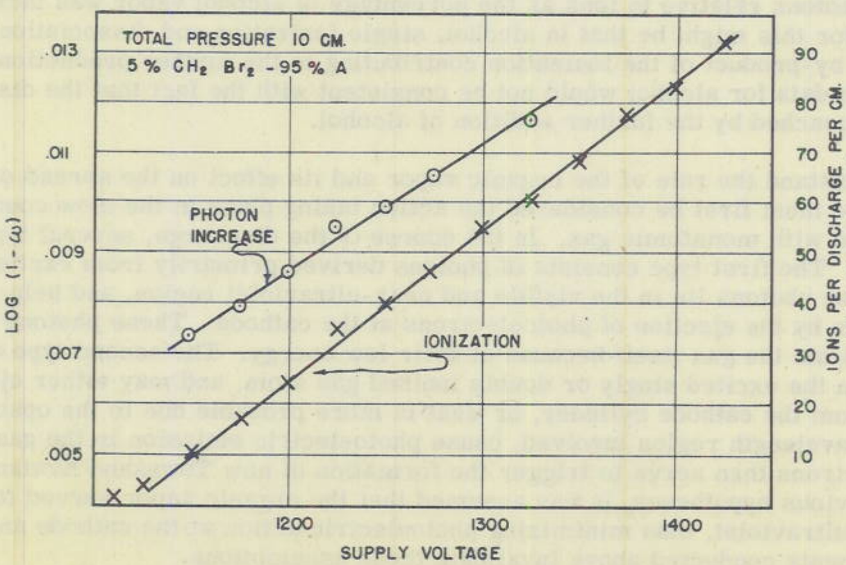

Fig. 12. Increase of Photons and Ionization with Voltage

have a smaller plateau before breaking into a continuous discharge. It was interesting to observe that the increasing rate of ion formation with voltage was independent of the type of vapor or percentage composition.

TABLE III

RELATIVE NUMBER OF PHOTONS PER DISCHARGE IN DIFFERENT FILLERS
- MEASURED AT OVERVOLTAGE OF 100 VOLTS -

Pressure (cm)	Percent Vapor (%)	Relative No. of Photons		Relative No. Photons Per Ion	
		C_2H_5OH	CH_2Br_2	C_2H_5OH	CH_2Br_2
5	5		.0165		35
5	10		.012		28
5	20		.008		12
10	5		.0091		30
10	10	.017	.008	45	24
10	20	.023	.0064	43	19
10	30	.036		110	

From the results it was also interesting to note that in the case of the methylene bromide filler, the slope of the photon increase with voltage decreased as the percentage of vapor is increased. A possible explanation of this is that a greater number of electrons lose energy by impact with the organic vapor molecule, which has a lower ionization potential than that of the argon, thus allowing fewer electrons to possess sufficient energy for ionization of the argon atom.

The data for alcohol-argon mixtures on the other hand, showed an increase in the number of photons relative to ions as the percentage of alcohol vapor was increased. The explanation for this might be that in alcohol, single ionization and dissociation occur, with the electron by-product of the ionization contributing to the further production of photons. However, the data for alcohol would not be consistent with the fact that the discharge may be heavily quenched by the further addition of alcohol.

To understand the role of the organic vapor and its effect on the spread of the discharge, there must first be considered the action taking place in the slow counter, i.e., a counter filled with monatomic gas. In the course of the discharge, several types of photons are created. The first type consists of photons derived primarily from excited neutral atoms. These photons lie in the visible and near-ultraviolet region, and help perpetuate the discharge by the ejection of photoelectrons at the cathode. These photons do not cause ionization within the gas itself because of their low energy. The second type of photon is derived from the excited singly or doubly ionized gas atom, and may either eject photoelectrons from the cathode cylinder, or what is more probable due to the opacity of the gas in the wavelength region involved, cause photoelectric emission in the gas itself. The emitted electrons then serve to trigger the formation of new Townsend Avalanches. On the basis of previous hypotheses, it was assumed that the organic vapor served to absorb radiation in the ultraviolet, thus minimizing photoelectric action at the cathode and in the gas. The experiments conducted above invalidate these assumptions.

The photons originating in the avalanche from excited argon atoms lie in the range of 11.5 to 15.7 electron volts, corresponding to 1070 to 790 angstrom units. The photoelectric action at the cathode may occur in most cases for photons of the order of magnitude of 4 electron volts. Thus, for localization of the discharge to the region in the immediate vicinity of the wire, either these photons must be strongly absorbed in the gas mixture, as hypothesized by Ramsey[15], or the number of photons produced should be lowered to the point where photoelectric action at the cathode has a sufficiently low probability.

The results presented herein show definitely that the action of the spread of the discharge, previously shown to be photoelectric in nature, is a function of the gas alone. The action of the vapor, as indicated by the lines of log $(1-w)$ of the same slope but displaced intercepts, is to poison the production of photons in the discharge. This would be explained by the electrons in the avalanche losing their energy by excitation and decomposition of the organic vapor molecule. This explanation is substantiated by the experiments of Spatz in which he shows that the organic vapor is broken down in the course of a discharge. That this process is so effective is due primarily to the fact that the energy necessary for excitation and decomposition of the vapor is considerably less than the energy required for the production of suitable photons to spread the discharge. Finally, the fact that the absorption coefficients are dependent only on the absolute amount of gas (argon) in the counter, definitely establishes the photoelectric action as a process occurring in the gas alone, and contradicts previously suggested mechanisms, such as the ultraviolet absorption of the vapor, to account for the localizing action of the mixture[14]. In addition, the experiments indicate that ionization is also produced after the initial avalanche, by photons originating from $A+$ excited ions, lying in the range of 43.3 - 15.7 = 27.6 electron volts.

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