Some Properties of the Parallel Plate Spark Counter I

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(Received October 25, 1948)

A parallel plate spark counter was constructed to provide a uniformly sensitive avalanche volume for the detection of ionizing radiation. It is shown that such a counter avoids the random delay errors inherent in counters with cylindrical geometry.

The spark counter provides a pulse of several hundred volts with a rise time of $3 \cdot 10^{-9}$ second, requiring no additional amplification for detection. The recovery times show a marked dependence on the cathode material and, while they may be several seconds long for some materials, recovery times of the order of one millisecond have been obtained with the use of lead and tin cathodes.

The problem of high resolution counting and also the problem of reducing the recovery time in spark counters is discussed.

INTRODUCTION

IN a recent letter[1,2] the authors published preliminary data on the characteristics of a parallel plate counter which was designed for the purpose of realizing the ultimate speed of a gas counter. It was shown that the counter manifested, even with an arbitrarily large aperture, both rise and delay times shorter than 10^{-8} second, and that the counter was therefore applicable to the measurement of lifetimes as short as 10^{-9} second. Since then, more quantitative data have been obtained, and the counter has been improved. It is proposed in this article to present a summary of data on the counter which will serve to outline its use as an instrument of nuclear physics.[3,4]

CONSTRUCTION

The parallel plate counter is an adaptation of a gas counter in which the electrodes have plane parallel symmetry. In contrast with the cylindrical geometry of the Geiger counter, the gas is contained in a uniform electric field between the electrodes.

Only a few design features of the counter are critical in its performance, and working models of widely differing designs have been constructed. The plane parallel surfaces are highly polished and cleaned with dilute acid before use. The anode material is copper, while the cathode substance is one of the metals described in the section on quenching for the minimum dead time. The electrodes are spaced with insulators whose effective length along the surface is several times the electrode spacing and which leave a free opening between the gas in the counting sensitive region and a large reservoir. The accuracy with which the electrodes are made parallel affects the amount of overvoltage permissible and the uniformity of the counting sensitivity with aperture.

Counters have been constructed with electrode diameters from $\frac{1}{2}$ inch to 3 inches with no change in properties. When soft beta-radiation is to be detected, a thick plate electrode design can be used with spacings up to 1 cm where the radiation is directed between the plates. Beyond 1 cm the pulse rise time becomes prohibitively long if the ultimate speed of the counter is to be realized. As an alternative, counters have been developed where the electrodes are thin metal foils stretched in a drum head mount, shown in Fig. 1, and with this design soft radiation can be detected directly through the plates. Figure 2 shows the counter constructed for the purpose of studying the variation of counter properties with spacing. The construction exemplifies the use of C type Lucite spacers with a thick plate counter. The cathode in this case is tin-plated copper.

Gas is introduced into the counters with the same precautions that are used in filling self-quenching Geiger counters. The additional requirement is that the vacuum system may be required to contain pressures as high as three atmospheres. The gas mixture is argon plus 10 percent butane.

THE COUNTER OPERATION

When the counter is used as an electron detector, small pulses are observed before the spark threshold is reached. These pulses have varying amplitudes, the maximum amplitude being one millivolt when the operating potential is 200 volts below the spark threshold. When the voltage has been raised to the sparking threshold, the maximum amplitude of these pulses is about 50 millivolts. The appearance of these pulses was characteristic of all the pressures and spacings investigated. The small pulses do not appear to be useful for high resolution counting since the pulse rise times are $5 \cdot 10^{-6}$ second. The

[1] L. Madansky and R. W. Pidd, Phys. Rev. **73**, 1215 (1948).
[2] See also Keuffel, Phys. Rev. **73**, 531 (1948).
[3] These results were presented at the Rochester Counter Conference in July, 1948.
[4] A second publication which enlarges upon the use of the counter for lifetime measurements is being prepared.

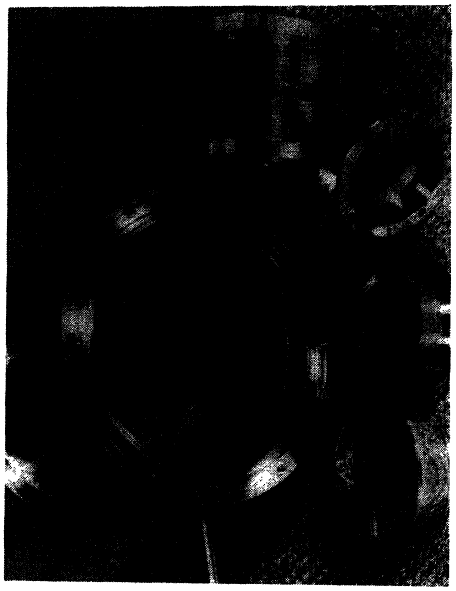

FIG. 1. Thin wall parallel plate counter.

spark counting region begins at an operating potential high enough to allow some of the avalanches to develop into a spark. More ionizing events become sparks as the operating potential is increased. The term "counting plateau" can be applied somewhat loosely to the spark counting region since the pulses here are uniform in amplitude and the spark efficiency must approach a saturation value of 100 percent for sufficiently high overvoltages. However, the spark efficiency always increases with overvoltage and for this reason the operating point is chosen where the overvoltage is a maximum without causing breakdown.

The end of the spark counting region is marked by spurious counting, the ultimate amount of overvoltage permissible depending on the dead time imposed on the counter by a quench circuit. The spark discharge after-effects, whether they reside in the electrodes or in the gas, cause spurious discharges if the overvoltage is restored too soon. These effects become more severe as the overvoltage is increased. It is clear, however, that these after-effects have a finite lifetime and that if the overvoltage is removed for a sufficiently long time, the counter will be quiescent when it is restored. If the maximum overvoltage can be taken to be a measure of the plateau width, then it is apparent that the plateau width must depend on the quench time imposed, a longer quench time compensating for the large discharge effects of high overvoltage. As an example, with the present technique of electrode preparation the maximum overvoltage is 200 volts for a 1-millisecond quench time. By measuring the coincidence counting rates for beta-radiation traversing both a 98 percent efficient Geiger counter and the parallel plate counter, the efficiency for electron detection is 10 percent at this overvoltage.[5]

Figure 3 is a plot of the spark threshold as a function of the product of gas pressure and the electrode spacing. The spark threshold is defined as the operating voltage at which sparks occur, either as observed on an oscilloscope or visually in the spark gaps. The criteria used in identifying the spark are threefold: (1) The discharge is a luminous filament in the gap. (2) The rise time of the spark pulse is less than 10^{-8} second. (3) The spark pulse amplitude is several hundred volts. For a particular gas mixture, the error in reproducing the threshold voltages is 3 percent. Within this accuracy, the threshold voltage is observed to be a function of pressure times spacing. The data are obtained over a continuous range of pressures from 10 cm to 150 cm Hg; the spacing is varied from 0.5 mm to 5.0 mm. The gas mixture is tank argon plus 10 percent butane. The properties of the counter are not significantly different for different pressures and spacings. However, if the detected particle traverses the counter perpendicularly to the plane of the electrodes, a lower limit on the pressure is required for maximum counting efficiency. In standard Geiger counter practice, a 98 percent efficient beta-counter is obtained with a pressure-spacing product $=20$ cm$\times$cm Hg. Thus, if the parallel plate spacing is 1 mm, the pressure should be 200 cm, and the corresponding operating threshold at this point is 5500 volts.

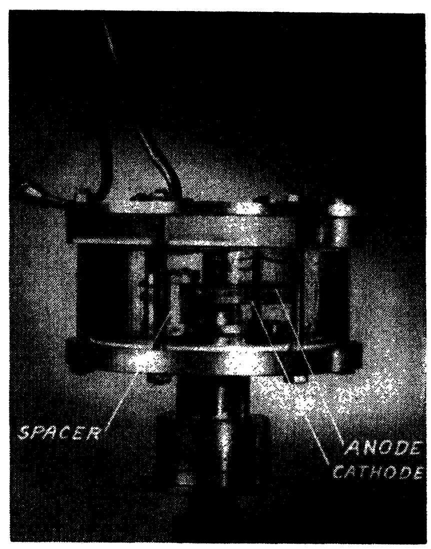

FIG. 2. Parallel plate counter with variable spacing.

[5] The efficiency in electron detection can approach 100 percent when extended plateaus such as reported by Keuffel are obtained.

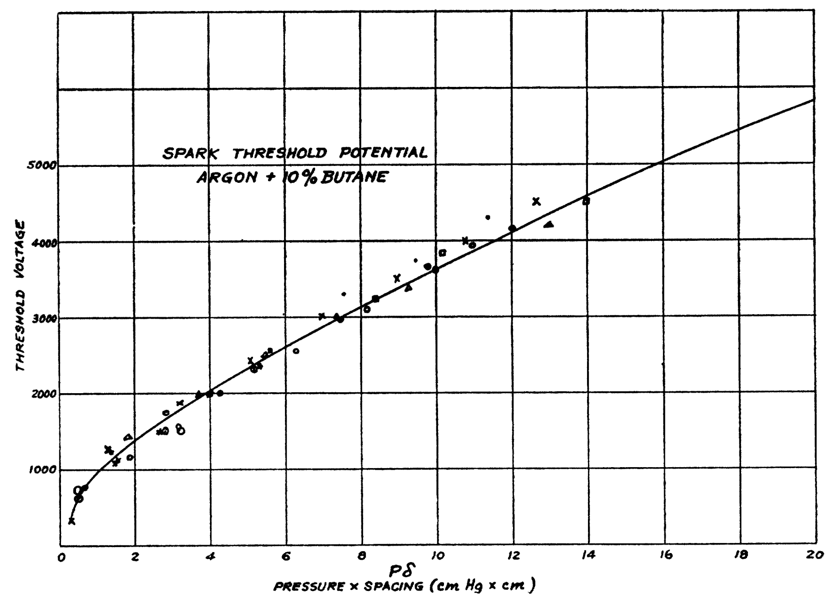

FIG. 3. Spark threshold potential.

QUENCHING

The quenching problem can be stated as follows: How soon can the overvoltage be restored after a spark discharge without causing a spurious counter breakdown? The time during which the overvoltage is removed from the counter is called the quench time or the dead time. Only quench times shorter than several seconds have been investigated, and in this range it has not been possible to quench the counter unless a 10 percent partial pressure of butane is added to the argon gas. With this gas mixture the counter can be quenched with an external resistor or an electronic quench circuit. The quench times then vary from several seconds to a millisecond depending on the cathode metal used in the counter.

Data on dead times have been obtained for a counter quenched with a Neher-Pickering circuit as shown in Fig. 4. The dead time is determined by the *RC* time constant of the circuit and is measured on a calibrated oscillograph sweep. The time constant is adjusted so that the number of spurious counts is less than 10 percent of the total counts recorded by the counter. Two methods of distinguishing between real and spurious counts were employed. The first is one in which the true count is identified by a coincidence count in a Geiger counter placed between the source and the parallel plate counter. In the second method the pulses are observed on a synchroscope where a spurious count can usually be identified as one which appears immediately upon the return of the overvoltage after a previous discharge. The following dead times were measured for counters operated at an overvoltage of 200 volts. The surface treatment is one of polishing and cleaning with appropriate acids.

Dead times	>0.1 sec.	0.01 sec.	0.001 sec.
Cathode material	Al Au Pt Brass	Cu Bi	Pb Sn

These dead times are much longer than are observed for Geiger counters. There also is a marked dependence of the dead time on cathode material. In the concluding sections, it will be proposed that the long dead times are due to a delayed electron emission from the cathode after a discharge.

DETECTION OF THE SPARK SIGNAL

Since the rise time of the spark signal is faster than the transit time of ordinary vacuum tubes, the detection instrument used in the preceding measurements is a fast synchroscope of the authors' design. The oscilloscope tube is a Dumont 5RP11 operated at 30 kilovolts. A photographable sweep 4 inches long whose duration is 3.10^{-7} second is obtained with a sufficiently sharp focus for a resolution less than 10^{-9} second. The signal is delayed through coaxial cable (RG 11/u) and fed

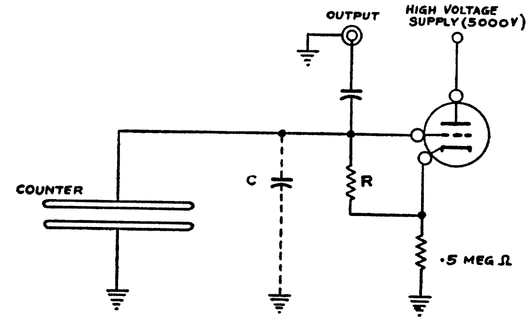

FIG. 4. Schematic diagram of quench circuit.

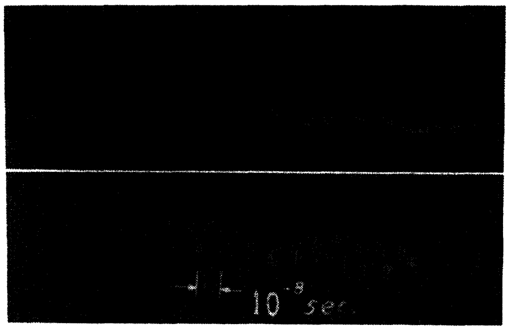

FIG. 5a. (Top) Photograph of spark pulse for a counter with a 1-mm spacing and 1 atmosphere of pressure. (Bottom) 100-megacycle calibration trace.

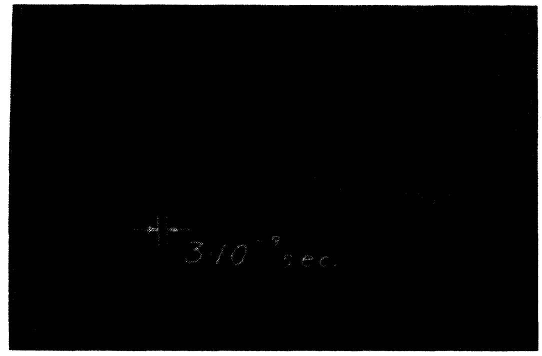

FIG. 5b. Photograph of spark pulse for a counter with a 4-mm spacing and 1 atmosphere of pressure, showing gradual pulse break.

directly to the vertical deflection plates of the oscilloscope. The complete circuit designated as a coincidence synchroscope will be described in another journal. The oscilloscope trace is photographed with 35-mm Kodak Linagraph Pan. film with an f: 1.9 lens.

A photograph of the spark signal trace on the fast synchroscope is shown in Fig. 5a with a 100-megacycle signal. The pulse in the photograph was formed by a counter with one atmosphere of gas pressure and an electrode spacing of one millimeter. The rise time of this counter pulse is measured to be $3\cdot 10^{-9}$ second, this time being measured from the pulse initiation to the first characteristic break in the rise. The error in locating the pulse break on the oscilloscope trace is somewhat less than 10^{-9} sec. The counter anode is coupled to a 50-ohm coaxial cable with a 10-micromicrofarad condenser, in order to reduce the external circuit load to a minimum. The total width of the pulse is determined by the time constant of this coupling circuit. Figure 5b shows a pulse trace for a counter whose spacing is 4 mm and whose pressure is one atmosphere. The linear part of the pulse rise appears to have the same slope as in Fig. 5a. However, there is no sharp break between the base line and the pulse rise. This gradual break introduces an error of about $3\cdot 10^{-9}$ sec. in the determination of the time at which the pulse was formed. This error is characteristic of the large spacings investigated, but does not seem to depend on the pressure. Therefore, larger spacings will reduce the accuracy in timing measurements.

In addition to the inherent speed of the spark discharge, further properties of the spark make possible the realization of this speed in practical time measurements. In typical operation uniform pulses of several hundred volts are obtained. As a result of this pulse magnitude, no auxiliary amplification is required for observation. Also, since the impedance of the spark is less than 50 ohms, the counter may supply a transmission line directly, and the necessity of using associated vacuum tube circuits for observation is eliminated entirely.

THEORY OF THE PARALLEL PLATE COUNTER

The ultimate time resolution of the standard Geiger counter is a direct consequence of its cylindrical geometry. The rise time (10^{-7} sec.) of the counter pulse is limited by the speed with which the discharge is propagated along the central wire. The well-known random delay time[6] of the Geiger counter pulses depends on the fact that a diffusion region exists between the point where the primary ionization is produced in the counter and the avalanche region surrounding the central wire where the pulse is actually formed. Since the primary ionization can be produced anywhere in the counter volume, this pulse delay introduces an uncertainty in time when the particle is detected, and the average value of this uncertainty is $5\cdot 10^{-7}$ second. This time can be reduced to $5\cdot 10^{-8}$ second by severe collimation of the detected beam to a region surrounding the central wire; however, this represents the final limitation in the shortness of time intervals which can be measured with the Geiger counter. The primary advantage of plane parallel electrodes in a gas counter is that the electric field is then uniform and the avalanche region includes the entire counter volume. Thus a primary ionization event should initiate an avalanche within the first mean free path of travel, virtually eliminating a delay error.[1]

An avalanche initiated in a uniform field characteristically develops into a spark. The spark propagation is described by Loeb[7] and the speed with which the spark is propagated has been measured by several investigators.[8] The proposed

[6] E.g., C. W. Sherwin, Rev. Sci. Inst. **19**, 111 (1948).
[7] L. B. Loeb, *Fundamental Processes of Electrical Discharges in Gases* (John Wiley and Sons, Inc., New York, 1939), pp. 426.
[8] H. Raether, Zeits. f. Physik **107**, 91 (1937); H. White, Phys. Rev. **46**, 99 (1934).

mechanism of the spark propagation is one in which the space charge produced by a small initiating avalanche causes a field distortion both at its leading and trailing edge. In these field distortion regions the avalanche sensitivity is increased as if the overvoltage were raised; recombination radiation from the avalanche can photo-ionize the gas and in the region of high avalanche efficiency start further avalanches. In successive steps, therefore, the spark is completely propagated before a single avalanche would have been completed, and the rise time is less than that which would be expected from electron mobilities in the gas. The speed with which the spark is propagated is limited only by the lifetimes of excited states in the gas. Streamer propagation times of approximately 10^{-8} second have been measured by Kerr cell observations of the spark. The parallel plate counter rise times of the order of 10^{-9} second agree in magnitude with the predictions of the streamer theory.

CONCLUSIONS

I. Time Resolution

In view of the properties of the parallel plate counter, its primary application lies in the measurement of very short time intervals. The definition of the time resolution of a particle detector depends on the type of measurement to which it is to be applied. As a point of departure, the measurement of a nuclear lifetime will be discussed since it is characteristic of all experiments in which one measures short time intervals. Consider a typical disintegration scheme where a β-transition is followed by a gamma-ray from the excited state of the daughter nucleus. The emission of the initial beta-ray indicates the time at which the excited state was formed, while the distribution of times of emission for the gamma-ray is a measure of the lifetime of the state. In practice, a conversion electron instead of the gamma-ray itself may be detected. A general experimental arrangement is shown in Fig. 6. Two counters, c_1 and c_2, are placed side by side with the source between them. The pulse from c_1 is made to trigger a sweep circuit which provides a time base on an oscilloscope screen. The pulse from c_2 is delayed in an artificial line and appears on the vertical plates. The delay is arranged so that, when c_1 and c_2 are triggered simultaneously, then the vertical pulse appears in the middle of the sweep. This central point is the true zero time point and pulses that appear to the right or left along the time base represent events that are delayed with respect to each other. In such an experimental study the resolution depends on two important properties of the counters. First, the rise time of the counter pulse limits the exactness with which the time of the pulse initiation can be determined. This is true since the time measurements are taken by photographing the pulses on the sweep. The break in the time base is an indication of the initiation of the pulse from the counter. Clearly, a very fast rise is necessary in order to have high accuracy in resolving the position of the pulses on the sweep. The rise time is also important in that it takes a finite voltage to trigger the sweep circuit. This in effect creates a delay between the initiation of the counter pulse and the initiation of the sweep. If the height and slope of the pulse are always the same, then this delay is a constant and does not effect the measurement. Small changes in the slope will cause this delay to vary introducing an arbitrary uncertainty in the true time interval to be measured. To minimize this effect a large pulse with a fast rise time is needed.[9]

The second limitation of this method is the inherent random delay errors in the counters. For example, if a particle enters the counter at a time t_0, then the pulse can originate at a time $t_0+\tau$, where the magnitude of the distribution of delays τ depends for the most part on counter geometry. Although a determination of such a distribution $P(\tau)$ provides a correction factor and allows a measurement of a lifetime somewhat shorter than the average delay, the existence of this error is the final limitation on the shortest lifetime that is capable of being measured. When the lifetimes are as short as 10^{-8} second, the Geiger counter ceases to be applicable to the counting problem, whereas the important range of applicability of the parallel plate counter is between 10^{-8} and 10^{-10} second.

II. The Quenching Problem

In order to explain the relatively long dead times which appear to be characteristic in this counter, it is necessary to seek other mechanisms than the simple clearing time of the positive ions which should be no longer than 100 microseconds. In addition, the difference in the work functions of the various cathode surfaces is probably insufficient to account for such wide differences in the dead time. The role of the cathode is more critical

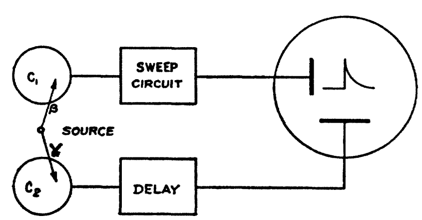

FIG. 6. Schematic set-up of the lifetime experiment.

[9] These errors also apply in cases where coincidence circuit techniques are used since the circuits are triggered by finite pulses.

here than in the Geiger counter for two reasons: (1) The total ionization in the spark is 1000 times that of the Geiger avalanche. (2) No buffer, diffusion region separates the cathode from the avalanche region.

The large variation of dead times with cathode surface suggests that the latter is very important in causing spurious discharges. Moreover, Malter[10] describes a mechanism which would give rise to delayed electron emission from the cathode surface after the discharge and cause a spurious count. He points out that surfaces with oxide layers may emit electrons for seconds after having been bombarded by an electron beam.

The Malter effect depends on an insulating layer on the cathode becoming highly charged during a discharge, the strong field thus induced at the surface being able to free electrons from the cathode metal below. It should be pointed out that the surface layers were positively charged by secondary emission. In the parallel plate counter it is possible to suggest that the surface is positively charged by the collected ions. If this effect can be used to explain the dead times in the parallel plate counter, the success of Pb and Sn cathodes could be ascribed to a lower resistivity oxide of Pb or Sn than of aluminum, for example. In this case the induced charge would leak off in a shorter time, and after-emission would not last so long.

If the cathode effects can be eliminated, the possibility exists that much better counters than reported here can be constructed. The dead times are not only important to the successful use of the counter for general counting problems, but also may affect the resolution properties of the counter. It is to be expected that higher overvoltages would give rise to shorter rise and delay times, and these overvoltages can be obtained only if the spurious effects they cause are eliminated. It is probable that the wide plateaus reported by Keuffel are a result of a more successful cathode treatment in which the oxide is mostly removed.[11]

[10] L. Malter, Phys. Rev. **50**, 48 (1936).
[11] Private communication.

SUMMARY

A comparison between the Geiger and the spark counter reveals the first as being superior in applications where a short recovery time and high efficiency are required in addition to the stability inherent in a counting plateau. However, in many problems where timing is important, the spark counter may prove to be the only counter with sufficiently high resolution for the experiments, at the same time having over-all characteristics which do not seriously limit its use as a detector.

Although the standard recording circuits cannot be utilized in the measurements of very short time intervals, a fast synchroscope requiring only an auxiliary sweep circuit represents perhaps a simpler instrument than many in use today. At the same time the difficult problem of video amplification is eliminated because of the large pulse amplitude.

The parallel plate counter is also a useful instrument for the study of gas discharge problems. Further work is planned in which the counter efficiency will be used as a measure of the total ionization required for the initiation of a spark. Also, more precise measurements of the spark pulse rise time can add significant information on the spark propagation. The studies seem to indicate a marked dependence of recovery time on the cathode, suggesting a delayed electron emission by the cathode surface.[12] Further work is in progress to investigate whether this process may be associated with the ultimate recovery times of all gas counters.

ACKNOWLEDGMENT

A major part of this work was performed at Brookhaven National Laboratory under the auspices of the AEC. The authors wish to express their gratitude to Dr. J. B. H. Kuper for the courtesy of his laboratory and to the technical staff for their excellent cooperation. The authors also wish to thank Professor H. R. Crane for his stimulating discussions.

[12] E.g., M. Tanaka, Phys. Rev. **48**, 916 (1935); H. Paetow, Zeits. f. Physik **111**, 770 (1939); L. Malter, see reference 18.

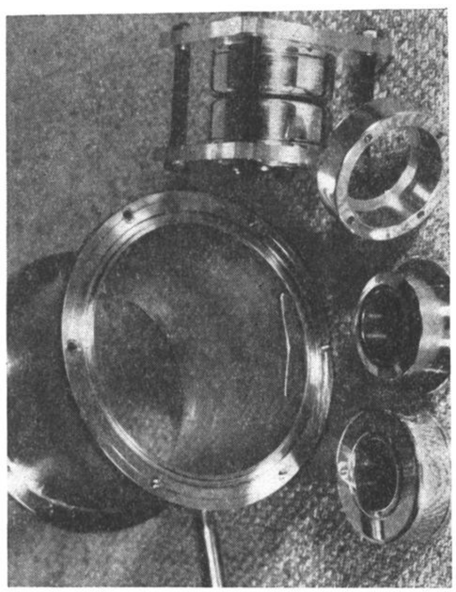

FIG. 1. Thin wall parallel plate counter.

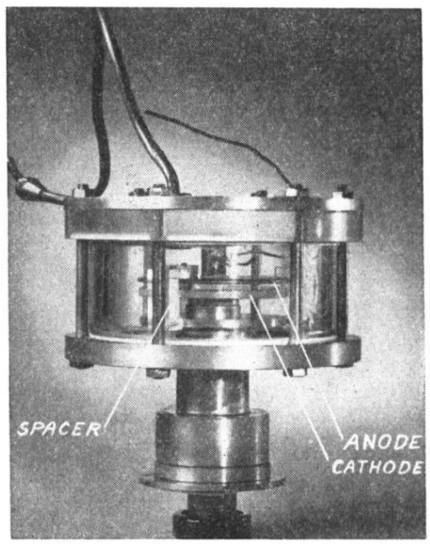

FIG. 2. Parallel plate counter with variable spacing.

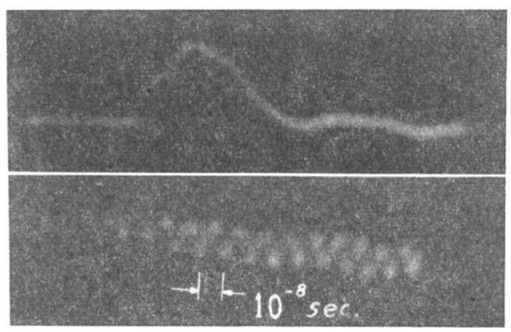

FIG. 5a. (Top) Photograph of spark pulse for a counter with a 1-mm spacing and 1 atmosphere of pressure. (Bottom) 100-megacycle calibration trace.

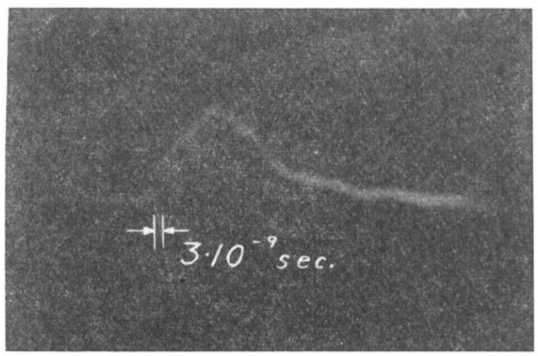

FIG. 5b. Photograph of spark pulse for a counter with a 4-mm spacing and 1 atmosphere of pressure, showing gradual pulse break.