THE GEIGER TUBE ELECTRON COUNTER

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ABSTRACT

Experiments are described which show that the sensitive surface of the Geiger tube counter is not on the wire electrode, but on the inner surface of the tube. This result explains the previously observed result that the operation of the counter is only slightly affected by the condition of the surface of the wire electrode. An explanation of the operation of the counter is offered which takes account of this additional information.

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I. INTRODUCTION

Recently the writer has reported [1] the results of experiments which were undertaken to discover the effect on the operation of the Geiger tube counter of subjecting the central wire electrode to different treatments. It was apparent from these experiments that neither the kind of wire nor the condition of its surface made much difference in the behavior of the counter. The writer has extended these experiments and has obtained information which indicates that the sensitive surface is on the inner wall of the tube which serves as the negative electrode. This paper describes the results which have been obtained and gives a qualitative discussion of the problems involved in attempting a complete explanation of the operation of the counter consistent with current ideas regarding the nature of gas discharges in general. In any attempt of this kind one is confronted with the problem of the conflicting theories of the conduction of electricity in gases which makes the development of a quantitative theory, which may be tested numerically, exceedingly difficult. Even in a discussion such as is offered here it is necessary to make more or less arbitrary assumptions regarding the elementary processes which are responsible for the formation of an electrical discharge through a gas. As an example of the kind of difficulty referred to, one may consider the fundamental problem of the rôle of the positive ion in the production of ions. There is to date no definite answer to the question whether it does or does not form new ions by impact under conditions which usually obtain in a discharge tube. In spite of numerous uncertainties of this kind it is possible to develop qualitatively an explanation which accounts for the main facts so far known about tube counters by making use only of assumptions with fairly strong experimental evidence supporting them.

The problem of the action of the counter involves considerations quite apart from those of a simple electrical circuit containing capacity and resistance. As can be seen from the diagram shown in Figure 1

[1] B. S. Jour. Research, 4 (RP167), p. 601; May, 1930.

of a typical arrangement of a tube counter, it is in reality a cylindrical condenser in series with a resistance of the order of several megohms. Any electrical discharge occurring in the counter will be controlled to a great extent by the values of the capacity and the resistance of this circuit, and certain features of the action of the counter depend on a proper adjustment of these values. These may be regarded as subsidiary to the successful operation of a counter, however, since not every circuit of this kind can be made to function as a counter.

A brief description of the operating characteristics of a counter will suffice to make clear the difference between it and a simple discharge tube. The most prominent feature in this connection is the existence of a range of voltage which, when applied to the counter, making the tube negative, does not cause an appreciable current to flow, not more than 10^{-9} amperes in most cases. With the voltage so adjusted, however, if the counter is working properly the entrance of a high-speed electron causes this current to jump up momentarily to about

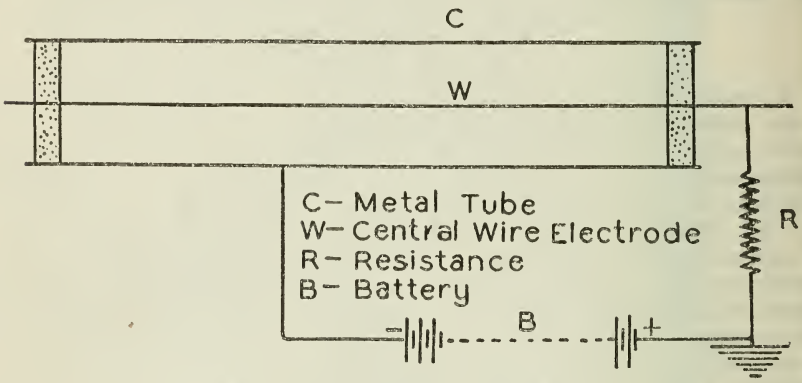

FIGURE 1.—*Electrical circuit of tube counter*

10^{-7} amperes for a small fraction of a second. The counter then immediately returns to its former condition. The duration of this discharge is dependent partly on the values of the resistance and the capacity of the circuit. In a good counter, however, the main cause for the sudden interruption of the discharge must be sought elsewhere, since the cessation is much more abrupt for any particular arrangement than could be expected from the nature of the electrical constants of the circuit alone. Furthermore, a counter once put into a sensitive condition will operate with widely different values of the resistance whereas a counter not sensitive for any one value of the resistance can not, in general, be made to work with any other resistance. It is the problem of what might be called the sensitizing of the counter which is primarily considered here. A further examination of methods of preparation which appear to produce counters sensitive to single electrons, as well as methods of preparation which fail to produce sensitive counters, has been made and an explanation of the results has been attempted along lines consistent with the present ideas concerning ordinary electric discharges in gases at the pressures used in the counter.

II. RECENT EXPERIMENTS ON THE LOCATION OF THE SENSITIVE SURFACE

It is important for the development of the explanation to be offered here to consider some facts concerning the behavior of tube counters which seem so far to have escaped observation. It has been assumed by Geiger [2] that the surface of the wire is the sensitive surface since it seems to require special treatment for successful operation of the counter. Kniepkamp [3] and also the writer [4] have been able to operate counters quite successfully using wires with no special treatment whatever. In fact, the writer has been unable to find any kind of wire or surface which will not work successfully for the central electrode. Experiments in this laboratory [5] have shown, however, that these counters are susceptible to adsorptive poisoning and this result has been interpreted by the writer to mean that the ordinary adsorption occurring on all surfaces exposed to gas is sufficient to provide a sensitive surface. A review of these experiments on the effect of poisons reveals, however, that the same effects would be observed if the sensitive surface were not on the wire, but on the inner wall of the tube. Although this seemed improbable at first, the writer is now convinced that such is the case, and this explains why any kind of wire or surface will serve as a central electrode. Attention was accidentally drawn to the possible importance of the inner surface of the tube when a brass tube counter, which had recently been "polished" with emery paper to remove radioactive contamination, failed to respond to the presence of a gamma ray source in the neighborhood. In consequence of this observation a

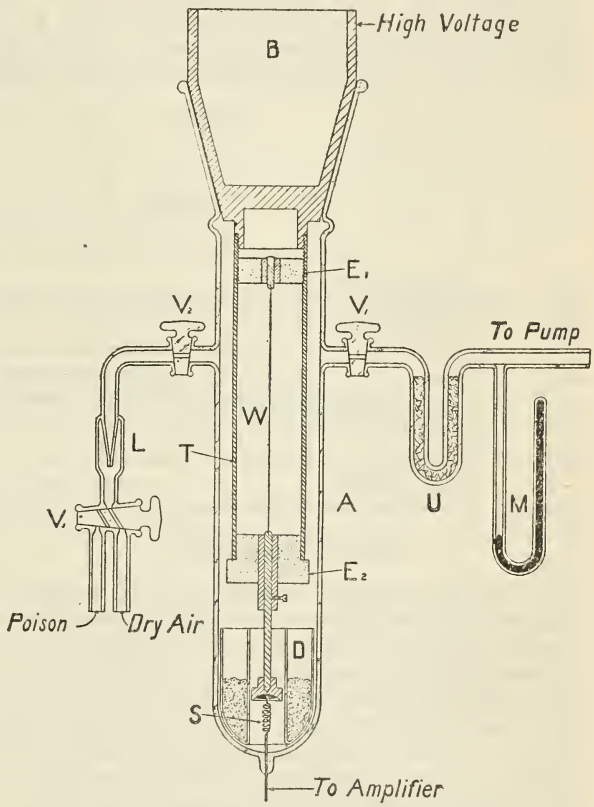

FIGURE 2.—*Apparatus for testing sensitive condition of tube counters*

[2] Geiger, H., and Müller, W., Phys. Z. S., **29**, p. 839; 1928; **30**, p. 489; 1929.
[3] Kniepkamp, H., Phys. Z. S., **30**, p.237; 1929.
[4] See footnote 1, p. 115.
[5] See footnote 1, p. 115.

considerable number of trials have been made of various kinds of surfaces. As a result it has been found that the nature of the surface on the inner wall of the chamber is important. Although the preparation of this surface is not as critical as the preparation of a point for a point counter, it seems to play a very similar rôle in the operation of the counter.

For investigating the effect of various surfaces, the apparatus described in the work[6] referred to above was used since it makes it relatively easy to change the counters and evacuate them. It is shown in Figure 2. The experiments, which were mainly qualitative in nature, consisted in evacuating the counter to a suitable pressure of dry air, say 3 cm, and then adjusting the voltage between 1,000 and 2,000 volts, and noting whether at any voltage it would respond to the presence of a gamma ray source when brought up to within a few feet of it. A summary of these trials has been arranged in Table 1.

TABLE 1

Metal	Treatment	Kicks per minute	
		Source present	Source removed
Copper	Polished with emery paper	99	42
Brass	Untreated	150	37
Copper	Heated in flame	165	65
Brass	Lacquered inside	32	25
Do	Lacquered as above; then coated with a layer of soot from a flame	31	63
Steel	Oxidized	118	33
Do	Oxidized as above and coated with a thin layer of vaseline	(1)	(1)
Copper	Coated with sodium silicate	(2)	(2)
Do	Coated as above then with soot	133	29
Steel	Oxidized in flame, left in moist air over night	52	40
Do	Freshly oxidized	143	40
Do	Coated with soot	182	57
Copper	Oxidized and reduced in hydrogen	89	38

[1] No kicks could be obtained. [2] No kicks.

In the first column is the kind of metal; the second gives the method of preparation and the third gives the number of kicks when a radium preparation was brought within a definite distance of the counter and when removed to a considerable distance behind a wall. It is at once obvious that the inner wall does not seem to require a very careful preparation. However, it is equally obvious that the nature of the surface does have an effect on the operation of the counter. Most significant in this connection are the experiments with counters lacquered inside and those coated with sodium silicate. It might be argued that the insulating properties of the lacquer prevented the counter from responding and that the soot was sufficiently conducting to permit it to operate. Sodium silicate, however, is a fairly good conductor so the only way that the soot played a part in this case was to alter the nature of the surface. The behavior of so-called bare metal surfaces is also peculiar, although very little can be said on this point without more experiments. Apparently a metal surface prepared in approximately the same way does not always yield a sensitive surface. This is not surprising when one considers the rapidity with which oxide films form on the surfaces of freshly cut metals.

[6] See footnote 1, p. 115.

When dealing with such a large surface, it is very difficult to make certain that all parts have received the same treatment and are in the same condition from the standpoint of adsorption. Consequently, it is not surprising that at times effects are not always definitely reproducible. For our present purpose, it is sufficient to know that some surfaces are not satisfactory for the inside of the tube in these counters and that we are, therefore, justified in assuming that the sensitive surface is in this case not on the wire, but on the inner wall of the tube.

The results mentioned above become more significant when it is recalled that clean metal surfaces emit electrons with great difficulty under bombardment by electrons or positive ions. Coating such metals with alkali earth oxides increases the facility with which they emit electrons under bombardment.[7] This and other similar effects suggests that a secondary process is involved in the operation of the counter. This process may be supposed to be the liberation of electrons from the outer wall of the counter, the ionization produced by these electrons, as they are drawn to the central electrode, constituting the major part of the ionization current which is necessary in order that the counter may respond. The following discussion assumes the existence of such a secondary process.

III. DISCUSSION OF OPERATION OF COUNTER

The operation of the counter can now be explained on the basis of the following assumptions, both of which have some experimental support: (1) Ionization by impact is produced only as a result of collisions of electrons with gas molecules. (2) Positive ions contribute to the production of ions by releasing electrons from the surface of the negative electrode.

Since these assumptions may appear entirely arbitrary, it may be well to point out what justification exists for them. As regards ionization by impact, it is generally agreed that most of the ionization produced in a gas when a current flows results from the collision of electrons with molecules. For currents produced at voltages below the sparking potential, the entire current can be accounted for in this way.[8] When the sparking potential is approached, however, there is a well-known more rapid increase in the current that can not be accounted for as the result of collisions of electrons with gas molecules. As Townsend points out in the paper just referred to, this additional ionization may be accounted for in several ways. It may be attributed to the impact of positive ions with gas molecules; it may result from the release of additional electrons from the negative electrode by the positive ions; or it may result from the photoelectric action of radiation falling on the negative electrode and thus releasing additional electrons. Each one of these views has been supported by some experimental evidence by various investigators. Townsend favors the view that the additional ionization is produced by impact of positive ions on gas molecules. There is at present, however, little or no direct evidence to confirm this view so that one may feel justified in excluding it. There are,

[7] H. D. Arnold, Phys. Rev., 16, p. 70; 1920.
[8] Townsend, J. S., Phil. Mag., 45, p. 444; 1923.

however, numerous recent experiments [9] [10] which give strong support to the idea that positive ions only produce additional ionization by releasing electrons from the negative electrode. The particular way in which this release of electrons occurs has been strongly debated by various authorities.

The writer favors the view that this release occurs as a result of electrostatic attraction between the negative and positive ions. The difficulty with the other obvious mode of release—bombardment of the cathode by positive ions—is illustrated by the example cited by Townsend to show that such an effect is impossible. He refers to the experimental fact that, in the case of a radial field of force between a wire and a coaxial cylinder, there is a critical value X_1 of the electrical field at the surface of the wire with which a small continuous glow discharge is maintained between the wire and cylinder. Let a be the radius of the wire, b that of the cylinder. It has been found experimentally that X_1 is independent of b, provided b is greater than a certain radius c. The value of c, of course, depends on a and the pressure of the gas. As Townsend remarks, in order to account for the fact that X_1 is independent of b, it is necessary to assume that, in the case of a positive current flowing from the wall to the cylinder, which is the case exemplified by the counter, either no electrons are set free from the surface of the cylinder or that the same number are liberated from a cylinder of large diameter as from one of small diameter. The electric field at the surface of the cylinder is $\frac{a\ X_1}{b}$, neglecting a distortion of the field due to accumulated charges on the surface; and, by increasing b, the intensity of the electric field near the surface of the cylinder may be reduced so that the positive ions would move with such small velocities that they could neither generate ions nor excite radiation on impact with the wall. There seems to be no escape from this argument. Consequently, the obvious solution to the problem thus presented is that the positive ions do not liberate electrons from the walls by impact, but by virtue of their electrostatic attraction for electrons on the walls. This idea is supported by Holst and Oosterhuis.[11] It is then very easy to see how the same number of electrons may be liberated from a cylinder of large diameter as from one of small diameter, since the number of electrons released is not directly connected with the velocity of the positive ion at the moment of impact. The only requirement is that the velocity of the positive ion should be great enough to prevent recombination and immediate neutralization of the electron as soon as liberated. This requirement is easily met, since Mohler and Boeckner [12] have been able to show that even the velocity of thermal agitation is sufficient to prevent recombination.

Since the experiments described in this paper show that the nature of the surface of the tube is the important factor in the operation of the counter, it is fairly certain that the gas layer on the tube wall and not that on the wire forms the sensitive surface which is disturbed by gas poisons. This renders the explanation given by the writer in a previous article no longer in accordance with the facts,

[9] Klemperer, O., Z. S. f. Physik, 52, p. 650; 1928.
[10] Müller, W., Z. S. f. Physik, 48, p. 624; 1928.
[11] Holst, H., and Oosterhuis, E., Phil. Mag., 46, p. 1117; 1923.
[12] Mohler, F. L., and Boeckner, C., B. S. Jour. Research, 3, p. 303; 1929.

since it was there assumed that the sensitive surface was located on the wire. With this new fact available and using assumptions (1) and (2) it is now possible to give an explanation which more nearly agrees with that offered for the point counter. It will be noted that in both cases the sensitive surface may now be assumed to be on the negative electrode. The chief difference between the two counters as regards principle of operation is that it is usually more satisfactory to use the point counter with the point negative while the tube counter only seems to work well with the tube negative. Thus in the case of a point we have a cathode of very small area in a very intense electric field while in the case of the tube the cathode has a very large area and is in a relatively weak field. This important structural difference is responsible, in the writer's opinion, for most of the differences in behavior between the two types of counters.

The stages of the process by which a count is registered may be outlined as follows: The electron to be counted produces a few pairs of ions as it passes through the gas of the chamber. This primary ionization is entirely too small to register on any of the usual instruments used for detecting the electrical impulse produced by counting. The positive ions move to the tube wall and the negative ions, presumably mainly electrons, go to the wire. As they pass to the wire they pass through the region of intense electric field and produce ions by impact, but even this ionization will be relatively feeble, representing currents which are only a small fraction of those observed when a count is registered. The amplification to be accounted for is of the order of 10^8. To account for the total ionization an additional supply of electrons is required. These come, according to the views set forth here, from the negatively charged tube; being released from the gas layer on the surface of the tube by the electrostatic attraction of the positive ions as they approach the walls of the tube. It is important to note, as shown above, that not all surfaces of the tube are sensitive, and this can be expected since it is reasonable to suppose that only certain types of surface will provide a layer of gas such that electrons may be released from it by positive ions. In such a case the additional ionization current required to register a count can not be obtained and the counter fails to function. It is also likely that a variety of surfaces would work here, since the electric fields are relatively weak and the time during which electrons are within a strong attractive field from the positive ion is relatively much longer than in the case of a point counter with positive points. This may be the explanation for the fact that a negative point must have a very careful preparation, whereas many kinds of surface will work in the case of the negative tube.

Such a discharge process as that outlined in the preceding paragraph should be self-sustaining. The counter, however, when it is properly registering counts, maintains a discharge for a very short period of time for each high-speed photoelectron which enters it, a period estimated as of the order 1/1000 second.[13] To interrupt the discharge in this way it is necessary to suppose that for some reason the positive ions very suddenly lose their ability to pull electrons from the cathode surface. Since our experiments point to a special condition of the surface required for operation, it is logical to conclude that the operation of the counter in registering a count so alters this

[13] Bothe, W., ZS. f. Phys., 59, p. 1; 1929.

special surface that, after the discharge has proceeded for this very brief space of time, it is no longer in the sensitive condition at that particular location on the chamber wall. The layer of adsorbed gas is so modified or disturbed that no electrons are released. As soon as the discharge stops, however, the cathode restores itself to its former condition by adsorption and is then in condition again to respond. This disturbed area of the surface probably is a small part of the total area of the tube, but owing to the relatively great surface of the tube wall affected, as compared with that of a point, this restoration does not need to occur quickly to register counts in rapid succession. This provides another reason why one would not expect the condition of the surface of the tube to be as critical as that of the point.

This explanation requires that a sensitive surface should have the property of releasing electrons on the approach of positive ions more readily than an insensitive surface. It might be expected that a sensitive counter would function at a voltage lower than the sparking potential for an insensitive counter. This seems to be true in general; but, if our assumption that the release of electrons by positive ions is independent of the mean kinetic energy of the positive ion, the applied voltage would not be affected. Furthermore, any small change of the applied voltage will not greatly affect the mean kinetic energy of the positive ions near the surface of the tube, since this is a region of weak electric fields. The mean kinetic energy of the positive ions is given by the product of the field strength and the mean free path.[14] Since the mean free path is inversely proportional to the pressure, the mean kinetic energy may be expressed in terms of volts per centimeter divided by the pressure in centimeters of mercury. For the usual tube counter the mean kinetic energy expressed as $\left(\text{kv/cm} \times \frac{1}{\text{cm of Hg}}\right)$ for the positive ions near the walls is from 0.1 to 0.01. Klemperer[14] has analyzed data on gas discharges and shows that, in the range of mean kinetic energies from 0.5 to 10 in the above units, the ratio of liberated electrons to incident positive ions increases by a factor of nearly a hundred. Since the mean kinetic energies used in his analysis are considerably higher than those existing in a counter it may be that at such higher energies impact is effective in releasing electrons from the gas layer.

On the other hand, extrapolating his figures to the values of kinetic energy of positive ions in the counter, the ratio of liberated electrons to incident positive ions becomes a very small fraction, of the order of 1/100,000. This seems to show that in the counter impact can no longer be effective in releasing electrons from the walls. Nothing definitely is known concerning the surfaces of the ionization vessels in which the measurements which he has analyzed were made, and it might be that these figures refer to a wall surface similar to that of an insensitive counter. If we are to accept Townsend's arguments supporting the view that the number of electrons liberated from the negative outer electrode by positive ions is independent of the diameter of the outer electrode, it is clear that the effect that Klemperer deduces does not exist, since the experiment which Townsend cites would seem to prove conclusively that if positive ions do liberate

[14] Klemperer, O., ZS. f. Physik., 52, p. 650; 1928.

electrons the number liberated is independent of the velocity of the positive ion.

In addition to giving more information regarding possible explanations for the action of the tube counter, the experiments here discussed appear to throw additional light on the nature of certain kinds of gas discharges themselves. Considerable support seems to be offered the idea that the release of electrons from the cathode may occur by electrostatic attraction, since by such an assumption a satisfactory explanation is readily obtained for the operation of the counter. There are strong reasons, as has been pointed out, for making the release of electrons from the cathode the important feature in the operation of the counter. It does not appear obvious how this may be accomplished by impact of positive ions under the conditions discussed. The release by electrostatic attraction, on the other hand, provides a method which avoids all difficulties associated with the kinetic energy of the positive ion in relation to its efficiency in releasing electrons. In conclusion the writer wishes to thank L. L. Stockman and H. L. Martin for helping in preparing and testing various kinds of counters, and Dr. J. H. Hibben for valuable suggestions.

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