THE SENSITIVE SURFACE OF THE GEIGER TUBE ELECTRON COUNTER

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ABSTRACT

Experiments with the new Geiger tube electron counter show that no preparation of the central wire electrode is necessary in contradiction to results reported by Geiger. Such wires as bare copper, bare steel, lacquered steel, oxidized tungsten, and oxidized nichrome work satisfactorily. All these wires cease to work when such gases as H_2S, SO_2, ethylene, or water vapor are admitted. This shows that at the pressure at which these counters work sufficient oxygen is adsorbed to permit the counter to operate. When another gas with different adsorptive properties is admitted, the counter can no longer function.

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I. INTRODUCTION

The recent development of the tube electron counter by Geiger [1] raises further interesting problems regarding the mode of action of counters. While, in general, this new form of counter seems to work much in the same way as the more familiar point-type counter, there are some differences which require special investigation. Furthermore, there is a slight disagreement regarding the importance of a specially activated surface in the tube counter which requires some attention before any conclusions can be reached on the subject. Although Geiger [1] reports that the same general method of preparing surfaces for active points also works for the wire electrode of the new counter, Kniepkamp [2] rather emphatically contradicts this point of view, stating that a bare untreated wire works as well as a specially prepared one.

In order to obtain further information on these points and to investigate the nature of these activated surfaces, the experimental work described in this paper was undertaken.

A brief description of the tube counter may help to make clear the nature of the problem. In its simplest form the counter is a metal tube with a fine wire stretched along its axis and insulated from it. To operate the counter the metal tube must be connected to the negative terminal of a battery of one to three thousand volts and the pressure of the gas in the chamber must be reduced to a few centimeters of mercury. It is also important to dry the gas in the chamber. Further, at least according to Geiger,[1] the wire electrode must be prepared, either by oxidation or coating with thin lacquer, for example,

[1] Geiger, H., and Müller, W., Phys. Z. S., **29**, p. 839; 1928: **30**, p. 489; 1929.
[2] Kniepkamp, H., Phys. Z. S., **30**, p. 237; 1929.

before the counter will respond to the excitation by individual beta or alpha rays. When properly prepared the counter is enormously more sensitive than the point type of counter for beta and gamma rays. This greater sensitivity is secured from the greatly increased active volume of the gas, since any beta ray or photoelectron traversing any part of the gas in the tube will be counted.

The questions which the present work attempts to answer are (1) is a specially prepared surface necessary for the wire electrode and, if so, (2) what is the nature of this surface?

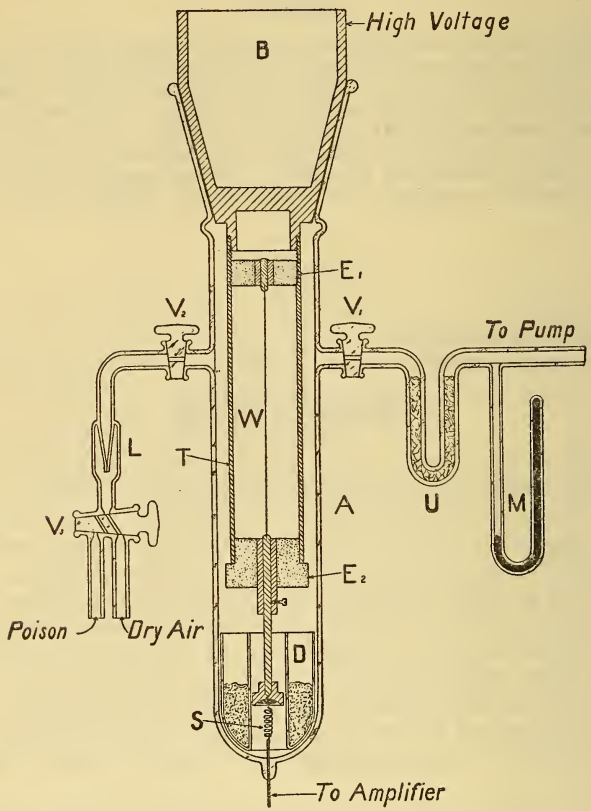

FIGURE 1.—*Modified form of Geiger tube counter to permit study of effect of different gases*

II. EXPERIMENTAL PROCEDURE

To facilitate the study of the effect of the presence or absence of coating on the wire, a form of the tube counter shown in Figure 1 was made. Since it was necessary to work at pressures below atmospheric, the whole counter was inclosed in the large glass tube *A*. This glass tube was fitted with a metal ground stopper *B*, making a vacuum-tight seal, and supporting the tube counter *T* by a threaded connection as shown. At each end of the tube *T* was a loosely fitted hard rubber bushing, E_1 and E_2, which supported the central wire electrode *W*. Connection from the outside to this central wire was secured by a tungsten wire, sealed through the lower end of the

glass tube A, carrying a spiral spring, S. The sharpened upper end of this spring penetrated into a lump of solder in the cup fitted to the lower end of the rod supporting the lower end of the wire W. This permitted the whole apparatus to be withdrawn at any time by removing the metal stopper B and yet insured perfect contact from the outside with the wire W as soon as the apparatus was replaced in the glass tube. The negative terminal of the high voltage is connected with the metal stopper B. To eliminate water vapor, a glass vessel, D, of special shape was placed at the bottom of the glass tube A and filled with P_2O_5. Side tubes were sealed on the tube A as shown with stopcocks at V_1 and V_2 to regulate the pressure and control the admission of gases. The tube going to the pump is provided with a closed mercury manometer, M, and a trap, U, filled with gold leaf to prevent mercury vapor entering the apparatus, since one of the problems to be investigated was the effect of so-called catalytic "poisons" on the central electrode. The operation of the counter is very sensitive to pressure so that some means was needed to introduce these gases without altering the total pressure of the gas. This was accomplished by means of the tube L on the left-hand side of the figure and the 2-way stopcock V_3. The tube L had an internal tip of fine bore so that with pump running and all stopcocks open a constant pressure of gas of a suitable amount was maintained in the glass tube A. One side of the 2-way stopcock V_3 was connected to a drying bulb containing dry air at atmospheric pressure. By turning the stopcock over, connection could be made to a vessel containing some other gas at atmospheric pressure. Thus the gas, the effect of which was to be studied, could be admitted without altering the pressure in the apparatus, since these gases were used considerably diluted with air.

For observing the operation of the counter, a vacuum tube amplifier, described elsewhere,[3] was used. A milliammeter, included in the output circuit, gave "kicks" of 10 to 15 scale divisions for each electron counted when the counter was working properly.

The first point investigated was whether a specially prepared surface is needed for proper operation. Preliminary trials seemed to indicate that some treatment of the wire, such as that recommended by Geiger, was required. This was later found not to be the case when bare copper, even after being freshly polished, gave satisfactory results. In fact, every kind of wire tried, including nichrome, tungsten, and lacquered steel, seemed to work, although some were a little less sensitive than others. These results are in agreement with the observations of Kniepkamp.[4]

It was considered of interest to investigate whether there might be some evidence that adsorbed gas has something to do with the operation of the counter, even though a specially prepared adsorbing surface is not required. Adsorption occurs, of course, on all metal surfaces and it might be that at the reduced pressure, the ordinary adsorption, plays some rôle in the processes occurring in the chamber during counting.

The simplest way to test this idea is to try the effect of catalytic "poisons" just as has been done by the writer[3] for some of the

[3] Curtiss, L. F., Phys. Rev., 31, p. 1060; 1928.
[4] Kniepkamp, H., Phys. Z. S., 30, p. 237; 1929.

substances which are successful as coatings for points. In attempting to apply this test an interesting fact concerning the nature of the gas layers was observed. It was thought sufficient, in order to try the effect of poisons, to expose the specially heated wires to the poison for a time at atmospheric pressure. The pressure of the gas, consisting of a mixture of the poisoning gas with air, was then reduced to the proper operating pressure. However, when this was done no effect of the poison could be observed. This led to a repetition of the experiments on the poisoning effect with points and it was found that here, too, the reduction of pressure eliminated the effect of the poison. Therefore, it appears that even the poisoning gas is held only very lightly to the surface of the electrode and may be removed, sufficiently at least to restore the activity of the point, merely by reducing the pressure for a few minutes.

When this fact was discovered it was decided to try admitting the poisoning gas at the operating pressure while the chamber was counting and observe whether any effect was produced. This must be done without changing the pressure in the tube. For this purpose the tube L and the 2-way stopcock V_3 (fig. 1) were added as described above. With a steel wire, treated with HNO_3 as the central electrode, H_2S and SO_2 were each tried, and as soon as the gas reached the chamber counting stopped. Here again the effect was almost identical with that which the writer has observed with the point-type counter. Oxidized steel wires prepared in a flame behaved in the same way. Steel wires coated with platinum black by dipping in chloroplatinic acid were also poisoned by H_2S, SO_2, and ethylene. Finally bare metal wires were tried and they also showed similar effects.

The case of lacquered wires is of special interest for here it might be supposed that the sole function of the lacquer is to form a coating of high electrical resistance which helps to interrupt the discharge started by an electron passing through the gas. If this were true then one would not expect any effect from the catalytic poisons. If, on the other hand, the lacquer itself were acting as an adsorbing surface for a layer of gas which was the real sensitizing surface for the wire, then it should respond to the poison gases in the same way as the other coatings. Experiments with H_2S, SO_2, and ethylene have shown that it poisons in quite the same way as wires treated in other ways and, therefore, there can be little doubt that it does serve to hold a gas layer which is very important to the action of the counter.

Having established quite definitely that the nature of the gas adsorbed on the interior parts of the counter controls its behavior, it becomes important to know what rôle is played by this adsorbed gas in the counting operation. This operation is critically dependent on the kind of gas adsorbed. One must expect, therefore, that this layer of gas enters in some important way into the production of ions which constitute the momentary current in the chamber necessary to register the entrance of an electron. In the absence of information to the contrary we may assume that the sensitive layer of gas is on the wire electrode. The main features of the experimental results to be considered are the facts that (1) the counter works best at about 5 cm pressure, (2) better results are obtained with the tube negative, (3) the admission of a poison will stop the operation of the counter, or at least make necessary a change in the operating voltage.

III. DISCUSSION OF RESULTS

Before entering into a discussion of the bearing of the experiments described above on the action of the counter, we shall recall briefly the explanation offered by the writer [5] as the result of experiments with the point-type counter of the function of the gas layer. The point-type counter works readily at atmospheric pressure and with the chamber walls either positive or negative. When the chamber walls were negative it was found that the operation of the counter was independent of the kind of gas on the point at atmospheric pressure. On the other hand, with the walls positively charged, the counter would work only when certain particular gases were used with certain kinds of surfaces on the points. The explanation offered for these facts was that in the case where the chamber walls are negative the necessary ionization for registering a count may be produced by a small primary ionization resulting from the entrance of an ionizing particle, such as an alpha or beta ray. This primary ionization liberates a relatively few electrons near the chamber wall which, in turn, are drawn toward the point by the strong electric field, and during this process at each impact produce additional electrons so that the ionization current builds up exponentially to a relatively large value. Since there is nothing to maintain this type of discharge, it ceases as soon as it has moved down to the point. This explanation of the operation when walls are negatively charged assumed that, at atmospheric pressure and with the electric fields employed, the electrons in one or two free flights can acquire energy equal to the ionizing potential of the gas and that the number of useful impacts—that is, those producing ionization of the gas molecules—are sufficient to produce the necessary ionization current by the time the disturbance has reached the point. These assumptions appear quite reasonable, although very little quantitative data exists on this topic to verify them.

Turning to the case of the point counter with positive walls, the situation is quite different. The primary ionization produces a few pairs of ions near the chamber walls, as before. In this case, however, the positive ions are drawn toward the point while the electrons go to the chamber walls. The electrons move in a weak electric field and can not be expected to acquire enough energy from the field to produce much additional ionization on their way to the chamber walls. The positive ions likewise are unable to produce further ionization, since their mean free path is much smaller than that for the electrons, and they can not therefore at atmospheric pressure in any reasonable number of free flights on the average, acquire enough energy to ionize a gas molecule. Consequently, they would move down to the point and the disturbance would cease without having produced enough ionization to register a count. This is undoubtedly what happens in a counter with an improperly prepared point. If, however, we now assume the point to be covered with a gas layer held by forces which are small compared with those binding an electron to an atom, an explanation is possible. Such a layer of gas may be supposed to have a lattice structure similar to that of the metal, so that the boundary between gas and metal is not clearly defined and electrons diffuse from the metal into the layer of gas.

Curtiss, L. F. Phys. Rev., 31, p. 1060; 1928.

Another possibility is that the gas molecules themselves are in a dissociated state, so that electrons are shared by neighboring molecules. When a positive ion strikes this layer, it can give up the energy it has acquired from the electric field in moving toward the point. This energy should be quite sufficient to produce a momentary evaporation of the gas layer at the point of impact and the free or shared electrons will find themselves exposed to the intense electric field existing at the point repelling them from it. As they are pulled out toward the chamber walls they readily acquire energy sufficient to ionize by impact, and the positive ions so formed return to the point to release additional electrons. This process continues until the gas layer at the tip of the point has been momentarily exhausted of electrons, when the discharge ceases. The gas surface can quickly secure a fresh supply of electrons by diffusion from the metal of the point when it is again ready to operate. This explains why it is possible to get a series of discrete counts corresponding to the entrance of individual particles into the chamber.

Turning our attention now to the tube-counting chamber, we will try to adapt the explanation given above to the method of operation which has been found successful. Success with this form of counter has so far only been achieved with chamber walls negative and the pressure reduced. Since the point counter works well at atmospheric pressure without special treatment of the point, one might expect the wire counter to do the same. The fact that it does not arises from the fact that the voltages required to operate the wire counter at atmospheric pressure are too high so that the range of voltages over which the counter might be expected to operate is relatively very small. This instability is a result of the difference in geometrical design of the two types of counters. For the same applied voltage a much more intense electric field exists near the point than near the wire. Consequently, only at very high voltages will the electrons moving toward the wire acquire enough energy between effective impacts to ionize the gas molecules. To remedy this difficulty of instability, the pressure in the counter is reduced so that the electrons may acquire enough energy in their longer free flights to ionize on impact with about the same voltage applied to the counter as in the case of the point-type counter. When this is done, however, there are many fewer effective impacts, for the distance the electron has to travel to reach the wire has remained unchanged while the number of molecules which might be ionized have been reduced greatly. The result is that not enough ionization has been produced to register a count, and the counter fails to work. However, if we now assume that there is a layer of gas on the wire with properties like that assumed when discussing the operation of a negatively charged point, a possibility exists to secure the necessary ionization for registering a count.

When the electrons released by the entrance of the original ionizing particle strike this gas layer they will possess relatively high energy and will be able to communicate considerable amounts of this energy to electrons in the layer of gas and produce what amounts to an ionization of this layer. The electrons thus released from the layer will be attracted into the positively charged metal surface and the positive ions formed will be driven out through the gas by the electric field. At the reduced pressure these positive ions may be assumed to acquire

sufficient energy to ionize by impact, and the number of effective impacts may be expected to be comparable with those of the electrons in the same field and at the same pressure. This release of positive ions from the wire will continue to supply additional ionization until the gas layer at that point on the wire is exhausted momentarily, when it will cease. Since we have on the wire an adsorbing surface adapted to adsorbing the particular gas molecules in the chamber in the correct way to proper operation, this layer will almost immediately restore itself. By thus using the gas layer as a source of positive ions it is possible to see how the ionization by impact is built up at reduced pressure to a sufficient amount to enable a count to be registered. It must be admitted, however, that this explanation puts a heavy demand on the ionizing properties of positive ions, and it is difficult to justify such a demand in view of the limited information now available on this subject.

The effect of the poisons in all these cases is to cause the counter to cease operation. All discharges cease in spite of the fact that the primary ionization is still produced at the entrance of each alpha or beta particle. This seems to mean that the poisoning gas is adsorbed on the surface in such a way that the adsorbed gas molecules can not be evaporated or ionized in a way to release the electrons or positive ions required to produce the ionization sufficient to "count" the particle.

This effect of certain gases gives a very decisive answer to the question of the importance of the gas layer. Whether it functions in the way outlined above or not, a proper kind of layer which is different for different surfaces on the wire or point electrode is quite essential to the successful operation of the counter.

The writer has found that a large part of the trouble which is given by point-type counters arises from the poisoning effects of gases and vapors. Before the study of the effect of gases was made no effort was made to seal or otherwise protect the interior of the counter from vapors in the room when working at atmospheric pressure. After it was discovered that water vapor, mercury vapor, H_2S, SO_2, and other similar substances which might exist in the air of the room in small amounts, were very harmful to the action of the point, a counter was prepared having a small drying bulb sealed to it with a thin mica window waxed over the opening. All points were made gas tight with wax. The point in this counter worked for six months without attention and at a practically constant voltage. For permanent points and wires it seems quite necessary to exclude water vapor in particular. This is a poison to which practically all surfaces are sensitive and is everywhere abundant unless precautions are taken to eliminate it. In the present state of our knowledge of the processes of ionization, it is not possible to give a quantitative proof of the explanation which has been offered, although it does appear reasonable and includes the more important experimental facts. For example, very little is known about the number of ions per centimeter path one might expect to be found by an electron or a positive ion released under the conditions existing in the counter. Involved in this question are two important factors which are very uncertain. One is, under what conditions of field strength and gas pressure an electron or a positive ion may acquire a kinetic energy equal to or greater than the ionizing potential. The other is, what determines the fraction

of the ions with this energy which succeed in making an ionizing impact with an un-ionized molecule. This fraction is known to be relatively small, but little is known regarding its magnitude under given conditions. A further point which must also be considered is the contribution which excited atoms may make to the processes occurring in the counter. Their potential energy may be of considerable consequence, but so little is known about the subject that nothing quantitative can be deduced concerning it.

The writer wishes to express his thanks to L. L. Stockman and to H. L. Martin for help in the experiments and in making the counts. He is also indebted to Dr. J. H. Hibben, of the Geophysical Laboratory of the Carnegie Institution, for much helpful advice and criticism.

WASHINGTON, December 12, 1929.