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ON THE PHOTOSENSITIVITY OF GLASS SELF-QUENCHING GEIGER-MÜLLER COUNTERS WITH EXTERNAL CATHODE*

by

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Self-quenching glass Geiger-Müller counters with external cathode show more or less photosensitivity. Counters which were constructed with the most cautious vacuum treatment become photosensitive only after some time of operation. In the following paper we describe some experiments made to clear up the photosensitivity. The effect is observed through the occurrence of spurious counts or double pulses in day light. We could distinguish between a photoelectric effect at the inner surface of the glass wall (surface effect) and within the gas volume (volume effect). The volume effect seems to be connected with the electron attachment to oxygen molecules which either were left in the tubes or created by the decomposition of the alcohol vapor. The probability of electron attachment increases considerably if the oxygen comes into a metastable state by light absorption. The negative oxygen ions coming in the neighborhood of the central wire, the anode, will lose in the high electric field their electron which will start a new avalanche while the real count will be almost completely over.

The second type of photosensitivity which we call the surface

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effect, seems to be connected with the decreasing of the work function of the glass by adsorbed gases - e.g. hydrogen coming from the decomposition of the alcohol vapor. The liberation of electrons from the glass surface by photons will thus be facilitated.

1. DESCRIPTION OF THE GEIGER-MÜLLER COUNTERS AND THEIR CONSTRUCTION.

The investigated counters are similar to those described by Maze [1]. The cathode has been formed by an aquadag layer on the outside wall of the glass tube (about 25 mm in diameter, 35-40 cm in length, and 0.5 mm wall thickness). The glass was an alkali-lime glass of Brazilian manufacture, the resistance of which was sufficiently low to allow the pulses to pass.

As an anode we had at the center of the cylindrical tube, a tungsten wire of 0.1 mm in diameter which could be degassed by electric heating.

After applying extremely clean vacuum treatment, the tubes were filled with 10 Torr (mmHg) of 99,87º G.L. (at 15ºC) ethyl alcohol vapor and 90 Torr of spectroscopically pure argon. They were made in a series of ten counters. Instead of degassing the tubes in the common way by using a resistance type furnace, we obtained good results by heating them with a system of infra-red reflectors.

These counters will be used for our cosmic ray research in the Bolivian Andes.

From the point of view of electrical behaviour and operation, this type of counter has already been well investigated by Aron and Gross [2].

2. OBSERVATIONS ON THE PHOTOSENSITIVITY OF THE COUNTERS.

It is well known that almost all Geiger-Müller-counters are more or less sensitive to light. The only way to suppress this is to protect them against light; for example, by painting them with an opaque black paint.

In the following, we call a counter photosensitive if the counter, exposed to a radioactive source, does not give the same plateau curve in daylight as it gives in the dark, as seen in fig. nº 1.

From the 600 counters that were constructed in our laboratory during the first eight months we can conclude that only those which were constructed under very cautious vacuum treatment had little photosensitivity, or were not photosensitive.

All counters that were considered bad, i.e., which had plateaux less than 150 volts with slopes steeper than 5 %/100 volts, were photosensitive. From this we must conclude that the photoelectric effect must have something to do with the gases that remained in the counters; perhaps in the gas volume or in the solid material, glass or metal parts.

The question remains: is it the gas (oxygen, water vapor or other gases or vapors) in the gas volume or the adsorbed gas on the walls, or both, that causes the photosensitivity?

We must distinguish between two forms of counters which are photosensitive:

1) those which show the effect from the very beginning of their operation and
2) those which become photosensitive only after some time of operation.

In general we can say that counters of the first group were not so well vacuum-treated as those of the second group.

As H. Neuert and Geerk found in 1950 [3] (and later M. L. MacKnight and R. L. Chassen [4]), their counters became photosensitive after a "life-time" of 10^6 to 10^8 pulses. It is easy to calculate the number of alcohol molecules decomposed by one pulse. The pulse height may be 100 volts; it is equal to

$$dV = \frac{Q_o}{C} = \frac{n \cdot e}{C} = \frac{n \cdot 1.6 \times 10^{-19}}{C}$$

Assuming that $C = 10^{-11}$ F, which corresponds to our counter size, we get for the number of electrons arriving at the cathode

$$n \approx 10^{10} .$$

The discharge being quenched by the alcohol vapor, an equal number of alcohol molecules must be decomposed. This means that after 10^7 pulses, 10^{17} oxygen or hydrogen or other diatomic gas molecules must have been created; but this number is equal to 1 % of impurity in

the gas volume of the counters of the first group with photosensitivity right from the beginning, or approximately, it is the number of molecules that occupy a monolayer on the wall.

The question whether the photoelectric effect occurs at the surface of the solid parts of the counters, or in the gas volume, has no sense in our opinion, because both the surface and volume effects happen. In the counters of the first group there will be the volume effect in majority at the beginning, as the inner surfaces of the counters will not yet have become "activated" by adsorbed molecules.

So we must distinguish between counters that are preferentially volume photosensitive and those that are preferentially surface photosensitive.

All counters become, after some time, more surface photosensitive. This is proved by H. Neuert and J. Geerk [3], Gross and Aron [2] and by our own experiments.

After observing the photosensitivity of their pure NH_3 counters, Neuert and Geerk [3] pumped the gas away and filled the counters with pure argon and alcohol vapor; the photoelectric effect continued. Immediately after the first 10,000 pulses we did the same with our counters of the first group, i.e. counters that showed photosensitivity right from the beginning. These counters after having been refilled with new argon-alcohol mixture became much less photosensitive (only 10 % of that before). But those of the second group which became photosensitive after some time, kept their photosensitivity almost unchanged after renewing the argon-alcohol filling. Counters of the second group only lost their photosensitivity after being degassed during pumping and being refilled with pure argon-alcohol.

3. ATTEMPT AT EXPLANATION OF THE PHOTOSENSITIVITY

Obviously the reason for the volume effect is that the gas or vapor filling was not pure enough; mainly oxygen or water vapor might be the contaminating components. And there is no doubt that the surface effect is involved with the products of the decomposition process of the quenching vapor adsorbed at the alkali-lime glass wall; perhaps activated for adsorption by carbon deposit coming from the decomposed

alcohol vapor. Counters that were not well baked out showed surface photosensitivity from the very beginning, but these we will not consider.

a) Volume Photosensitivity

The light that can pass the glass must have a wave length longer than 3,500 Å. The photons entering the counter from outside can thus have an energy only smaller than 3.5 eV. But there is no gas atom that can be ionized by such a small energy. Collisions of the second kind, i.e. by gas atoms excited to a metastable state, are unlikely.

The most likely explanation of the volume effect seems to us that which takes into account the formation of negative ions promoted by photons.

It is known that the probability of electron attachment to oxygen is much higher than that of all other gases. The probability of the formation of negative oxygen ions lies between 10^{-4} and 10^{-3} [5], but this is sufficiently high in the case of our counters, because the mean free path for electrons is of the order of 10^{-4} cm, so that an electron passing the counter will have more than 10^{4} collisions with the gas and vapor molecules. As J. Franck and W. Grotian [6] pointed out, the probability of electron attachment to oxygen molecules lies some ten powers higher for molecules that are already excited than for molecules in the ground state. As it is known, on the other hand, that oxygen can come into several excited states (7,608; 6,867; 6,283 Å) with wave lengths longer than 3,500 Å, but within the visible light, such excitations might occur in our counters. There are excited metastable oxygen molecules which have life-times of about seven seconds [7]. And thus the probability of the formation of negative ions seems to be rather great. As is known [8], negative oxygen ions will give rise to spurious counts, or double pulses. They will have about the same velocity as the positive ions; arriving in the immediate neighborhood of the central wire, i.e. in the high electric field, they may lose their electron and this will start a new avalanche, while the real count has almost finished.

Some counters with volume photoeffect show a maximum in the count-

ing-rate-voltage-curve before reaching the plateau, as seen in fig. nº 1. Perhaps this might be explained as well by observing the probability curve for the formation of negative ions [5]. Here there is known to be a slight maximum of the curve for oxygen and air, and this might give reason for suspecting the existence of resonance-phenomena. Whether there is relation or not between the maximum of this curve and the maximum of our curve in fig. nº 1, cannot be decided from our experiments. But the maximum in the probability curve makes it seem likely that the formation of negative ions can produce spurious counts or double pulses that will disappear in some amount after exceeding the voltage maximum for the probability of electron attachment.

At this point we should like to emphasize how necessary it is to degas the tungsten wire, as it is well known that tungsten easily adsorbs oxygen; electrons arriving at the wire with comparatively high energy may release oxygen and this will give more possibilities for the photoeffect as described. Experiments have borne this out.

b) Surface Photosensitivity

The surface photoelectric effect is somewhat easier to understand. By approximately 10^{10} electron collisions during each pulse, the alcohol vapor decomposes into hydrogen, oxygen and carbon. This latter will deposit on the walls and thus form a good adsorption surface for the gases, so that the work function of the wall will be considerably changed. It is a well known fact that the work function will be decreased if electropositive atoms, as e.g. hydrogen, will be adsorbed in a monolayer. As B. Abendroth [9] pointed out, the photosensitivity of any material will be increased by several powers of ten, when water vapor has been adsorbed by the material. They found as well, a maximum of the photosensitivity when the adsorbed layer had been a monolayer of molecules. In our tubes such a monolayer is reached with about 10^{17} molecules, but this number is in fact the number of alcohol molecules which will be decomposed after 10^{7} pulses which will turn the counter extremely photosensitive.

This fact of a maximum photosensitivity at surfaces with a monolayer of adsorbed molecules may perhaps explain the observation [10] that

tubes of the described type which were not baked out at all did not show photosensitivity. It is known that unprepared alkali-lime glass surfaces often show an adsorption layer (especially formed by water vapor) of a thickness greater than 30-40 monolayers [11]. Of course the life-time of such roughly made counters will be much shorter, because the adsorbed gases or vapors will enter the volume and contaminate the filling.

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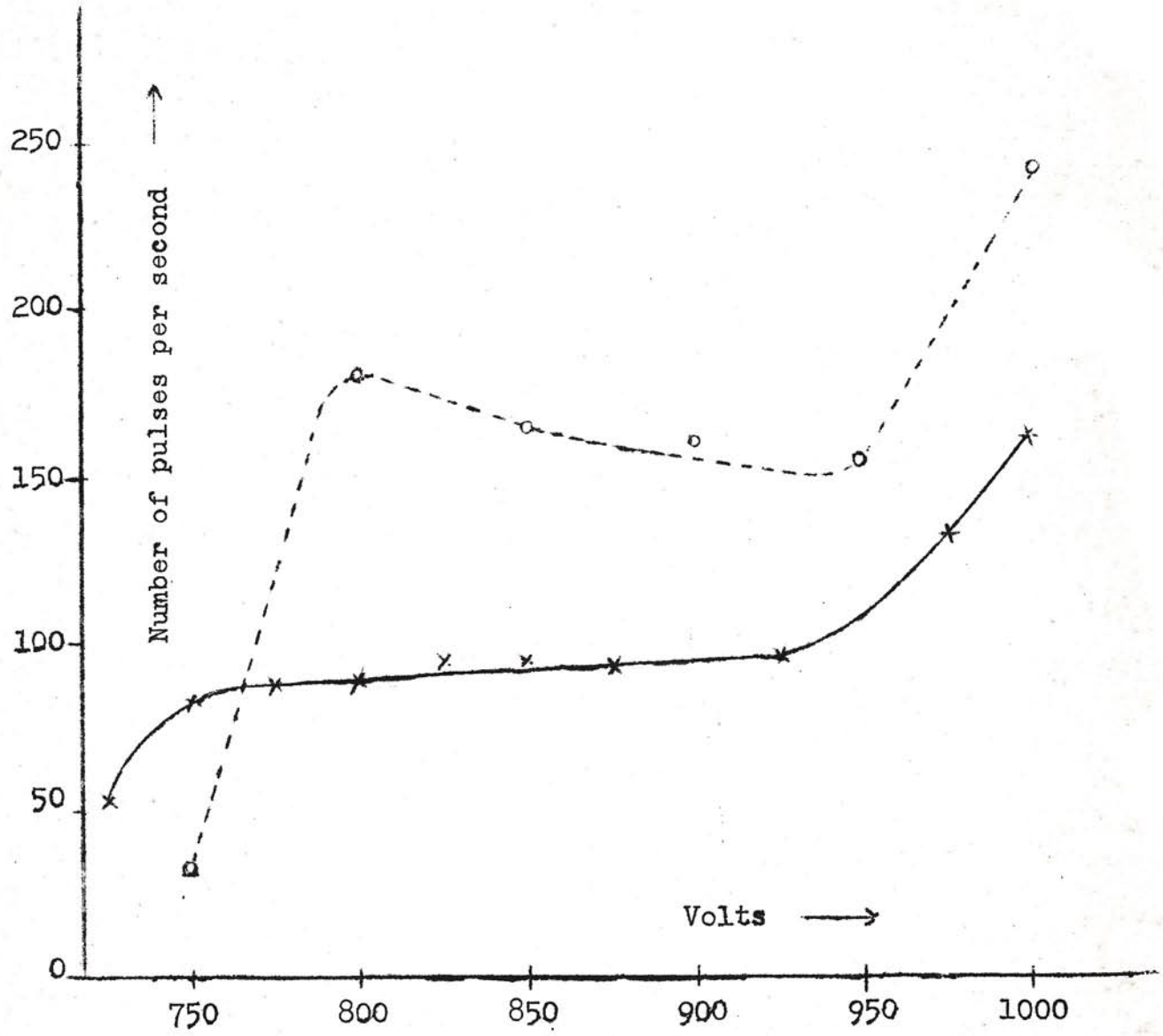

FIG. I

Plateau curves of the Geiger-Müller counter with external cathode.

Full line : counts in the dark.
Broken line : counts in daylight.