Delayed Emission of Electrons from the Cathode in a Counter When Operated above the Plateau

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February 25, 1949

EXPERIMENTS on the discharge in the conventional Geiger-Müller counter tube in the voltage range above the plateau were reported recently by one of us.[1] Results suggested that any given discharge was initiated by an after-emission of electrons or photons excited by the preceding discharge. The experiments did not show whether it was the cathode, anode or gas which was mainly responsible for the after-emission, and an investigation of that point is the subject of the present note.

A double counter was prepared having a brass envelope 1 inch in diameter and 10-inches long, with a 10 mil tungsten wire 3-inches long mounted in each end. A cylinder $\frac{3}{4}$-inch inside diameter and 3-inches long, inside the brass envelope, formed the actual cathode. This could be slid from one end to the other by tilting the envelope, so it was possible to make it serve as the cathode for first one wire and then the other. The envelope was filled with 9 cm argon and 1 cm alcohol vapor. The plateau, for each counter, extended from 1050 to 1150 volts. The two wires were connected to independent counter circuits and scalers. The measuring procedure was simple: with the cathode cylinder surrounding the first wire 2000 volts were applied to the counting circuit connected to that wire, so as to produce the well-known rapid succession of spurious counts, and this was allowed to continue for 2 seconds. Then the cylinder was slid to the other end, where the voltage was adjusted for normal counting. The counting rate *versus* time was obtained by photographing the lights of the scaler and a clock with a movie camera. A strong activity was found to result from the high voltage discharges. No counts were obtained when the same procedure was carried through without the application of the high voltage in the first position. A series of runs was made with the same gas mixture, but with different metals for the sliding cathode. The decay curves, as shown in Fig. 1, turned out to be quite

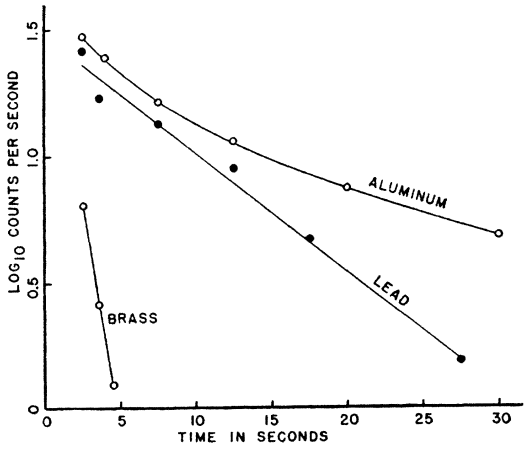

FIG. 1. Decay curves of the counting rate for different cathodes.

different from one another, which makes it evident that the delayed counting is predominantly due to the cathode surface. One cathode tried (iron) gave no counts above background, which means either that it acquires very little activity or that it dies away in a shorter time than 2 seconds, which is the time occupied in transferring the cathode in our experiments. All the metals were given the same preparation—they were dry polished in a lathe with fine steel wool, and were not touched or washed in any way.

It should be remarked that in the case of aluminum, the cathode had to be aged before it was used, because it was found that the polishing process gave it initially an activity of about 900 counts per second, which seemed to have a "half-life" of about three hours. None of the others showed appreciable initial activity, although they were used in one half hour to one hour after being polished.

The delayed emission of electrons from surfaces which have been strongly bombarded has been studied by a number of workers.[2-6] The "half-lives" found agree in order of magnitude with those found by us in the counter tube. The indication is, therefore, that when a Geiger counter is subjected to voltages above its plateau the same general phenomenon occurs, but on a much smaller scale, amounting to only a small number of electrons per second. A reasonable explanation for the rapid succession of spurious counts which the counter gives above its plateau is that each count is initiated by the delayed emission of electrons from the cathode, excited by the preceding count.

[1] H. R. Crane, Phys. Rev. **75**, 985 (1949).
[2] M. Tanaka, Phys. Rev. **48**, 916 (1935).
[3] L. Malter, Phys. Rev. **50**, 48 (1936).
[4] H. Paetow, Zeits. f. Physik **111**, 770 (1939).
[5] R. W. Pidd and L. Madansky, Phys. Rev. **75**, 1175 (1949).

Neutron-Hydrogen Mass Difference from the $T^3(p,n)He^3$ Reaction Threshold

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March 7, 1949

THE threshold for the reaction $T^3(p,n)He^3$ has been measured by observing the neutrons produced when protons from the Los Alamos electrostatic generator strike a target of tritium absorbed in zirconium.[1] The absolute value of the threshold energy was established relative to the highly accurate $Al(p,\gamma)$ resonance at 993.3 kev quoted by Herb, Snowden, and Sala.[2]

An assembly carrying the tritium-zirconium plate, a piece of clean $\frac{1}{32}$-inch aluminum, a LiF crystal, and a zirconium metal blank allowed rapid interchange of targets in the vacuum. A large liquid air trap was placed immediately in front of the targets, all of which were thick for protons in our energy range.

Gamma-rays were counted in double coincidence at right angles to the proton beam and neutrons were counted at 0°. Neutron background below threshold and gamma-ray coincidences from protons on the zirconium blank were negligible. The Al target was scraped clean, immediately put into the vacuum and a beam run on it within about ten minutes; with the beam on, the Al and LiF targets ran at near a dull red heat. Over a period of six days no shift of more than ± 1 kev was observed in either the Al resonance step or the $T^3(p,n)He^3$ threshold indicating that no appreciable contaminating layer built up on these targets during the experiment. The tritium-zirconium plate had not been used previously, but had been in air long enough to cause some concern over the possibility of an appreciable oxide coating on the surface. After having obtained a neutron threshold on this target in its original condition the plate was removed from the vacuum, the surface cleaned with number 600 carborundum and another measurement of the threshold made as quickly as possible. The two values of the threshold so obtained were within 0.7 kev of each other, whereas the energy ripple of our machine is approximately 1.5 kev. Proton currents on the tritium-zirconium targets were kept at about one-fifth of those on the other targets to avoid loss of tritium by heating.

The width of the step in the gamma-ray yields were about 2.0 kev for Al and about 1.0 kev for F. The thresholds for $T^3(p,n)He^3$ and $Li^7(p,n)Be^7$ were determined to plus $\frac{1}{2}$ kev

and minus 1 kev. Assuming the Al(p,γ) resonance to lie at 993.3 kev we then found the F(p,γ) resonance at 873.1 kev and the $Li^7(p,n)Be^7$ threshold at 1880 kev agreeing with Herb, Snowden, and Sala's values to well within our voltage ripple. This scale then puts the $T^3(p,n)He^3$ threshold at 1019_{-1}^{+3} kev, giving a Q value of -763.7 kev, where the mass factor used was 0.749_5.

Assuming zero-neutrino mass and a beta-ray end point of 18.3 kev this threshold measurement gives the $n-H$ mass difference as 782 ± 1.5 kev. The 18.3-kev end point which gives the T^3-He^3 mass difference has been measured in this laboratory by Graves and Meyer[3] and by McKibben and Shurig.[4] This value is in agreement with other recent results.[5]

The neutron-proton mass difference determined here is roughly 18 kev lower than that given by Bell and Elliott[6] and that reported by Jenkins.[7] The systematic errors, aside from the absolute energy scale, which one would expect in our experiment are all such as to raise the threshold of $T^3(p,n)He^3$ and therefore the neutron-hydrogen mass difference.

[1] Graves, Rodriguez, Goldblatt, and Meyer, private communication, to be published in Rev. Sci. Inst.
[2] Herb, Snowden, and Sala, Phys. Rev. **75**, 246 (1949).
[3] E. R. Graves and D. Meyer, private communication, to be submitted for publication in Phys. Rev.
[4] J. L. McKibben and A. Shurig, private communication.
[5] Curran, Angus, and Cockcroft, Nature **162**, 302 (1948).
[6] R. E. Bell and L. G. Elliott, Phys. Rev. **74**, 1552 (1948).
[7] Reported by Mr. Jenkins at the February, 1949, meeting of the American Physical Society in Berkeley, California, Supplementary Programme.

On the Liberation of Ions by Electron Bombardment

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March 8, 1949

Trump and Van de Graaff[1] have recently proposed that the electrical breakdown between metallic electrodes in a high vacuum is due to the emission of positive ions from the anode under the electron bombardment. From direct measurements they deduce the liberation coefficient A of ions by electrons, *viz.* the average number of ions emitted per incident electron, as a function of its energy. The curve they give for a steel anode has a marked maximum of 10^{-3} ions/electron at approximately one thousand volts and a flat minimum, *viz.* an almost constant value of $A=2.10^{-4}$, between 20 and 180 kv; a steep increase follows as far as 225 kv. The maximum is attributed to ionization of the residual gas.

We have studied with greater care the phenomenon in the low voltage range with the aim of reducing as much as possible the effect of the residual gas, in order to determine a possible threshold for the phenomenon of the secondary emission of ions. The arrangement of the electrodes is shown in Fig. 1.

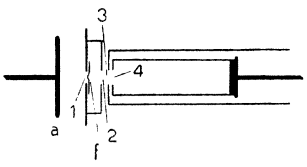

Fig. 1. Arrangement of the electrodes.

The diaphragms 1, 2, 3, 4 have, in this order, the following diameters: 2.7, 3.2, 3.7, 4 mm. The distance between the anode a and the cathode f (the emitting part of which is at the level of diaphragm 1), can be altered as desired. The vacuum, maintained by oil diffusion pumps and liquid nitrogen traps, is measured by means of a radiometer foil gauge and an ionization gauge.

The electrons hit a small area of the anode a around the axis of the system, and it is possible to observe directly the dark mark they produce if the apparatus contains a small amount of organic vapor.

The geometry of the experiment and the configuration of the field is such that if there is emission of ions from a due to incident electrons, the ions will follow the same path as the electrons but in the opposite direction. They will mainly fall in the Faraday cylinder c, which is functioning as a collector, as in the analogous arrangement of Trump and Van de Graaff, provided the initial speed of the ions is negligible as we think is true in our case.

The curves 1 and 2 of Fig. 2 have been obtained with a steel anode at distances of 6 and 12 mm from the cathode respectively, at the lowest pressure we could reach—about 10^{-6} mm Hg. In curve 1 the maximum is hardly noticeable; in the other it is well marked. It has been very difficult to obtain a curve without the maximum, working as we usually did with the apparatus under continuous pumping, for it is extremely sensitive to small variations in the conditions of vacuum and of the anode surface. The flat portion of the curve is, on the contrary, easily reproducible. The ordinates of this portion—and of the maximum too—are less than those found by Trump and Van de Graaff by a factor between 200 and 2000 in the interval examined by us (i.e. to 70 kv).

To reproduce approximately the values of these authors we took off the liquid nitrogen from the trap, so admitting the oil vapors (Apiezon oil B) into the apparatus. The pressure shown by the radiometer gauge (which in this range of pressure reads approximately absolute pressures) increases by a factor ~5, while the ionization gauge shows an increase by a factor ~10: the current in the Faraday cylinder increases by a factor ~200 with the same electronic current, as represented by curve 3 of Fig. 2 (distance 12 mm) for which the ordinate axis on the R.H.S. of the diagram has been used.

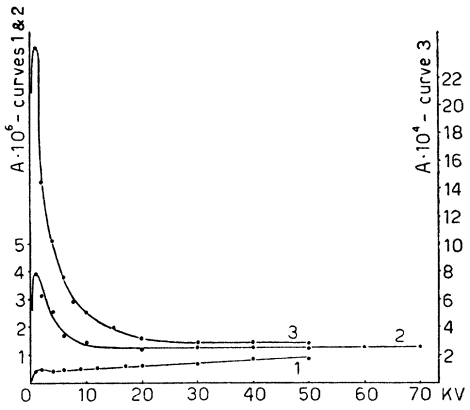

Fig. 2. Liberation coefficient A as a function of electron energy.

It seems to us that the values of these factors make it difficult to explain the current observed in these conditions as a mere effect of the ionization of the gas. We may note also in this connection that the maxima in the effective cross section of ionization by collision in the known gases generally occur at speeds of the order of a hundred and not of a thousand volts, as would be shown in the curves of Trump and Van de Graaff and in ours. We could perhaps postulate some surface effect on the anode, due to the presence of organic vapors. Only further experiments may settle this question.