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Certain Properties of a Spark Counter for Counting α-Particles

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It is shown that at the expense of a continuous corona discharge a spark counter possesses self-stabilizing characteristics. Investigations were made on the counting characteristics in relation to their dependence on various electrode spacings and on the humidity. It is shown that the efficiency of the counting increases with increasing humidity.

1. INTRODUCTION

IN recent years there has appeared a series of investigations[1-5] devoted to the analysis of a new type of spark counter. The idea of using a spark discharge for counting ionizing radiations is not new. In 1935, Greinacher proposed a spark counter in which a small sphere or wire of diameter 0.5-1.5 mm served as the anode and a metallic plate served as the cathode. The anode was separated from the cathode by a distance of 0.5 mm[6].

A spark discharge appears in Greinacher's counter when it is operated in air at atmospheric pressure in the presence of ionizing radiations. The duration of the discharge is limited by a quenching circuit and is approximately 0.01 sec long. The faults of this type of counter are the following: the large slope and the small length of the counting characteristic, the unstable operation, the indeterminate operating volume and also the small resolving power. It is necessary to point out that a discharge in this particular counter is caused not only by α, but also by β- and γ-particles. These counters acquired no practical use because of these faults.

In reference 7 it was shown that all these faults could be corrected if a flat metallic plate were used as the cathode, and a thin (diameter 0.1 mm) metallic wire was used as the anode. The wire was stretched parallel to the plane of the cathode and was located a distance of 1 - 1.5 mm from it. A counter of this type is generally operated in air at atmospheric pressure and, most important of all, a discharge in it is caused only by particles of large specific ionization. Because of the simple construction of such counters and the easy recording of the pulses (the magnitude of a pulse is very large and may reach a value of several thousand volts), such counters have, in individual cases, several advantages over other methods for counting α-particles, slow neutrons and fission fragments of uranium[4,5].

An important characteristic of spark counters is the ability to count these forms of radiation in the presence of practically an unlimited background of β- and γ- radiations. Such counters are very directional.

In Fig. 1, the schematic shows a section of the spark counter in two directions. Here A is the anode in the form of a wire, and K is the flat cathode. The arrow points in the direction of flight of the α-particles; the α-particles are counted only in that case in which the angle ϕ is not larger than 5 - 6°. The related angle, ψ, may attain the considerably larger value of 40 - 50°. Within these limits, the intense ionization of the α-particles

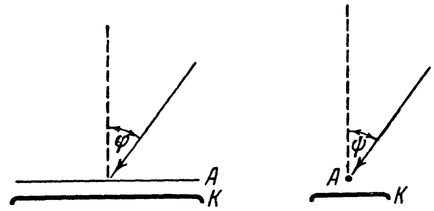

Fig. 1. A section of the spark counter. A -- anode, B -- cathode.

[1] R. D. Connor, Proc. Phys. Soc. (London) 64, 30 (1951)

[2] M. Ronald and B. Payne, J. Sci. Instr. 26, 321 (1949)

[3] R. D. Connor, J. Sci. Instr. 29, 12 (1952)

[4] P. Savel, Compt. rend. 235, 156 (1952)

[5] P. Savel, Compt. rend. 234, 2596 (1952)

[6] H. Greinacher, Z. Phys. 16, 165 (1935)

[7] W. V. Chang and S. Rosenblum, Phys. Rev. 67, 222 (1945)

causes the appearance of a spark discharge. The pulse is counted by an electronic circuit.

Present work is devoted to the investigation of the properties of the spark counter, in particular, to the dependence of the counting characteristics on the inter-electrode spacing, the humidity, the temperature, etc.

2. EQUIPMENT

A tungsten filament of diameter 0.1 mm, fastened to the plexiglass frame, served as the anode of the counter; a carefully polished plate of silver or brass served as the cathode. It was possible to change the distance between the cathode and the anode by means of a micrometer screw. As a source of α-particles, a preparation consisting of a mixture of radium, and mesothorium was deposited in a thin layer on a plexiglass disc 30 mm in diameter. For testing the dependence of the counting efficiency as a function of the angle ψ, the source was attached to a special holder and was set at various angles. (The axis of rotation of the preparation coincided with the direction of the wire. See Fig. 2.) Radiations from the surface in these cases were limited by a slit diaphragm, 5 mm wide and 30 mm long, placed 3 cm from the wire.

Since the sensitive region of the counter is limited to a region approximately 0.5 mm[1] wide, the only α-particles recorded are those which lie within the angle shown as a shaded region in Fig. 2. This produces a naturally collimated beam of α-particles.

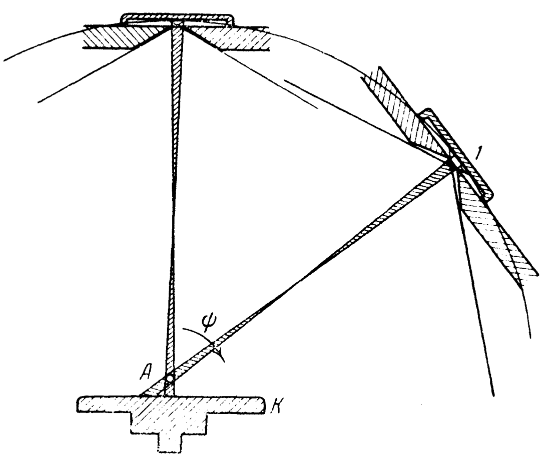

Fig. 2. A -- tungsten wire, K -- cathode, 1 -- source.

The pulses were counted by a scaling circuit, PS - 64. A rectifier supplied the high voltage for the wire (anode). The pulses arising from the discharge appeared across a voltage divider consisting of two series resistors, R_1 and R_2 ($R_1 = 5\,M\Omega$, $R_2 = 5\,k\Omega$), shunted by condensers C_1 and C_2. Pulses appearing across R_2 were fed to an amplifier which is in cascade with this scaler. This apparatus is mounted very close to the anode of the counter. For measuring the large corona currents, a microammeter was placed in series with the circuit*.

For measuring the dependence of the efficiency of the counter on temperature and humidity, the equipment was placed in a specially hermetically-sealed box (for decreasing the effect of ozone, produced by the discharge, the hermetically sealed volume was made equal to 1 m^3).

3. EXPERIMENTAL RESULTS

In Fig. 3 (curve *1*) a count-rate characteristic of a spark counter is shown. (The distance l between the wire and the plate was 1.5 mm; the diameter of the wire was 0.1 mm; the source was undiaphragmed.) The count-rate per minute, N, is plotted on the ordinate axis, and the full voltage V_B, of the high voltage supply is plotted on the abscissa. Also shown in this Figure is the corona current, I, (Curve *2*) as read on the microammeter**. As is seen from the Figure, the value of the corona current in the working range of the characteristic reaches large values (several hundred microamperes). Noting that, in the circuit of the counter, the value of the quenching resistance is several megohms, it follows that the potential difference between the anode and the cathode will be significantly smaller than the full voltage V_B. The spark counter under consideration we may consider as a corona stabilizer. The degree of stability in the cathode, as shown by Veksler[8], is determined by the ratio of the internal resistance of the dis-

[8] B. I. Veksler, A. V. Groshev and N. A. Dobrotin, *Experimental Methods of Nuclear Physics*, Moscow, 1940

* The values of R_1, R_2, C_1 and C_2 are to a large degree arbitrarily chosen. Because of the short duration of the pulse (approximately 10^{-8} sec), clearly, the condensers play the basic role in the divider circuit.

** It is necessary to state that we did not observe a peak at the beginning of the counting characteristic as is described in a series of papers [e.g., see reference 1, R. D. Connor, Proc. Phys. Soc. (London) **64**, 30 (1951) and reference 2, M. Ronald and B. Payne, J. Sci. Instr. **26**, 321 (1949)]. Possibly the absence of the peak is explained by the fact that this characteristic disappears on using an uncollimated beam of α-particles.

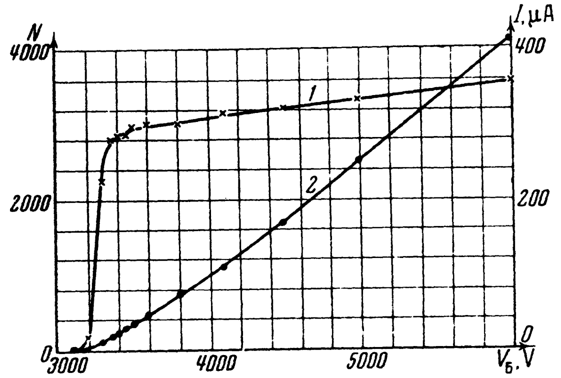

Fig. 3. *1* -- a typical counting characteristic of a spark counter; *2* -- the value of the corona current.

charge space and the external resistance, $R_1 + R_2$. Obviously, the true voltage in the counter will be

$$V_{A-K} = V_B - RI, \quad (1)$$

where R is the value of the quenching resistance ($R \approx R_1 + R_2$) and I is the value of the corona current.

The count and corona characteristics of the spark counter which are shown in Fig. 4 were constructed from the basic data of Fig. 3. The abscissa depicts the voltage during the discharge interval, V_{A-K}. It is understandable that the slope and length of the counting characteristic will depend on the value of the quenching resistance $R = R_1 + R_2$, since, by changing the value R, the degree of stability of the voltage V_{A-K} will change.

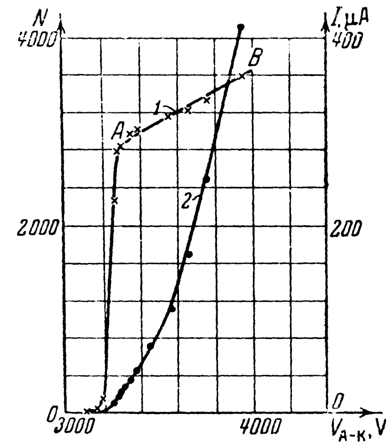

Fig. 4. *1* -- counting characteristic, and *2* -- corona characteristic of the spark counter, computed from the data in Fig. 3.

For illustration purposes, Fig. 5 shows the family of counting (curves *1* - *6*) and corona (curves *1'* - *6'*) characteristics for various values of resistance, R (R was varied from 2.5 to 150 MΩ).

Determining V_{A-K} from Eq. (1), all these curves can be combined into one counting and one corona characteristic, shown in Fig. 6. This Figure clearly shows the change in slope and magnitude of the counting rate with increasing values of quenching resistance. Increasing R increases the degree of stability, and even with significantly larger V_B, the voltage V_{A-K} on the counter still only corresponds to the initial rise of the counting

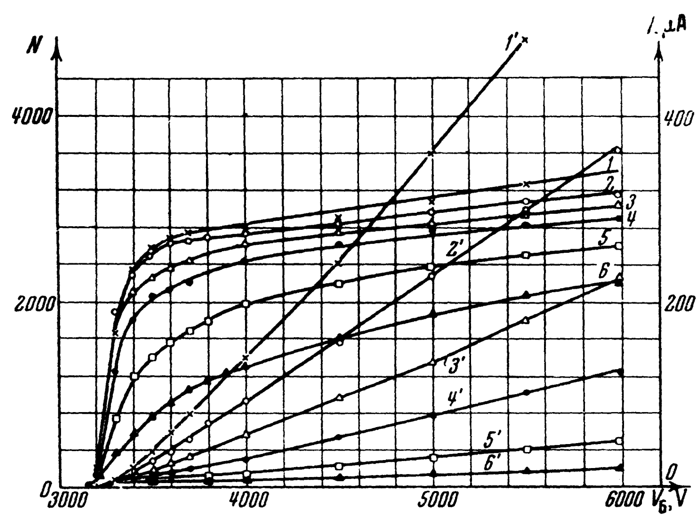

Fig. 5. *1* - *6* counting and *1'* - *6'* corona characteristics for various resistors: *1* = 2.5; *2* = 5; *3* = 10; *4* = 20; *5* = 50; and *6* = 150 MΩ.

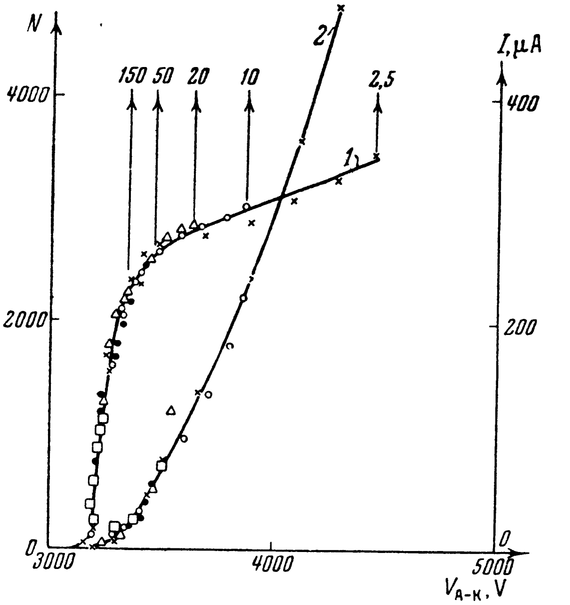

Fig. 6. *1* -- counting and *2* -- corona characteristics for various resistors: ×= 2.5; ○ = 10; △ = 20; = 50; = 150 MΩ, computed from the data of Fig. 5.

characteristic in Fig. 6.

In Fig. 6 the arrows show the limiting value of V_{A-K} for various resistances and a voltage V_{A-K} = 6000 V. With the resistance R = 150 MΩ all of the counting characteristic lies in the steep region of the curve. This causes the large slope of the counting characteristic in Fig. 5, and correspondingly, the small efficiency.

As was mentioned previously, the sensitive region of the counter, through which the α-particle should pass in order to initiate a spark discharge, has a very small volume and extends with a corresponding drop in efficiency at a distance of 0.5 mm around the center of the wire. It is obvious that the sensitive region around the wire is determined by the geometry of the electric field. The force field should be somewhat extended in the direction of the cathode. For determining the form of the sensitive region the equigradient planes of the system were computed. The curves in Fig. 7 were obtained for a wire to plate distance of 1.5 mm and for the potentials V_{A-K} = 3300 V and V_{A-K} = 4000 V (curves *1* and *2*). These particular potentials correspond to the points *A* and *B* on the counting characteristic shown in Fig. 4, and are equal to a value of E/p = 20 V/cm-mm of Hg. At present it is difficult to know precisely the dimensions of the sensitive volume. It is possible to hypothesize that the sensitive volume is

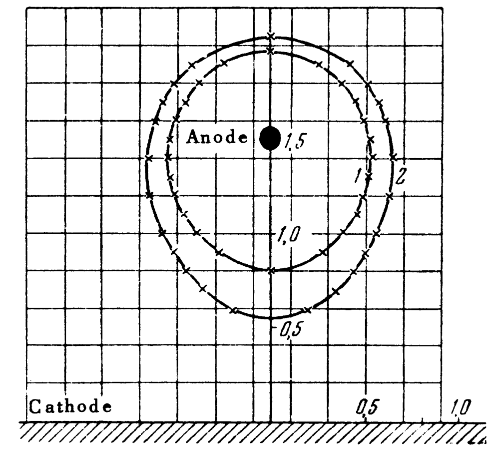

Fig. 7. Equigradient planes of the wire-plate system for E/p = 20 V/cm-mm of Hg.

positioned within the region bounded by the curve for E/p = 20 V/cm-mm of Hg, outside of which the negative ions begin to decay and the value of the Townsend ionization coefficient becomes largely equal to zero[9]. From the Figure it is seen that by increasing the potential of the wire, the sensitive volume expands. This leads to an increase in the number of counted particles and seems to affect the magnitude of the slope of the counting characteristic.

From these considerations, one must expect that the slope of the counting characteristic will change, depending on the angle at which the α-particles enter into the sensitive volume. To examine this hypothesis the number of counted particles was determined as a function of the angle ψ. The results of these measurements are shown in Fig. 8, where curve *A* is for V_{A-K} = 3600 V and curve *B* is for V_{A-K} = 4200 V. While ψ = 0 the number of counted particles increases, for example, by 5%, while at angles ψ = 30 - 60° the relative sensitivity increases 35 - 60%.

Two counting characteristics (linear part) for ψ = 0 and ψ = 40° are shown in Fig. 9.

It is obvious that the form of the counting characteristic already shows the existing dependence of the counter characteristics on the spacing of the anode relative to the cathode. Figure 10 illustrates a family of counting (*1* - *4*) and corona (*1′* - *4′*) characteristics for a wire-to-plane spacing of 1 to 5 mm and R = 5 MΩ. Now noting the decrease of effective counting rate with an increase of the distance, it is obvious that the connection

[9] N. A. Kaptsov, *Electrical Phenomena in Gases and Vacuum*, Moscow, 1950

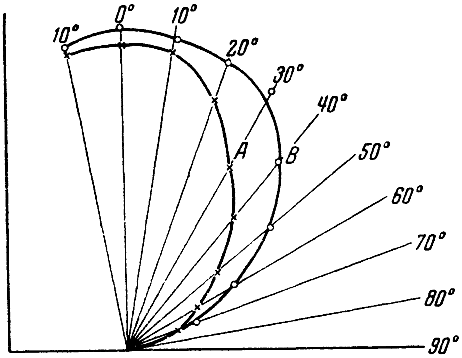

Fig. 8. The number of counted particles as a function of the angle ψ for the two values of voltage: A = 3600 V, B = 4200 V.

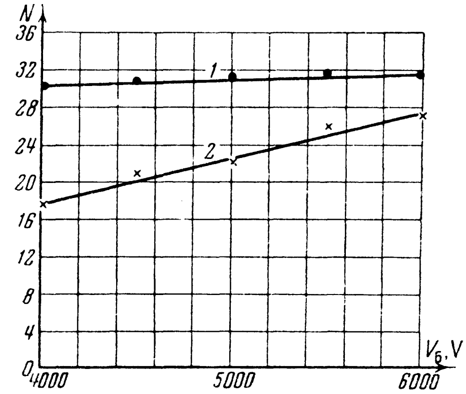

Fig. 9. *1* -- $\psi = 0°$, *2* -- $\psi = 40°$.

is due to the decreased probability of starting a streamer in a region of small field gradient. It is necessary to note that beginning with a distance of 3 mm the appearance of a visible spark is not generally observed at the start of the characteristic curve.

It should be noted that the substitution for the wire-plate system of electrodes, of a wire-cylinder or half cylinder system, improves the quality of the counting of the apparatus. By this change the efficiency of counting is increased at the expense of the geometry of the electric field. This is shown in Fig. 11. For comparison, the variation in counting sensitivity as a function of the impinging α-particles for a wire and plate system (curve *2*) and a wire and semicylinder system (curve *2* ′), for a semicylinder of radius 1.5 mm, are shown. The counting efficiency at $\psi = 0$ we set equal to unity. As seen in Fig. 11, for the wire-semicylinder case, the counting sensitivity remains constant to the 60° angle. At larger angles the decrease in sensitivity can be explained as caused by the decrease of the electric field due to the edge effect.

The final important characteristic of this counter is the constant stability of the apparatus with changes in temperature and moisture. Experiments indicate that the sensitivity of the counter is strongly dependent on the amount of water vapor. As illustrated in Fig. 12, three counting characteristics (for a wire-plate structure) are shown for various water vapor pressures: 22 mm of Hg (curve *1*), 12 mm of Hg (curve *2*), and 5.6 mm of Hg (curve *3*). The corona characteristics are also shown in this Figure. As seen from the

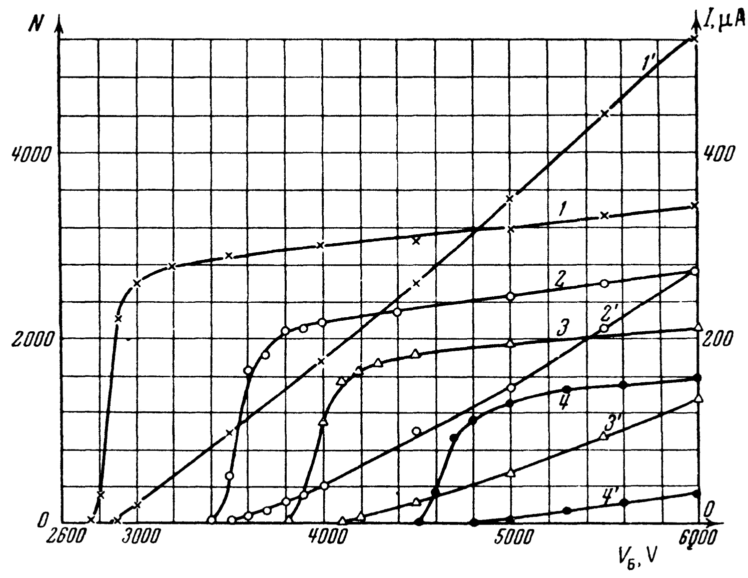

Fig. 10. *1* - *4* counting and *1*′- *4*′ corona characteristics for various wire-to-plate spacings: *1* = 1; *2* = 2; *3* = 3; *4* = 5 mm.

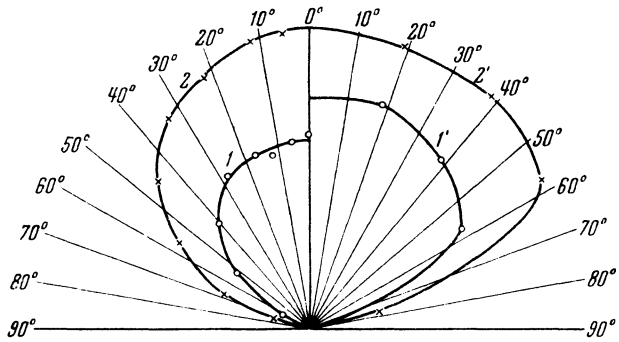

Fig. 11. The change in the sensitivity of the counter with the angle of the impinging α-particle: *2* -- for a wire-plate system, *2'* -- for a wire-semicylinder system.

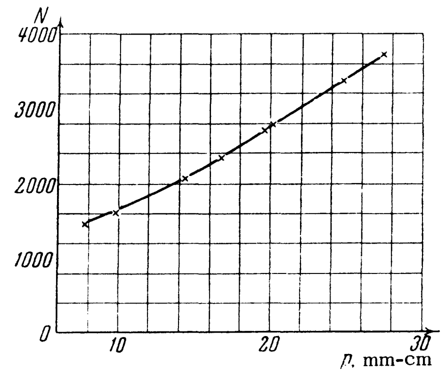

Fig. 13. The dependence of the countrate on the water vapor pressure.

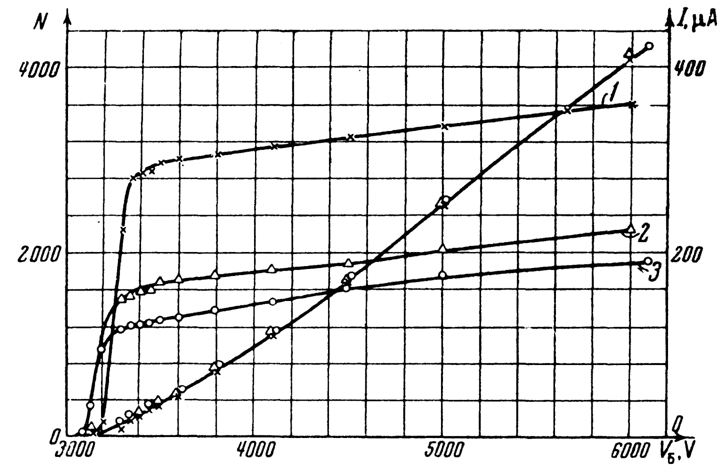

Fig. 12. *1, 2, 3* -- counting and corona characteristics (wire-plate system) for various water vapor pressures: *1* - 22; *2* - 12; *3* - 5.6 mm of Hg, $T = 23.5°$ C, a spacing $A - K = 1.5$ mm.

Figure, there is a rapid fall in efficiency of counting on decreasing the humidity (the value of the corona current at the same time remains constant).

In Fig. 13, the curve of the dependence of the counting rate (at constant voltage, $V_B = 4000$ V, on the counter and the spacing, $L = 1.5$ mm) on the water vapor pressure is shown. The observed dependence of the efficiency of counting on the moisture is a deficiency of the spark counter, and, in carrying out a number of measurements, periodic checks on the stability of the apparatus must be made. It is necessary, therefore, to state that in the practical case, the dependence of the counting rate on a change in humidity is rarely observed. Also, it is not difficult to control the stability of the apparatus.

The character of the angular dependence of the sensitivity of the counter does not change with changing humidity. This is seen from the companion curves *2* and *1*, and *2'* and *1'* of Fig. 11, for vapor pressures of 23.7 mm of Hg (curve *2*), 3.7 mm of Hg (curve *1* for wire-plate electrodes), 22.3 mm of Hg (curve *2'*), 6.0 mm of Hg (curve *1'* for wire-semicylinder electrodes).

The increase in the efficiency of the spark counter by increasing the humidity, apparently, is linked with the formation of heavy negative ions. Increasing the humidity increases the probability of forming heavy negative ions and as a result of this, diffusion is decreased. This fact may bring about the development of spark apparatus operating under more favorable conditions and consequently counting α-particles with greater efficiency.

Translated by I. B. Berlman
57