A NEW GAS-DISCHARGE TRACK DETECTOR: THE STREAMER CHAMBER [1)]

B. A. DOLGOSHEIN and B. I. LUCHKOV

P. N. Lebedev Physics Institute, Academy of Sciences, U.S.S.R.

Submitted to JETP editor November 4, 1963

J. Exptl. Theoret. Phys. (U.S.S.R.) **46**, 392-395 (January, 1964)

A new device for recording the tracks of charged particles—the spark chamber [1-4]—has recently been developed and successfully applied in the experimental physics of elementary particles. The principal advantage of the spark chamber over other track detectors is its speed. However, the spark chamber exhibits anisotropy in the degree of localization of particles travelling at various angles φ with the direction of the electric field E. The spark follows the particle trajectory only up to the angles $\varphi \approx 30$—$40°$.[1,3] If a particle travels making a greater angle φ, a spark "shower" is formed along the particle path parallel to **E**.[1,3] The trajectory of such a particle is well defined in the electrode plane,[5] but the third coordinate parallel to E is known only to within the value of the interelectrode distance. Another disadvantage of the spark chamber is the difficulty of recording the interaction and decay of particles.

We shall describe a new type of gas-discharge chamber—the "streamer" chamber—which records equally efficiently the particle tracks along any direction, reproducing the space configuration of the event.[2)]

The essential feature of the streamer chamber is the use of an incomplete spark discharge. The point of passage of the particle is indicated not by a spark but by a streamer, or more exactly by the initial portions of all the streamers which form from the electron avalanches along the particle path. The gas discharge in the chamber is stopped artificially at that stage when the electron avalanches grow into streamers and the latter begin to travel to the electrodes at a velocity of $\approx 10^8$ cm/sec.[6] The radiation of the gas in the streamer plasma makes the track visible. The particle track consists of a series of luminous streaks which are the initial portions of the positive and negative streamers. The length of the streaks depends on the duration of the electric field pulse and can be made sufficiently short. It is clear, from the mechanism of the track formation, that a large number of particles, irrespective of their direction, can be recorded in the streamer chamber.

The chambers used by us were in the form of Perspex boxes measuring $700 \times 500 \times 100$ mm or $600 \times 500 \times 250$ mm. The electrodes were duraluminum plates or glass with a transparent conducting coating which permitted photography through the electrode. The chambers were filled with neon at pressures of 0.3—1 atm.

The pulse supply circuit is shown in Fig. 1, the main features of which are a powerful pulse voltage generator (PVG) and an auxiliary device for forming short voltage pulses (≈ 50 nsec). The PVG consisted of a 20-stage Arkad'ev–Marx generator,[7] which gave a maximum voltage amplitude of 460 kV. The device for the forming of the short pulses was an air spark gap between two steel spheres, fixed to the chamber plates. The breakdown in the spark gap occurred a certain time after the arrival of the voltage pulse at the electrodes,[8] and this interval could be easily varied by altering the distance between the spheres.

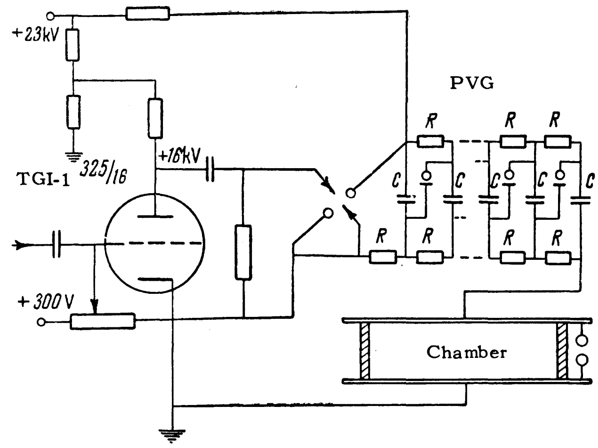


FIG. 1. Circuit for pulse supply of the chamber

Figure 2 shows photographs of cosmic-ray tracks in a streamer chamber. The chamber was placed so that the electric field made an angle of 90° with the vertical and the cosmic rays traversed the chamber almost parallel to the electrodes. The tracks were photographed through a transparent glass electrode (along the direction of the field **E**) and through a side wall (at right angles to the field **E**) using the objectives Yupiter-3 [Jupiter-3] (1:1.5) and R-Biotar (1:0.85) and type 13 aircraft film (sensitivity 3000 GOST units).

Figure 2a shows a photograph of a single cosmic-ray particle taken through the side wall. The distance between the electrodes was 100 mm. The particle track is seen to consist of a series of luminous streaks which are the initial portions of the streamers developing along the field **E**. The length and brightness of the streaks are seen to vary because of the fluctuations in the development of the electron avalanches and streamers. On the average, the streak length in this case was ~ 10 mm. The earlier stopping of the discharge in the chamber, by breakdown of the air gap, narrowed the track quite easily. Tracks with streak lengths of $\approx 2-5$ mm were easily observed with the naked eye. The brightness of the tracks decreased with reduction of their thickness and narrow tracks (2—5 mm) were not recorded on the film.

Figure 2b shows a photograph of a cosmic-ray particle taken through the transparent electrode. The track in this projection is brighter since each streamer is projected into a point. The thickness of the track and the scatter of the point around the trajectory of the particle is smaller than in the usual spark chamber and the brightness of the points is more uniform. It follows that the precision of the localization of the particle trajectory in the streamer chamber is better than in the spark

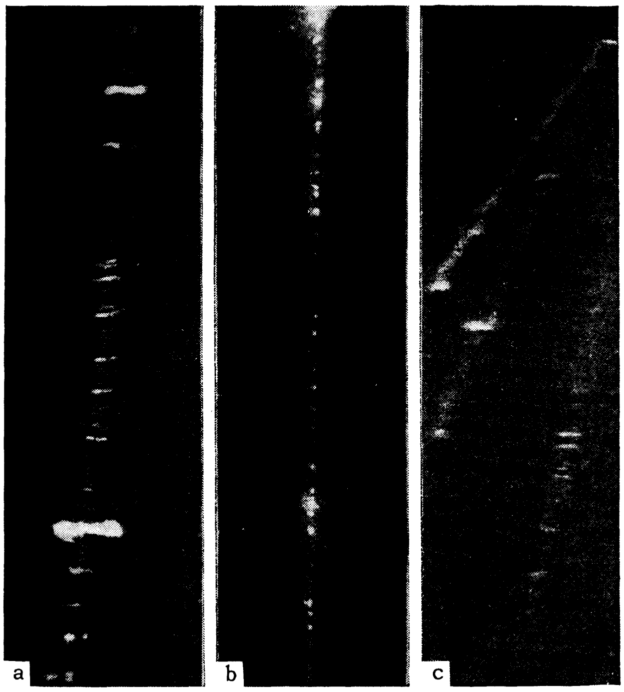


FIG. 2. Photographs of particle tracks in a streamer chamber: a) a single cosmic particle travelling across the chamber almost parallel to the electrodes, photographed through the Perspex side wall with the R-Biotar objective (1:0.85); b) a cosmic particle passing parallel to the electrodes, photographed through the transparent electrode with the Jupiter-3 objective (1:1.5); c) a three-particle shower, photographed with the R-Biotar objective through the side wall of the chamber.

chamber under projection conditions.[9,5] In this projection, we can observe quite accurately the interaction of particles with matter and measure the curvature of the trajectories in a magnetic field. The projection obtained by photographing through the side wall serves only to determine the point of motion of the particle through the chamber.

Figure 2c shows a photograph of a shower of three particles which intersect the chamber at various angles φ.

Apart from the noted advantages of the streamer chamber, it must be pointed out that its dead time should be considerably shorter than the dead time of the spark chamber because the charge density in the plasma of the initial streamer is considerably lower than that in the spark channel. Therefore, the streamer chamber is obviously an even faster track detector than the spark and discharge chambers. The problem of measuring the density of ionization of the particles in the streamer chamber also looks more promising than in the spark chamber. In conclusion, we note that the streamer chamber is a very convenient device for the study of the initial stages of a spark discharge.

The authors thank Professor A. I. Alikhanyan for his continuous interest in this work, V. V. Dmitrenko and V. V. Chizhov of the Moscow Engineering Physics Institute Problems Laboratory, and L. V. Sukhov of the Physics Institute of the U.S.S.R. Academy of Sciences, for their great help.

1)This paper was presented at the All-Union Conference on cosmic Rays, Moscow, 1963. The first results were given in the diploma work of V. V. Chizhov, Moscow Engy. Phys. Inst., in June, 1963.

2)Recently, a communication appeared about a chamber workworking under similar conditions.[10]

[1] S. Fukui and S. Miyamoto, Nuovo cimento **11**, No. 1, 133 (1959).

[2] Spark Chamber Symposium, Rev. Sci. Instr. **32**, No. 5 (1961).

[3] M. I. Daĭon and G. A. Leksin, UFN **80**, 281 (1963), Soviet Phys. Uspekhi **6**, 428 (1963).

[4] Proc. Conf. on Instrumentation for High-Energy Physics, CERN, Geneva (1962); Nucl. Instr. Meth. **20** (1963).

[5] Dolgoshein, Luchkov, and Moiseev, PTÉ (in press).

[6] J. M. Meek and J. D. Craggs, Electrical Breakdown of Gases, 1953 (Russian Transl., IIL, 1960).

[7] A. A. Vorob'ev (ed.), Vysokovol'tnoe ispytatel'noe oborudovanie i izmereniya (High-Voltage Test Equipment and Measurements), Fizmatgiz, 1960.

[8] G. A. Mesyats, Dissertation for Candidate's Degree, Tomsk University, 1961.

[9] A. I. Alikhanyan and M. I. Daĭon, Voprosy fiziki elementarnykh chastits (Problems of Elementary Particle Physics), AN ArmSSR, 1963.

[10] Mikhaĭlov, Roĭnishvili, and Chikovani, JETP **45**, 818 (1963), Soviet Phys. JETP **18**, 561 (1964).

Translated by A. Tybulewicz
54

OPTICAL TRANSITIONS BETWEEN CLOSELY SPACED IMPURITY CENTERS AND THE RELATED PHOTOCONDUCTIVITY

Sh. M. KOGAN, T. M. LIFSHITZ, and V. I. SIDOROV

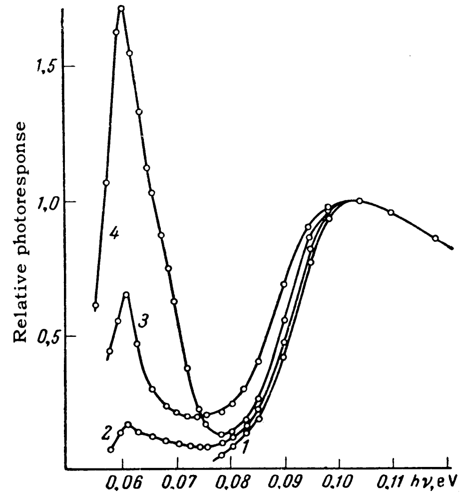
Radio Engineering and Electronics Institute, Academy of Sciences, U.S.S.R.

Submitted to JETP editor November 6, 1963

J. Exptl. Theoret. Phys. (U.S.S.R.) **46**, 395-396 (January, 1964)

If a semiconductor is doped with two types of impurity, giving rise to two different energy levels, then at a sufficiently high impurity concentration, when the wave functions of the impurity states partly overlap, optical tunnel transitions of carriers become possible between nearby impurity centers of different type. We shall assume that the concentration of the centers with the shallower level is high. Therefore, a carrier, which finds itself at one of these centers after an optical transition, can take part in "jump" conduction along these centers. This gives rise to a characteristic photoconductivity. Carriers cross over from one impurity state to another without being transferred to the free bands (the conduction band or the hole band). This phenomenon may be observed also when the necessary two levels are due to a single impurity which may have several charge states.

The effect just described was observed in germanium—doped with zinc and compensated with antimony—at the temperature of liquid helium. Zinc forms two acceptor levels in Ge, which are separated by 0.03 and 0.09 eV from the edge of the valence band. The concentration of zinc in different samples varied from $\approx 10^{14}$ to 3×10^{17} cm^{-3}. The concentration of antimony was in each case selected so that the 0.03 eV level was completely and the 0.09 eV level partly filled with electrons. The photoconductivity spectra of these samples were measured. The results are shown in the figure, from which it is evident that at zinc concentrations of $\lesssim 10^{15}$ cm^{-3} the spectrum has a shape typical of the impurity photoconductivity due to the photoionization of Zn^-.[1] On increasing the zinc concentration, a photoconductivity peak appeared beyond the long-wavelength edge, the maximum of the peak lying at the photon energy of 0.06 eV. The height of the peak rose with the concentration of zinc but its position was not affected.



Photoconductivity spectrum of Ge:Zn:Sb. Zinc concentration (in cm^{-3}): 1) 1.2×10^{15}; 2) 1.6×10^{16}; 3) 4×10^{16}; 4) 3×10^{17}. Field 50 V/cm, T = 4.2°K.

The appearance of this peak is due to an optical transition of a hole from a Zn^- ion to a nearby similar ion. A second hole of the resultant neutral atom Zn^0 wanders along the Zn^- ions and contributes to the jump conduction. A confirmation of this interpretation is provided by the characteristic photoconductivity spectrum (a narrow peak), the exact coincidence of the peak position (0.06 eV) with the difference of the energies of the two zinc levels, the concentration dependence of the height of the peak, the absence (or a very small value) of the photo-Hall effect at the peak, and the presence of a considerable "jump" conduction along the zinc levels.[2]

The effect described cannot be related to an optical transition of a hole to an excited state in the same Zn^- ion because, as shown in [3], there are no optical transitions with the energy ≈ 0.06 eV inside Zn^- ions in Ge.

It is interesting to note that an increase of the electric field to ≈ 200 V/cm splits the peak into four components.

The authors are grateful to S. G. Kalashnikov for valuable discussions.