ОБЪЕДИНЕННЫЙ
ИНСТИТУТ
ЯДЕРНЫХ
ИССЛЕДОВАНИЙ

Дубна

E 2324

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ЛАБОРАТОРИЯ ЯДЕРНЫХ ПРОБЛЕМ

1965

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IONIZATION MEASUREMENT IN A STREAMER CHAMBER

Recently the spark chambers with a large discharge gap began to be widely applied as a useful tool of experimental high energy physics.

The first experiments are in progress/1,2/ where the chambers operating both in the spark and in the streamer regimes are used as track devices.

The development of high voltage pulse generators/3-6/ which allow to obtain pulses of amplitudes of some hundred kV and some nanosecond length has led to an improvement of the spatial isotropy of the particle track location in the streamer chamber.

One may hope that a further investigation of the discharge mechanism in the streamer chamber and the modification of the methods for obtaining short high voltage pulses of amplitudes up to million volts and some nanosecond length and shorter, will allow to get a higher light yield and homogeneity of brightness of the tracks going under various angles to the direction of the electric field. It is true that the problem of the weakness of the light in the streamer chamber may be also solved using light amplifiers/7,8/ allowing to increase the sharpness depth of the track photography in such chambers.

It has been shown in a series of investigations/9-13/ that the streamer chamber is quite a perspective track instrument which gives possibility to determine precisely the spatial coordinates of the charged particles independently of their direction to observe the tracks of the particles produced inside the chamber, to reproduce the passage of a single particle as well as of many particles with the same efficiency and also to measure the particle momenta with a high accuracy by means of the curvature in the magnetic field.

One of the important parameters which may be used for the particle identification is the ionization produced by the particle. For this reason there naturally arises the problem of the possibility for measuring the ionizing power of the charged particle in the streamer chamber.

Lyubimov, Pavlovsky et al./14/ have investigated this problem in detail for the chambers, operating in the spark regime. In their papers the theory of the gas discharge in large gap two electrode spark chambers is given. The number of the clusters and the brightness of spark breakdown are considered as parameters of ionization measurement in the spark chambers. However, the use of the second parameter seems to be less suitable because the corresponding operating regime of the chamber has a number of limitations. Besides, the ionization measurements in these chambers are connected with the deterioration of the track quality.

Fukui and Zacharov[15] and Habel et al.[16] have pointed out the presence of the ionization effect in the form of the increased density of the luminous centers of the track of the strongly ionizing particle in the projection spark chamber.

The main parameters of ionization measurement in the track devices such as cloud and bubble chambers, are the density of the points representing the image of the track and the brightness of this track. The greater the number of primary ions, the greater the number of the points in these chambers.

Chikovani et al.[17] on the basis of the qualitative model, for the production of the streamer track, have concluded that the track brightness is the most convenient parameter for the measurement of the charged particle ionization power in the streamer chamber. As to the number of luminous centers, it is a slowly varying function of the number of primary electrons. Indeed, let us consider the production mechanism of a streamer track[18,19,9,10]. The charged particle passing through the chamber gives rise to a chain of ions and electrons along its path. Before the electric field is applied, the diffusion of the electrons takes place in the chamber. From the moment when the high voltage pulse is applied, each electron moving in the electric field, gives rise to the electron avalanche at the head and the tail of which the electrons are concentrated as well as the cloud of the positive ions, respectively.

At a certain moment the head of the avalanche may be considered as a dipole in the center of which ionization reaches the state of plasma and the electric field is practically equal to zero. At the same time the electric field at the ends of the dipole becomes equal to the doubled external electric field. The number of the electrons in the avalanche amounts to 10^8 (Meek's condition) and is considered to be critical for the transformation of the avalanche into a streamer. The primary plasma sphere is rapidly drawn along the electric field into a streamer column owing to the intensive production of the additional streamers by the photoelectrons produced at both ends of the primary avalanche where the magnitude of the electric field is maximal.

The extension of the streamer column takes place in both directions with a velocity of at least 10^8 cm/sec.

In a track spark chamber the growth of the streamer column is ceased at some millimetres by an external shunting spark gap.

The total time of the production of the visible track – τ is summed up of the time τ_{tr}, necessary for the transformation of the avalanche into a streamer and of the time τ_s of the streamer growth, i.e.

$$\tau = \tau_{tr} + \tau_s \tag{1}$$

In the track regime τ_s has a magnitude of some nanoseconds and constitutes a small part of τ.

If the distance between the primary electrons $\ell \leq 2\rho/\sin\alpha$ where ρ is the radius of the critical sizes of the avalanche and α is the angle between the direction of the particle motion and the direction of the electric field, then the neighbouring avalanches may be combined together and may develop as a single avalanche. Naturally the increase of the number of the primary electrons per unit of length of the particle track increases the probability to combine electrons into a single avalanche and their multiplicity in such combination. This brings to the decrease of the time τ_{tr} of the avalanche streamer transformation and to an earlier growth of the avalanche up to the critical sizes.

The quantitative calculation of the dynamics of the development of a streamer track depending upon the specific ionization is given in the paper by Chikovani et al.[9]. The curves given in this paper represent the dependence of the production probability of the luminous centers upon the distance advanced by the avalanche in the Meek's units, demostrate the decrease both of the time of the avalanche streamer transformation τ_{tr} and the fluctuations of this time $\Delta\tau_{tr}$ as the primary specific ionization grows.

Similar results are given by Shneider[20] for the time of discharge development and the statistical fluctuation in the growth of the electron avalanche up to the critical size, for the number of the primary electrons, producing a single avalanche equal from 1 to 8.

Thus, the higher the primary specific ionization, the earlier the avalanche streamer transformation begins, which brings to the increase of the time τ_s of the streamer column growth and therefore to the enhancement of the bringtness of the streamer track. The conclusion made by Chikovani et al.[9] that it is impossible to use the number of luminous centers as a parameter for ionization measurement, is based on their observations, they have made for the number of the luminous centers per 1 cm which for different operating regimes of the chamber appears to be 1,5-2. This is by more than an order smaller than the number of the primary electrons, produced by a particle with minimum ionizing power.

Such a small number of luminous centers points out the combination of the primary electron group into a single avalanche and the restriction of the development of the neighbouring avalanches by the field of the starting avalanche.

In the above cited paper the distance at which the restriction of avalanche takes place is equal to 6 mm. However, this distance cannot be ascertained because at other parameters of high voltage pulse and other conditions of photography, the observed number of the luminous centers reaches an order of 10 per 1 cm[20]. Thus, the number of luminous centers may possibly also serve as a parameter for the measurement of the specific ionization. Apparently, it is true, that this parameter will sooner reach to a saturation than the parameter of the brightness in the streamer chamber.

The results of our first experiment[21] on the track brightness measurement of protons of various energies in the streamer chamber have shown a certain enhancement of the particle track brightness as the specific ionization increases.

The purpose of this paper is to investigate the questions related to the ionization measurement in the streamer chamber in more detail.

Experimental Arrangement

A 50x35x15 cm^3 track spark chamber filled with neon up to 1 atm has been exposed to the proton beam of 680 MeV synchrocyclotron at Dubna (fig. 1). One of the chamber electrodes is made of duraluminium and, the second, the "transparent" one, is made in the form of a row of tightwires on glass. The "transparent" electrode and the side walls are made of 6 mm glass and are cemented together with epoxy resin The high voltage pulse applied to the chamber is formed by the usual Marx generator.

The Marx generator is triggered by 3-fold coincidence scintillation counter telescope (1,2,3). The chamber has worked in the streamer regime with an external air cutting spark gap which was fired by the pulse triggering the Marx generator. The high voltage pulse had an amplitude of ≈ 150 kV and a length of about 60 ns on the height 0,10 U_{max}; the exponential rise time till the breakdown is about 40 ns.

The proton beam with energies $E_1 = 660$ MeV ($\Delta E/E = 0,4\%$), $E_2 = 106$ MeV (15%), $E_3 = 57$ MeV (20%), $E_4 = 47$ MeV (20%) and $E_5 = 33$ MeV (20%) (taking into account the thickness of the materials of th counters and the glass) has been passed through the spark chamber (S.C.) at an angle of 90° to the electric field. The decrease of the energy from $E_1 = 660$ MeV was carried out by slowing down the protons in a polyethelene absorber with a thickness of 180 cm (C_1), 186-188 cm ($C_1 + C_2$).

The proton beam slowed down in the absorber C_1 to an energy $E = 130$ MeV has been deflected by an analyzing magnet (M) and then the further slowing down of the protons has been carried out in the absorber C_2 located just in front of the chamber to obtain protons of lower energies;

To calculate proton energy use was made of the curve of the proton energ decrease depending on the thickness of the polyethelene absorber[22] and of the tables for the proton energy loss depending on energy[23].

Measurement of the Ionizing Power of the Particles Going at an Angle of 90° to the Electric Field

During the present experiment three runs I, II, III were carried out corresponding to the three different values of the streamer track formation times τ_I, τ_{II}, τ_{III} determining the different stages of the formation of streamers of lengths from 6 to 11 mm at 660 MeV proton energy.

The change of τ was achieved by varying the breakdown distance of the shunting spark gap. When other conditions are unchanged ($E/p = 13$ v/cm. Hg for all the runs), such change of τ are the consequence of the varia tion of $\tau_{\bullet}$ in formula (1).

In each run the track of the proton of various energies were photographed at a fixed length of high voltage pulses (figs. 2,3,4). The tracks have been pho tographed simultaneously in two projections, both through the "transparent" electrode along the direction of the electric field (figs. 2,3,4"A") and in the side projection perpendicular to the direction of the electric field ("B" figs. 2,3,4).

The photography of the projection "A" has been carried out by a stereo-camera with relative apertures of one objective f/2 and of the second one f/4 and with a magnification 18 on a photographic film with a sensitivity of 1300 standard units.

The side projection "B" has been photographed by means of lens "Jupiter-9" with relative aperture f/1,5 and magnification 14 on a photographic film with sensitivity of 3000 standard units.

By photographing all the three runs I, II, III on the same film and developing them entirely, we have provided the homogeneity of the background on the whole film.

The obtained pictures show clearly the growth of the streamer columns (projection "B") and the enhancement of the brightness of the proton track (projection "A") as their ionizing power increases.

At this time the features of the streamer are changed too. If at the proton energy $E_1 = 660$ MeV in all runs the streamers have the form of strips, then the characteristic stretches will appear as the ionization is increased and the streamers are developed.

Treatment of the Results

The following operations have been carried out by the authors treating the obtained data:

a) The measurement of the streamer lengths. The average length of the streamers of the given track has been determined by measuring the average width of the track by means of a projector (projection "B" figs. 2,3,4). The distribution of the average width $\bar{\ell}$ for the track of protons of various energies is given in fig. 5 and in Table 1. The given errors correspond to a single standard deviation. As it has been noted by us the growth of the streamers takes place practically during the time interval $\tau_a = \tau - \tau_{tr}$ and it is natural that the fluctuations of τ_{tr} as well as of τ itself (which is a function of the stability of the operation of the shunting spark gap) determine the straggling of the average track width $\Delta\ell$.

It is clear that the straggling of the streamer length along the given tracks reflects the fluctuations in the development of the avalanches up to the critical sizes $\Delta\ell_{tr}$ and the straggling of the average width of the track $\Delta\ell$ from track to track for protons with energy $E_1 = 660$ MeV reflects the straggling of $\Delta\tau$.

According to the histogram given in fig. 5 the root-mean-square straggling of the high voltage pulse length $\Delta\tau$ till the cutting of the development of the streamers which is determined by the root-mean-square straggling of the width of the streamer tracks σ_ℓ, is equal to $\approx 1.5-2.5$ ns for protons with energy E_1 in various runs. If the velocity of the development of the streamers is 10^8 cm/s then $\Delta\ell = 1$ mm corresponds to $\Delta\tau = 1$ ns.

Naturally the straggling of the location of the tailing edge of the pulse is increased as the air spark gap is enlarged. The increase of the average width of the tracks in dependence upon the specific ionization is approximately the same for all the runs (fig. 6).

The calculations carried out by Chikovani et al./17/ for analogous conditions of the operation of a streamer chamber give the elongation of the streamer from 6 mm, for the minimum ionizing particles, to 9 mm for the particles with four-folded ionization, which is in good agreement with the data given in fig. 6. To clear up how much does the parameter of track brightness as a function of the streamer length make possible the ionization measurement in a streamer chamber, it is necessary to check the dependence of the track brightness upon the average length of the streamers both for the weakly ionizing particles and for the strongly ionizing particles.

b) The photometry of the proton tracks obtained in the streamer chamber. The photometry of the streamer tracks obtained by photographing the particle tracks along the electric field has been carried out by means of a microphotometer MF-4 by the method described by Bjornerud/24/. Previously a check was made of the linearity of the dependence of the device reading upon the quantity of the entering light. The width of the slit has been chosen approximately equal to the width of the track. The length of the slit was equal to about 1/14 of the whole track length without the endings of the tracks which were omitted at the time of photometry.

The transparency of the track was measured both visually, by the readings of the galvanometer, and with the help of the automatic recording. Both methods gave similar results for the transparency measurement of some tracks, so that later on we were satisfied by measuring mainly the galvanometer readings.

During the measurement of the background transparency the readings of the galvanometer were kept at about 0.9 and this value was roughly kept for the whole length of the film in consequence of good background homogeneity, unlike the clound chambers, in case of which it is difficult to obtain such homogeneity of background.

For each position the photometry of about 10-15 tracks has been carried out. For each track, the transparency A_i of about 10-12 non-overlapping parts of the track, and the background transparency A^1_{0i} and A^2_{0i} from both sides for each part of the track have been measured. Then the average transparency of the background was determined $A_{0i} = \frac{A^1_{0i} + A^2_{0i}}{2}$. While determining A_i the track parts containing very bright points ($> 3\sigma$) have been omitted. The magnitude equal to $T_i = A_i / A_{0i}$ has been accepted as a relative transparency, and the magnitude $f = \Sigma f_i / n$ where $f_i = 1 - T_i$ has been taken as a abscuration parameter, characterizing the track brightness. The error of the observer, determined by a number of measurements, did not exceed $\approx$ 3-4 %. The observed dependence of the track brightness upon the width of the slit, has been found to be in good agreement with the calculation according to the formula $f_{a'} = f_a - c(a' - a)$ where a' is the width, differing from the average track width a and the coefficient $C = 0.05 - 0.07$. The error of the average width of the track, conditioned by the choice of the width of the slit, is about 5-7%.

The results of the photometry of the proton tracks are given in Table I in the form of the average abscuration $\bar{f}$ for the group of the protons with the given energy.

The dependence of the brightness on the average length of the streamer columns, for the protons having an ionizing power equal to $I = 1.2\, I_{min}$, has been found to be linear (fig. 7).

The data of the three runs, carried out to find out the dependence of the track brightness on the average length of the streamers $\bar{\ell}$ for the whole ionization interval, are given in fig. 8. (The straight line presents the linear dependence given in fig. 7).

As is seen from fig. 8, the brightness of the streamer tracks cannot be explained only by the lengthening of the streamer columns since the observed value of the blackening for the particles with high ionizing power ($I \geq 3\, I_{min}$) is higher than the straight line, presenting the linear dependence of the brightness on the streamer length. The values of run III, corresponding to the proton energies 57 and 47 MeV are near the saturation value of the instrument and, therefore, they may be lowered.

The data presenting the dependence of the track brightness on the specific ionization are shown in fig. 9. To make clear whether the increase of the number of the streamer column is one of the causes of the enhancement of track brightness as the ionization increases, we have measured the number of the luminous centers (projection "A"). Dolgoshein et al./10/ have pointed out that the density of the streamer columns decreases as the primary ionization decreases. (At neon pressures in the chamber < 300 mm Hg).

c) Measurement of the number of the luminous centers. The number of the luminous centers n per unit of length of the streamer track has been determined by means of diaprojector. The account has been made independently by two observers from each other taking into account all the visible centers, including those with the smallest diameter. The results of the measurement are given in Table 1.

To count the number of the luminous centers in run III is found out to be impossible at proton energy lower than 600 MeV, due to the joining of many streamer centers into a single luminous band. The dependence of the number of the luminous centers on the specific ionization and the average length of the streamers are given in figs. 10 and 11, respectively. Although the obtained data show an increase of the luminous center number as the ionization increases, however, within the limits of the statistical errors, almost a similar increase is observed as the streamers are lengthened in case of weak ionization $I = 1.2\, I_{min}$ owing to the increase of the time length τ ($\tau_{III} > \tau_{II} > \tau_I$). The enhancement of the brightness as the streamer is elongated helps to reveal the corresponding luminous centers on the film, which explains the increase of the number of the luminous centers at weak ionization.

A small excess of 10-15 % of the average number of the luminous centers over this increase is visible at proton energies 57 and 47 MeV. This increase of the number of the luminous centers may partly explain the predominance of the brightness of this track group over the brightness determined only by the lengthening of the streamers.

The delay time of the high voltage pulse with respect to the passage of the particle t_d has been determined by us earlier and was equal to 1-1.2 μs. However, the high number of the luminous centers, the fluctuation in the diameter of the luminous centers and rather wide transversal size of the tracks, 2-2.5 mm for the run I, 4 mm for run III, make one think of the presence of a longer delay of the high voltage pulse. To estimate the delay time of the high voltage pulse t_d the coordinates of the centers of the luminous points have been measured. Then, by the method of least squares the approximating line was drawn and the average square straggling of the center σ was determined from this line.

Comparing the obtained values of root-mean-square stragglings, which for various runs are from $\sigma = 0.6$ to $\sigma = 0.9$ mm, with the curve of the dependence σ on the high voltage pulse delay t_d /9/, we get the magnitude t_d equal to 2 μs for the present experiment.

Discussion of the Results

The given experimental data show that the track brightness may indeed serve as a convenient parameter for the ionization measurements in the streamer chamber (fig. 9). Meanwhile, it is evident that the cause of the enhancement of the track brightness is not only the lengthening of the streamers (fig. 8).

To show more vividly the character of the tracks depending on the ionizing power of the particles in fig. 12 the photographs of the incomplete proton tracks having the same average track width $\bar{l}$ and different brightness are given.

Table 1 shows, that the best groups for such a comparison are the groups of runs III, (660 MeV) and II (47 MeV) the characteristic tracks of which are shown also in fig. 12. It is evident from the photograph that the distances between the luminous centers is decreased and the brightness of separate streamer columns is increased as the ionization increases (perhaps owing to the joining of the streamers). The distribution of the streamer lengths along the given track l'_i built for the same tracks (fig. 13), shows the expected decrease of the straggling of the streamer lengths $\Delta l'$ in agreement with the decrease of the fluctuation in the avalanche development as the ionization increases.

To compare the quality of the tracks of various runs the proton track is shown on the same photograph taken from the group with the lowest brightness, run I, (660 MeV).

In Table 1 are given the values of the average blackening $\bar{f}$ for the proton group under investigation with their root-mean-square errors σ_f which characterize the brightness straggling of the tracks entering into the same group with the given energy $E + \Delta E$. The energy straggling ΔE may give its contribution to σ_f only at low energies. The main factor determining σ_f is apparently the straggling of the length of high voltage pulse $\Delta\tau$ because of the straggling of the tailing edge of the pulse. This factor may strongly be decreased by applying a corresponding shunting spark gap under pressure. This kind of straggling strongly affects the brightness of the tracks especially in case of under developed streamers when the light yield is so small that it is the threshold of sensitivity of the photographic system. Apparently, the highest error $\sigma_f \approx 30\%$ in run I for protons with $E = 660$ MeV is explained by this circumstance.

The accuracy of the determination of the blackening of a track with a known ionization is, of course, of most interest for the determination of the error in the measurement of particle ionizing power . For this purpose for each track we determined its relative root-mean-square error σ'_{f_i} / f'_i of the determination of the average blackening f_i . The relative root-mean-square errors $\sigma_f / \bar{f}$, calculated for each group of protons with the given energy, are given in Table 1.

As was stated, the error $\sigma_{f'}$ as well as $\sigma_{l'}$ must be determined mainly by the fluctuation of the time of the avalanche development which according to papers[4,20] reaches to its maximum value of about 7% for weakly ionizing particles. Taking into account that under our condition the fluctuations of the time $\Delta\tau_{tr}$ is the significant part of the time τ_s ($\tau_{tr} \gg \tau_s$) it is clear that the fluctuations in the development of the streamers will be much greater than 7%.

The energy loss straggling, which according to Landau's theory is ≈ 20%, may apparently affect the brightness straggling along the tracks of the weakly ionizing particles. However, this question needs a further investigation. So the error of the ionizing measurements will be maximum for the weakly ionizing particles. As it is seen from Table I, the measurement accuracy of the ionization $I = 1{,}2 I_{min}$ is about 20-25% and in case of triple and more ionization it not worse than (10-15)%.

One may think that in case of short time delays and better parameters of high voltage pulse, the accuracy of the particle ionizing power determination will be improved.

Fig. 14 shows the curve calculated by Chikovani et al.[17] which presents the relative brightness of the particle tracks in the streamer chamber depending on the specific ionization assuming a linear dependence of the streamer brightness on its length. The experimental points present the relative blackening of proton tracks to the blackening of the tracks of the protons with an ionization $I = 1{,}2 I_{min}$ (the data given in Table I on the average blackening $\bar{f}$ and the errors of the average value of $\bar{f}$ have been used).

We assume that the brightness of the tracks with ionization $I = 1{,}2 I_{min}$ is the same as that with minimum ionization I_{min} which in reality, may not take place.

However, even with this assumption, the measured value of the relative brightness exceeds the calculated values. As is seen from fig. 14, the greatest enhancement of the track brightness is observed when the specific ionization grows up to the four-fold magnitude after which this enhancement is slackened though more slowly. It is interesting to mention that with the change of high voltage pulse duration τ the streamer chamber may be used for the study of such processes where it is necessary to investigate the particles with the ionization power exceeding a certain one.

The main difficulty of the ionization measurement in a streamer chamber is the inhomogeneity of the brightness of the particle tracks.

Therefore, unless an operating regime of the chamber with more isotropic brightness is achieved then for each operating regime of the chamber it is necessary to build calibration curves for particles with known ionization and going at various angles. Besides, the accuracy of the brightness determination of the tracks by photometry will be low without a sufficiently good depth of sharpness.

Measurement of the Ionization of the Particles Going at Angles 55-67° to the Electric Field in the Streamer Chamber

To determine the track brightness dependence on ionization at various particle directions to the electric field and the limit angle, (i.e. the angle at which development of the streamer column takes place along the trajectory of the particles), depending on the ionization, the chamber was rotated under certain angles α to the proton beam. The measurement have been carried out with two lengths of the high voltage pulse τ_{II} and τ_{III}.

The results of the photometry are shown in Table II. The angles between the proton track and the direction of the electric field α_i have been measured by means of a projector. Then the average angle $\bar{\alpha}$ and the root-mean-square errors of the determination of the angle σ_α were found. The dependence of σ_α on the angle α is given in fig. 15. The photographs of the two projections of the proton tracks with the given energy at various angles are shown in figs.16,17.

The photograph of the tracks of protons with various energies at the given angles is shown in fig. 18.

Let us consider the mechanism of the production of the inclined tracks and the transition from the streamer regime into the aligned spark operating regime of the chamber. (At very short lengths τ, it is possible that in spite of the orientation of the streamer along the particle path the streamer regime will be kept).

The illustration of this mechanism is given in fig. 19 (a)/19/. If the distance between the avalanches is $\ell \leq 3\rho$ then the space charge field between the heads of neighbouring avalanches will have a magnitude of about the external field, the additional streamers will be produced within this region and the streamer column will be developed along the particle path. Fukui points out that though at any angle, the streamer may in principle be developed in parallel to the particle path, however, at an angle $\alpha = 60^\circ$ the disturbance of the configuration of the charge field is so great, that the streamers no longer follow the particle trajectory. At a distance between the avalanches $\ell > 3\rho$ (fig. 19b) the space charge field between two avalanches cannot be higher than the external electric field and the streamers will develop independenty, i.e. as they are developed from separate electrons.

It is known that, practically, the aligned spark regime operates will the angles of $\alpha = 45^\circ$.

It is clear that by increasing the ionization/7/ and by shortening the rise time of the high voltage pulse, the angle of the following of the discharge along the track, i.e. the maximum angle must be increased.

The obtained results (figs. 16,17) confirm the dependence of the maximum angle on the ionization. It is seen from fig. 20 that at minimum ionization the track brightness changes very little by the change of the angle and only at $\alpha = 58^\circ$ the brightness is sharply increased indicating a transition into a aligned spark regime. A different picture is observed at $E = 106$ MeV. Here the track brightness already at $\alpha = 63^\circ$ begins to rise.

The photographs of these tracks, visually demonstrating the curving of the streamers along the path of the particle (figs. 21, 22) also serve as a good illustration. The dependence of the track brightness on the ionization at various fixed angles α is given in fig. 23. From the figure it is seen that as the track brightness is increased at the growth of the ionization depending on the angle, simultaneously, the character of this dependence at angles < 67° somewhat changes.

Ionization Measurement in the Streamer Helium Filled Chamber

The chamber has been fielled with technical helium at a pressure of 1 atm and measurements were performed analogous to those when neon filling was used.

Tracks with a brightness sufficient for photography, have been obtained when the cutting of the growth of the streamers takes place later than in case of neon. This is clear as 10 kV/cm is not sufficient for obtaining short streamers. Two runs I and II have been carried out by us, corresponding to the formation times of the streamer tracks τ_I and τ_{II} ($\tau_I < \tau_{II}$). The measurements of the average lengths of the streamers by the width of the tracks (projection "B" fig. 24) in runs I and II have given the values 17-20 mm.

Because of the long time of the growth of the streamers τ_s and their weak luminescence we have not succeeded in making an unambiguous conclusion about the change of the lengths of the streamer columns as the specific ionization is increased.

The photographs of the proton tracks for two energy values in both projections are given in fig. 24.

The track luminescence (projection "A" fig. 24) is of somewhat a diffusive nature.

The results of the photometry and the measurement of the number of the luminous centers per 1 cm of the track length are given in Table III and fig. 25.

The obtained dependence of the track brightness on the specific ionization in helium is of nature similar to the one of neon.

However, detailed investigation of the mechanism of the ionization in the chamber filled with helium requires a better operating regime of the chamber.

Acknowledgements

The authors would like to express their gratitude of Prof. A.Alikhanian for this interest and help in this work, to Dr. A. Tyapkin for the suggestions to measure the dependence of the limit angle on the ionizing power of the particles and for his help.

The authors are grateful also to Dr. A. Pisarev and Dr.I. Vasilevsky their help in carrying out these experiments and helpful discussions, to V. Prokhorov and A. Philozov for their direct help in the measurements, to L. Akhverdova for performing the treatment of the materials and to Yu. Zavensky for his assistance.

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Received by Publishing Department
on August 5, 1965.

Table I

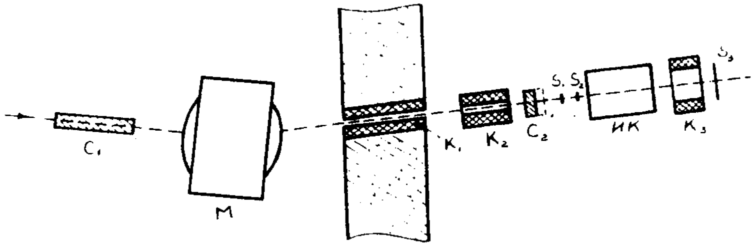
E (Mev)	I/I_{min}	Meas. values, run	I	II	III
660	I.2	$\bar{n}$	4.35 ± 0.6	5.0 ± 0.6	6.5 ± 0.4
		$\bar{\ell}$	6.0 ± 0.8	7.3 ± I.0	II.8 ± I.I
		$\bar{f}$	0.I9 ± 0.06	0.27 ± 0.03	0.4I ± 0.04
		$\sigma_f/\bar{f}$	23 %	25 %	20 %
I06	3.36	$\bar{n}$	5.9 ± 0.8	5.8 ± 0.7	-
		$\bar{\ell}$	9.5 ± I.I	9.3 ± I.3	I4.7 ± I.5
		$\bar{f}$	0.40 ± 0.06	0.4I ± 0.06	0.70 ± 0.05
		$\sigma_f/\bar{f}$	I5 %	I5 %	8 %
57	5.4	$\bar{n}$	6.90 ± 0.75	6.3 ± 0.6	-
		$\bar{\ell}$	9.5 ± I.2	II.2 ± I.5	I5.6 ± I.9
		$\bar{f}$	0.44 ± 0.08	0.53 ± 0.08	0.84 ± 0.03
		$\sigma_f/\bar{f}$	I2 %	I0 %	7 %
47	6.3	$\bar{n}$	7.3 ± 0.6	7.7 ± I.0	-
		$\bar{\ell}$	I0.0 ± I.3	II.7 ± 2.2	I8.I± 2.3
		$\bar{f}$	0.49 ± 0.06	0.57 ± 0.06	0.84 ± 0.02
		$\sigma_f/\bar{f}$	I2 %	II %	7 %
33	8.5	$\bar{n}$	-	-	-
		$\bar{\ell}$	-	-	22.0 ± 3.8
		$\bar{f}$	-	-	0.93 ± 0.05
		$\sigma_f/\bar{f}$			4 %

Table II

run	α	E (Mev); I/I_{min}		
		660; I.23	I06; 3.36	57; 5.4
II	58°	0.60 ± 0.I2	0.78 ± 0.09	0.66 ± 0.08
	63°	0.36 ± 0.06	0.74 ± 0.II	-
	67°	0.35 ± 0.I0	0.55 ± 0.II	-
	90°	0.27 ± 0.03	0.4I ± 0.06	0.53 ± 0.08
III	58°	-	-	0.99 ± 0.0I
	6I°	0.76 ± 0.08	-	0.98 ± 0.02
	90°	0.4I ± 0.04	-	0.84 ± 0.02

Table III

E (Mev)	I/I_{min}	run / Meas. values	I	II.
660	I.23	$\bar{f}$	0.I5 ± 0.03	0.27 ± 0.04
		$\sigma_f/\bar{f}$	38 %	I6.7 %
		$\bar{n}$	I.6 ± 0.4	2.7 ± 0.4
I5I	2.56	$\bar{f}$	0.28 ± 0.05	-
		$\sigma_f/\bar{f}$	I6 %	-
		$\bar{n}$	3.00 ± 0.25	-
II7.5	3.08	$\bar{f}$	0.27 ± 0.04	0.44 ± 0.02
		$\sigma_f/\bar{f}$	23 %	2I.6 %
		$\bar{n}$	3.3 ± 0.2	2.60 ± 0.I5
64.5	5	$\bar{f}$	0.3I ± 0.08	0. 55 ± 0.08
		$\sigma_f/\bar{f}$	I8 %	I2.4 %
		$\bar{n}$	3.3 ± 0.6	3.3 ± 0.6



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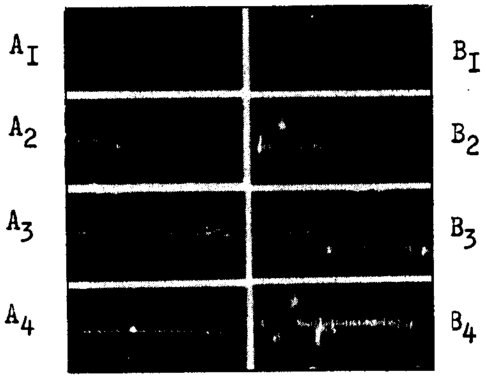

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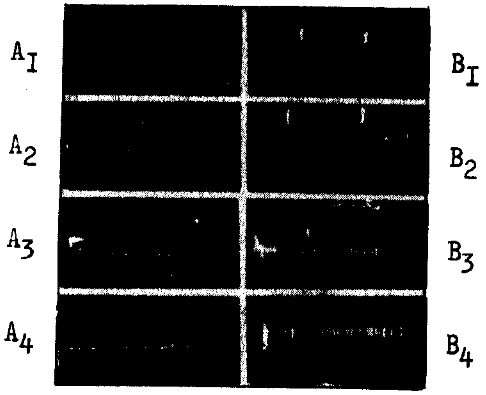

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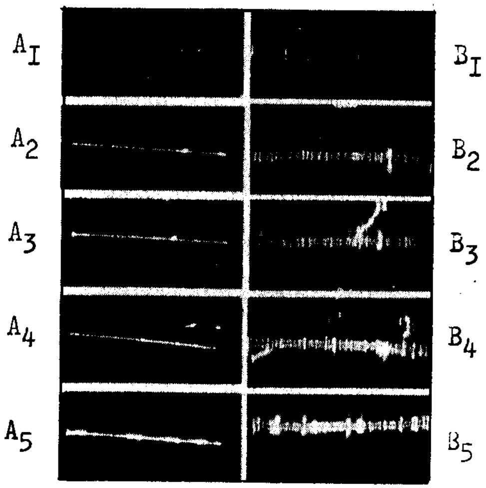

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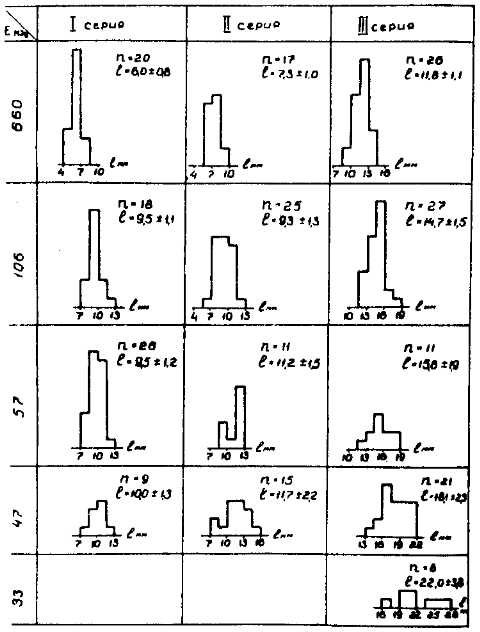

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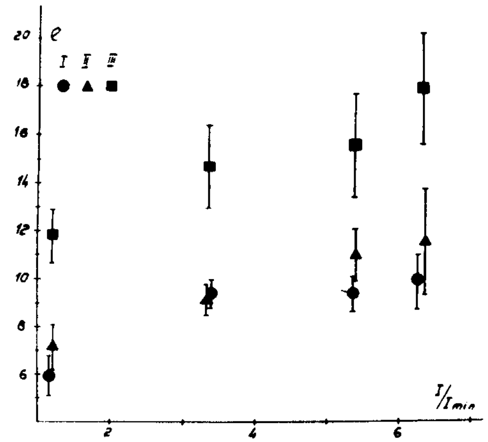

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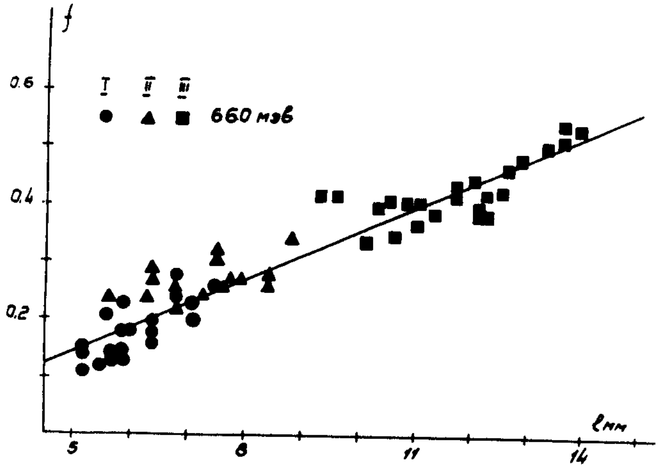

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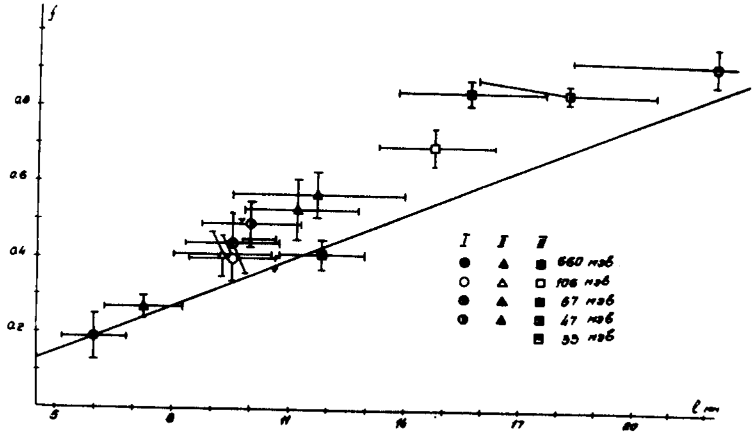

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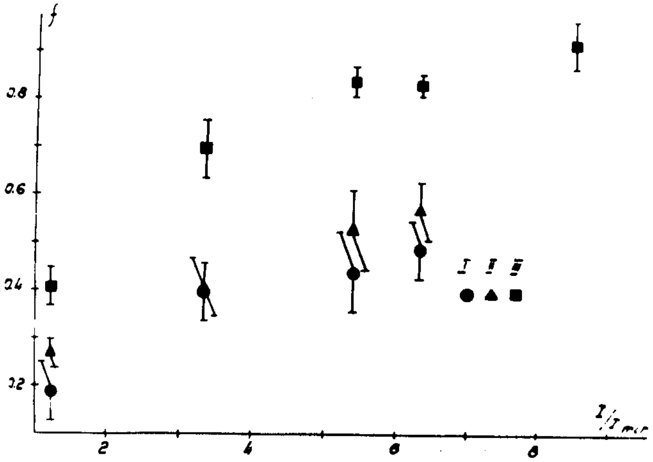

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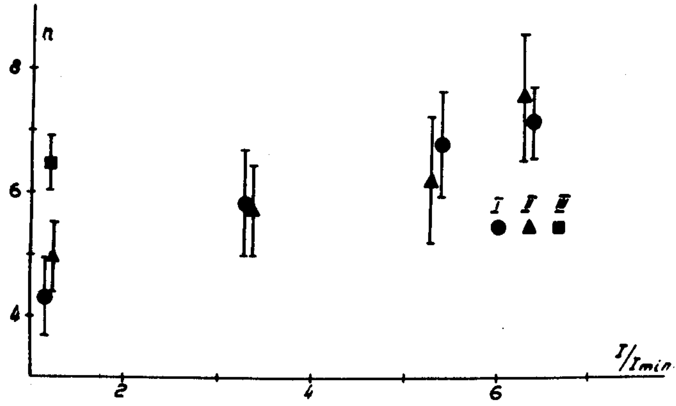

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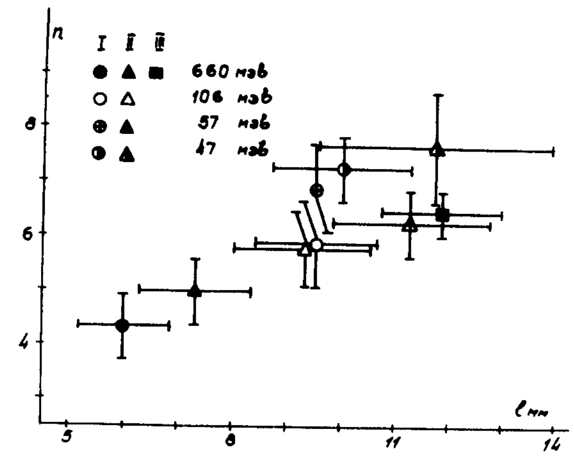

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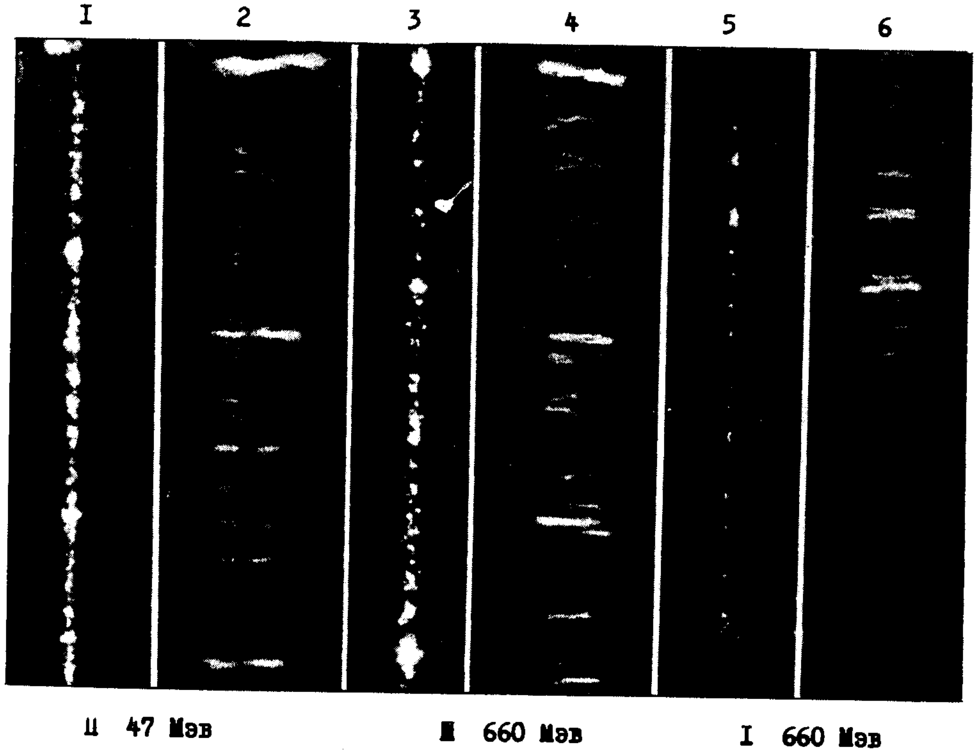

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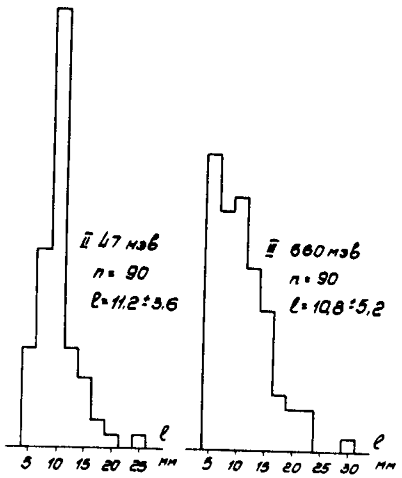

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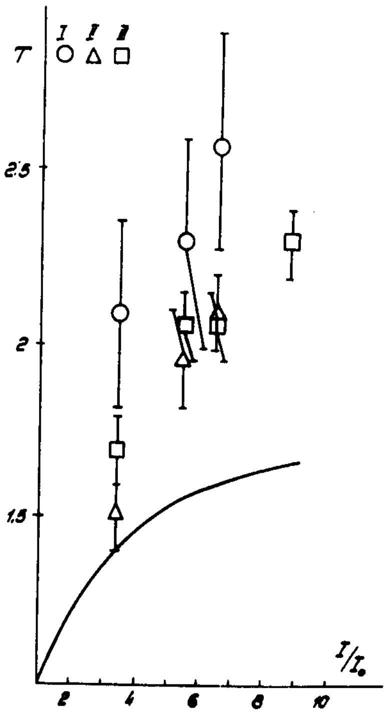

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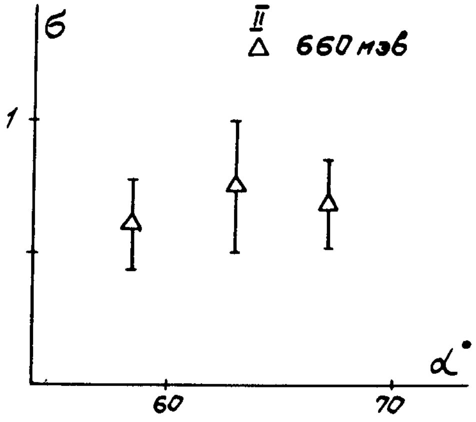

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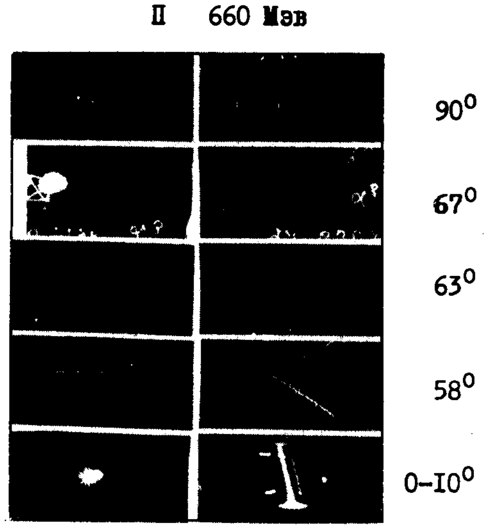

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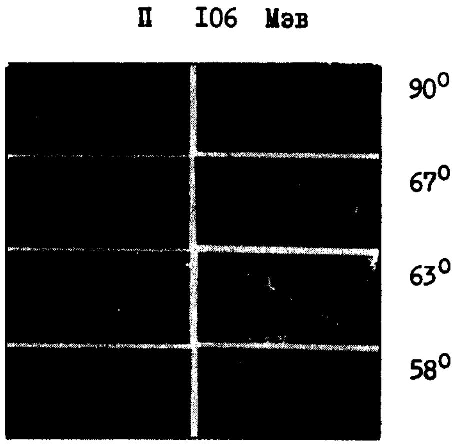

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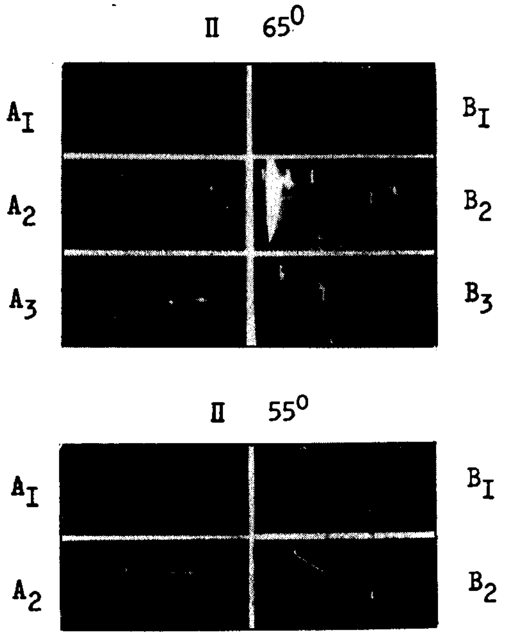

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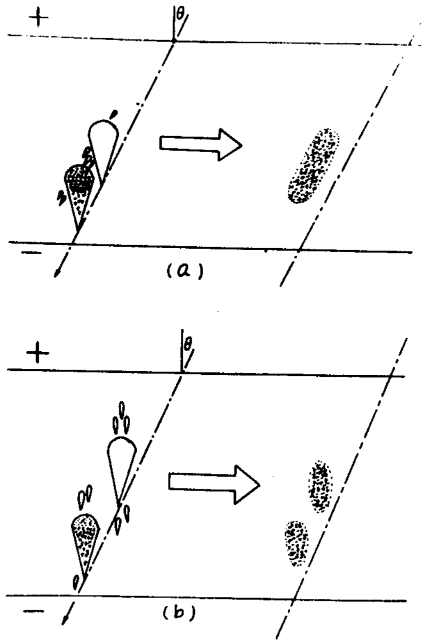

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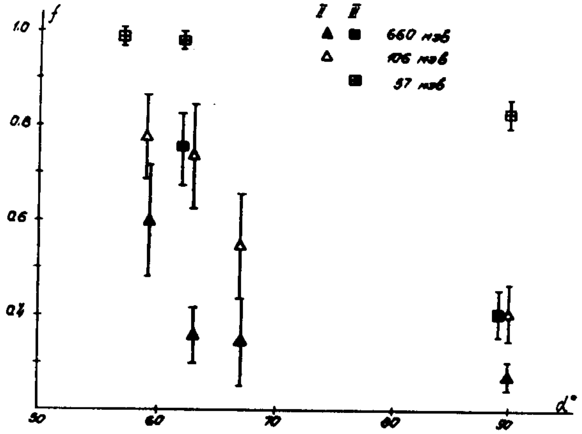

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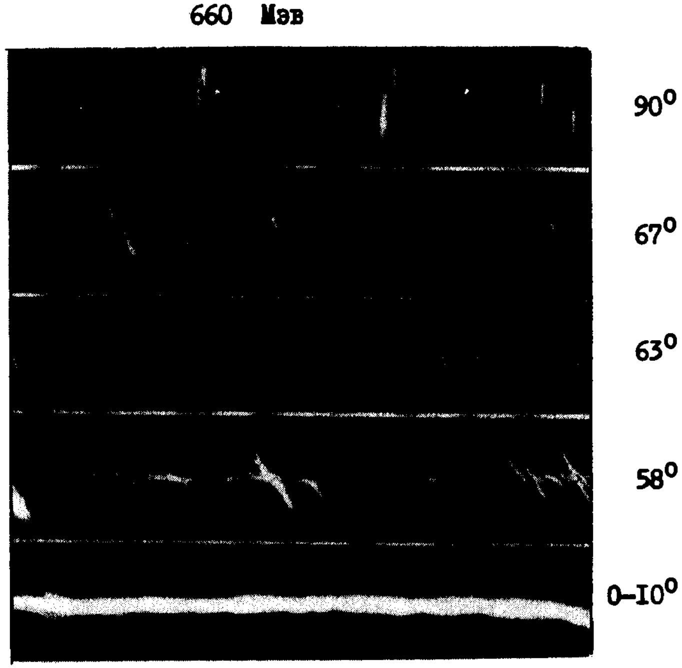

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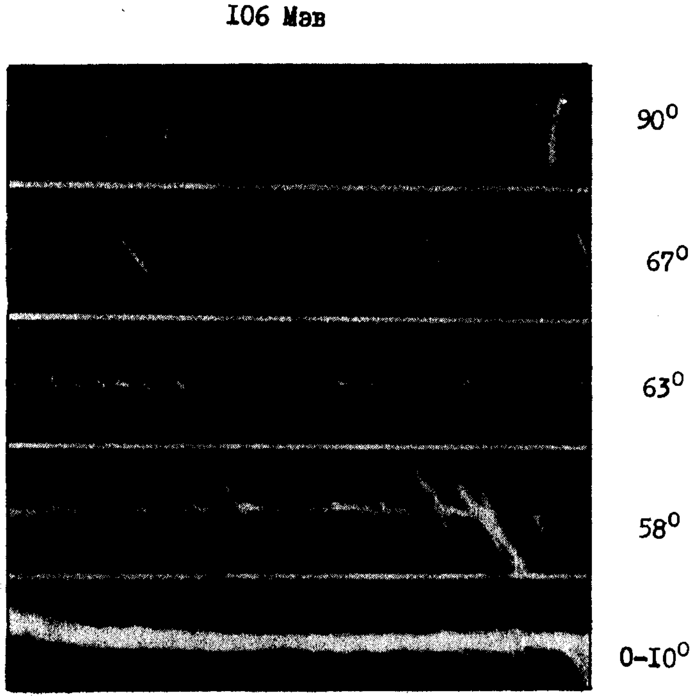

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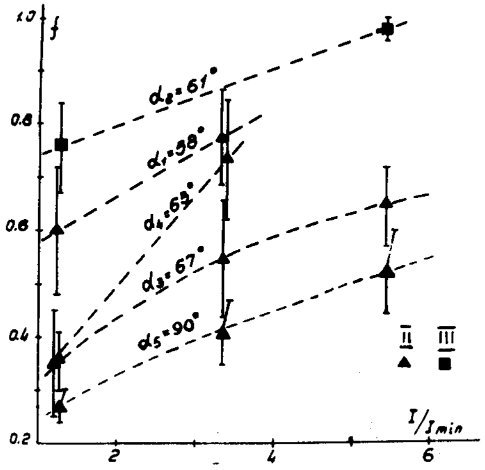

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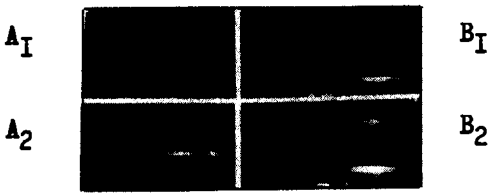

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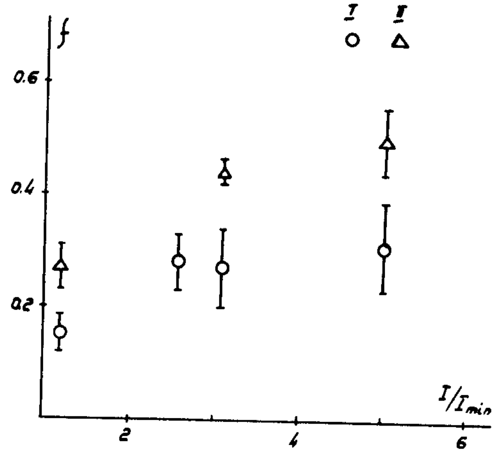

Fig. 25