INVESTIGATION OF IONIZATION LOSSES OF RELATIVISTIC PARTICLES IN NUCLEAR EMULSIONS

Z. V. ANZON, A. Kh. VINITSKIĬ, Zh. S. TAKIBAEV, I. Ya. CHASNIKOV, and Ts. I. SHAKHOVA

Nuclear Physics Institute, Academy of Sciences, Kazakh S.S.R.

Submitted to JETP editor May 12, 1964

J. Exptl. Theoret. Phys. (U.S.S.R.) **47**, 2051-2054 (December, 1964)

Relative ionization measurements in NIKFI-R and Ilford G-5 emulsions in the energy range attainable in accelerators are presented. Within the experimental errors the ratio of the ionization value on the plateau of the ionization curve to the minimum ionization value is the same for the two emulsions. The mean value of the ratio is 1.104 ± 0.010. The observed ionization-momentum dependence is in agreement with that calculated from the Sternheimer equation with the parameters $I = 270$ eV and $T_0 = 2$ keV.

THE ionization-energy relation calculated from the Sternheimer formula[1] is usually used for identification of relativistic particles in nuclear emulsions. This formula contains two parameters —the ionization potential I and the maximum energy transfer T_0, —whose values have not yet been definitively established. The values of I and T_0 assumed by different workers fluctuate over wide intervals, which in turn leads to different values of the ratio of the plateau ionization to the minimum ionization. The curves most frequently used to identify particles are those calculated by Barkas[2] and by Stiller and Shapiro.[3]

The purpose of the present work is to study the dependence of the ionization characteristic B (the blob density) on γ (the particle energy in units of the rest mass). For this purpose we carried out special measurements of the relative ionization in tracks of 2, 3, 4, and 5-BeV protons and 3.8-BeV π mesons in stacks of NIKFI-R emulsion irradiated at the Joint Institute for Nuclear Research. These stacks were irradiated practically simultaneously in a 9-BeV proton beam, in a direction perpendicular to the emulsion plane. The ionization values measured in the tracks of these particles of known energy and mass are the basic calibration points for determination of the true behavior of the ionization-energy curve in the region $3 < \gamma < 30$. We also used ionization and energy data obtained from secondary particles generated by 9-BeV protons[4,5] and by 7.5-BeV[6] and 17-BeV[7,8] π mesons.

We selected those particles whose identification was most reliable and did not vary with the choice of curves having different ratios of plateau ionization i_{pl} to minimum ionization i_{min}. To avoid errors due to nonuniform development of the emulsion, we determined the relative ionization B/B_0, where B_0 is the blob density in the tracks of the primary particles. In each secondary particle track we counted a sufficient number of blobs that the error did not exceed 2.5%. The particle energy was determined from multiple scattering. Ionization values in the plateau region were determined by measuring the ionization in tracks of energetic electron-positron pairs and δ-electrons. As a control, the δ-ray energy was determined in two different ways: from multiple scattering and from the emission angle.[5] The blob densities for the electron-positron pairs and the δ-rays were identical.

Figure 1a shows values of the ionization $i = B/B_0$, normalized to that of 9 BeV protons, as a function of γ. To increase the statistics, the secondary particles were combined into groups having nearly the same value of γ. The curve of Stiller and Shapiro[3] is plotted in the same figure with $I = 376$ eV and $T_0 = 2$ keV ($i_{pl}/i_{min} = 1.15$). An obvious difference between the Stiller-Shapiro curve and the experimental points can be seen in the plateau region, which confirms the data of Alekseeva[9] in the region $\gamma > 200$. However, Alekseeva et al find a maximum at $\gamma = 100-150$ in the ionization-energy curve obtained from tracks of electron-positron pairs. Ionization measurements are extremely uncertain for electrons of these energies (50—75 MeV), since correction for nonuniform development is made difficult by the strong scattering. Therefore, more reliable determinations of the ionization-energy function in this region can be made using high-energy π mesons.

Figure 1b shows results obtained from second-

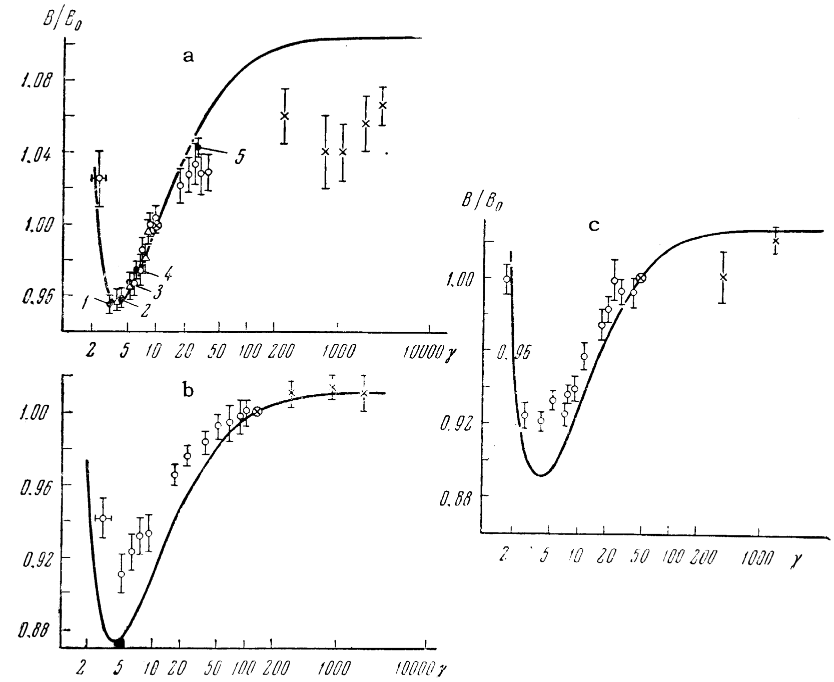

FIG. 1. Variation of blob density with particle energy. The ionization data are normalized to the following: a – 9-BeV protons (NIKFI-R emulsion), b – 17-BeV π mesons (Ilford G-5 emulsion), c – 7.5-BeV π mesons (NIKFI-R emulsion). Δ – secondary protons, o – secondary π mesons, $\times$ – electrons. Points 1, 2, 3, and 4 in Fig. 1a correspond to ionization of protons with energies 2, 3, 4, and 5 BeV, respectively; point 5 corresponds to ionization of 3.8-BeV π mesons (points 1, 3, and 5 were obtained previously[5]); the solid curves are taken from the work of Stiller and Shapiro.[3]

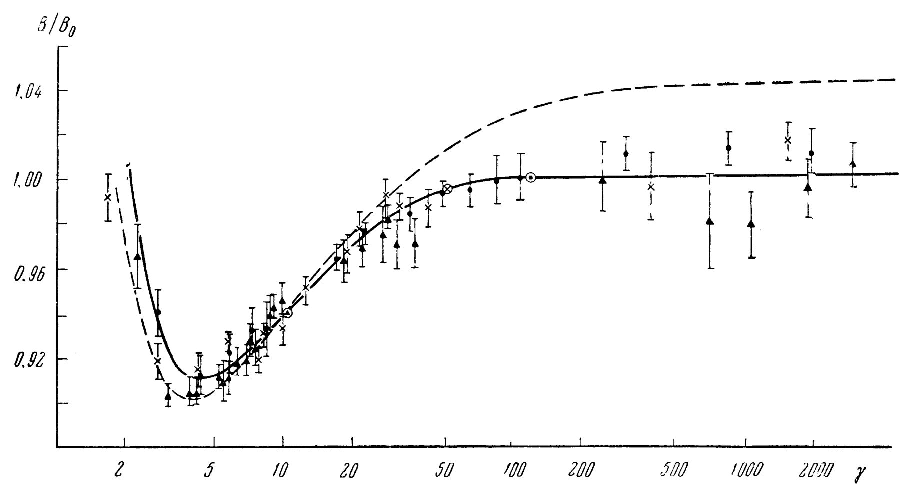

FIG. 2. Combined data on the variation of relative ionization with particle energy. The points referring to primary energies of 9 (▲), 7.5 ($\times$), and 17 (●) BeV have been normalized to the curve (solid line) calculated from the Sternheimer formula using I = 270 and T_0 = 2 keV. The curve of Stiller and Shapiro[3] (dashed line), normalized to the ionization of 9-BeV protons, is shown for comparison.

ary particle tracks, and also from the tracks of electron-positron pairs and δ-rays in a stack of 600μ Ilford G-5 emulsion irradiated by 17-BeV π mesons ($\gamma = 122$) in the CERN accelerator. The experimental points and curve have been normalized to the ionization value corresponding to 17-BeV π mesons. As can be seen from Fig. 1b, no peak is observed in the ionization-energy relation in the region $\gamma \sim 100$, and there is agreement between the experimental points and curve for $\gamma > 50$. However, in the region of the minimum the experimental points lie above the curve. If we calculate the ratio of the plateau ionization to the ionization at the minimum according to data normalized to 9-BeV protons (Fig. 1a) and 17-BeV π mesons (Fig. 1b), it turns out that these ratios agree within experimental error and are equal to 1.103 ± 0.012 and 1.108 ± 0.015, respectively.

Similar results have been obtained in the measurement of secondary particle and electron tracks in a stack of NIKFI-R emulsion irradiated by 7.5-BeV π mesons (Fig. 1c). The ratio i_{pl}/i_{min} is 1.105 ± 0.018 in this case. Figure 2 shows the curve calculated from the Sternheimer formula with parameters I = 270 eV and T_0 = 2 keV, for which $i_{pl}/i_{min} = 1.10$. Plotted in the same figure are the combined data obtained in emulsions irradiated by the calibration beams: 9-BeV protons, 7.5- and 17-BeV π mesons. The total number of tracks measured amounts to more than 500 only in the case of secondary particles (these were mainly π mesons). The number of tracks of electrons with $\gamma \geq 200$ is more than 60. It is evident that the curve calculated by us agrees satisfactorily with experiment within the experimental errors. A difference of $\sim 1\%$ observed between the data for different types of emulsion is probably due to the fact that the ionization was determined from the blob density. Conversion to grain density, which more accurately corresponds to the ionization loss, may remove this discrepancy.

The authors are grateful to Professors V. I. Veksler and S. I. Lyubomilov for their cooperation in irradiation of the emulsion at the Joint Institute for Nuclear Research, to Professor W. O. Lock for providing the emulsions irradiated at CERN, and to their colleagues G. B. Zhdanov and M. I. Tret'yakova at FIAN for discussion of this problem.

[1] R. M. Sternheimer, Phys. Rev. **88**, 851 (1952); **89**, 1148 (1953); **91**, 256 (1953); **103**, 511 (1956).

[2] J. W. Barkas, Preprint UCRL-2579, 1954.

[3] B. Stiller and M. M. Shapiro, Phys. Rev. **92**, 735 (1953).

[4] Botvin, Takibaev, Chasnikov, Pavlova, and Boos, JETP **41**, 993 (1961), Soviet Phys. JETP **14**, 705 (1962).

[5] Takibaev, Chasnikov, Shakhova, and Anzon, Trudy, Nuclear Physics Institute, Academy of Sciences, Kazakh S.S.R., **6**, 94 (1963).

[6] Vinitskiĭ, Golyak, Rus'kin, and Takibaev, JETP **44**, 424 (1963), Soviet Phys. JETP **17**, 289 (1963).

[7] Anzon, Vinitskiĭ, Eremenko, Takibaev, Chasnikov, and Shakhova, JINR preprint R-1535, 1964.

[8] Anzon, Vinitskiĭ, Loktionov, Strel'tsov, Takibaev, Chasnikov, and Shakhova, JINR preprint R-1535, 1964.

[9] Alekseeva, Zhdanov, Tret'yakova, and Shcherbakova, JETP **44**, 1864 (1963), Soviet Phys. JETP **17**, 1254 (1963).

Translated by C. S. Robinson
298