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Abstract

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THE CROSS SECTION OF INELASTIC PROTON-PROTON INTERACTION AT PROTON ENERGIES ABOVE 7 BeV

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The measurement of the cross section of inelastic proton–proton interaction (as the difference between the interaction of protons in paraffin and in graphite) was carried out during the 1955 expedition under conditions analogous to those used in determining the proton–carbon-nucleus cross section ([1–3]). The measurements were made in the stratosphere at an altitude of 20–25 km at latitude 31° N with protons of mean energy of the order of 20 BeV.

The instruments for determining the cross section (see Fig. 1) consisted of a telescope (rows of counters D, A, B, C), which selected a vertical beam of charged particles, and a system of counters that recorded the products of the interaction of protons with the material of filters placed inside the telescope. All counters (including the telescope counters) were connected to a tube hodoscope. In measurements with the penetrating component of cosmic radiation, between rows B and C of the telescope counters there was a filter of 8 cm Pb + 0.9 cm Al. The filters Σ, made of paraffin and graphite,* were mounted on a carriage and, throughout the flight, automatically, every 3 min., were alternately inserted into the space between rows A and B of the telescope counters and withdrawn from it, so that measurements with paraffin and graphite alternated during the flight. A detailed description of the apparatus, its characteristics, and also a description of the methods for determining the inelastic-interaction cross section are given in papers ([2,3]).

The cross section of inelastic proton–proton interaction was determined by two methods: 1) from the change in shower production in lead when a substance containing hydrogen was placed in the telescope (the method of decreasing the flux of single shower-producing particles owing to interactions in hydrogen); 2) by direct measurement of the number of electron-nuclear showers from paraffin and graphite (showers from paraffin and graphite were recorded by the counters K, K_1, B, L_1, L, located in the upper part of the apparatus and directly surrounding the filter Σ under investigation).

It should be noted that, in proton–proton interaction, the formation of a shower consisting only of neutral fast particles is considerably less probable than in the

Fig. 1. Diagram of the arrangement of counters and filters in the instrument

Figure 1: Fig. 1. Diagram of the arrangement of counters and filters in the instrument

collision of a proton with a complex nucleus. Therefore one may regard the method of direct observation of showers in hydrogen as practically free from correction for interactions due to the formation of only neutral fast particles, in contrast to what was encountered in determining the proton-carbon-nucleus cross section ([3]).

To determine the cross section of inelastic proton-proton interaction we used the flight data of two instruments (Nos. 3 and 5) with a lead filter and of one instrument (No. 7) without a lead filter.

* In the drawing, the contours of the graphite filter are indicated by a solid line; the contours of the paraffin filter, by a dotted line.

In order to make the conditions for recording showers arising in paraffin and graphite approximately the same, we used graphite in powdered form (density of the graphite powder 1.0—1.1 $g \cdot cm^{-3}$; density of paraffin ~ 0.95 $g \cdot cm^{-3}$). We always selected the thickness of the graphite filter in $g \cdot cm^{-2}$ so that it was equal to the amount of carbon, in $g \cdot cm^{-2}$, contained in the paraffin filter. The difference between the thicknesses of the paraffin (18.8 $g \cdot cm^{-2}$) and graphite (16.0 $g \cdot cm^{-2}$) filters gave the amount of hydrogen in the paraffin (2.8 $g \cdot cm^{-2}$).

The Σ filters made of paraffin and graphite were placed in the telescope so that the positions of their centers coincided (see Fig. 1). Therefore the distance between the lower surface of the filter under investigation and row B of the telescope counters was 2 cm greater in the case of graphite than in the case of paraffin. This circumstance introduced a difference into the conditions for recording δ-showers from paraffin and graphite. Therefore, in order to determine the contribution of δ-showers to the showers from paraffin and graphite recorded by us and to introduce the corresponding correction into the measurement results, we determined, at sea level, under the conditions of the flight geometry actually recorded by the instrument, the percentage of δ-showers among the total number of recorded single particles. This percentage in measurements with the hard component proved to be: for paraffin $(6.45 \pm 0.13)\%$, for graphite $(7.10 \pm 0.15)\%$ of the recorded number of single particles passing through the instrument. The correction to the measured number of showers on hydrogen enters as the difference of these percentages, i.e. has the value $(0.65 \pm 0.20)\%$ of the recorded number of single particles. The values of the correction for the formation of δ-electrons: for paraffin 6.45% and for graphite 7.10%, were adopted by us both in measurements with the hard component,* and in measurements with the full intensity of cosmic radiation,** at sea level and in the stratosphere.***

Fig. 1. Diagram of the arrangement of counters and filters in the instrument

* Visual examination of the hodoscopic photographs of δ-showers from the hard component at sea level showed that the admixture of nonlocal showers was insignificant (not more than 2%). In this connection we considered a shower to be nonlocal if it was impossible to draw a straight line through the triggered counters (among those located inside the solid angle of the instrument) corresponding to the path of the particle that formed the δ-shower.

** An investigation of the formation of δ-showers was also carried out by us at sea level for the full flux of particles of cosmic radiation with an instrument without a lead filter. The percentage of showers obtained in these experiments and recorded by the counters surrounding the graphite (paraffin) proved to be, for graphite, (10.23±0.24)%, and for paraffin, (9.63±0.24)% of the recorded number of single particles. However, analysis of the hodoscopic photographs of these showers showed that the increase in the percentage of showers in measurements with the full flux of cosmic particles (with an unchanged difference of (0.60 ± 0.34)% between the data for graphite and paraffin, due to the arrangement of the filters) is explained mainly by an admixture of nonlocal showers, whose number is considerably larger than in measurements with the hard component of cosmic radiation. Therefore, when introducing the correction for δ-showers in measurements with the full intensity of cosmic radiation, we adopted the values of the percentage of δ-showers among the recorded single particles obtained for the hard component: for paraffin 6.45%, for graphite 7.10%.

*** In 1949-1950 K. I. Alekseeva and S. N. Vernov carried out special experiments on observing the formation of δ-electrons by the full flux of cosmic-radiation particles at ···

The percentage of δ-showers from the lead filter recorded by the counters M, M_1, C, E, N_1, N, which directly surrounded the lead, did not change, within the statistical accuracy of our measurements, when the filter Σ under investigation was placed in the telescope, and on the average was equal to $(6.85 \pm 0.12)\%$ of the single particles registered by the instrument.

We calculated the cross section for the inelastic proton—proton interaction from the ratio of the fluxes of single non-shower-producing particles in the presence of paraffin (I_p) and graphite (I_gr) in the telescope; this ratio is related to the mean free path L_p^H for the inelastic proton—proton interaction by the relation

$$\frac{I_\text{p}}{I_\text{gr}} = e^{-2.8/L_p^\text{H}}.$$

The amount of hydrogen in the paraffin was $2.8\ \text{g} \cdot \text{cm}^{-2}$. The correction for the influence of interactions due to primary α-particles was very small and therefore was not introduced. In the method of direct observation of showers from paraffin N_ℓ^p and graphite N_ℓ^gr, the flux ratio is obtained as a result of measuring the quantity

$$\frac{N_\ell^{\mathrm{p}} - N_\ell^{\mathrm{gr}}}{I_{\mathrm{gr}}},$$

since

$$\frac{I_{\mathrm{p}}}{I_{\mathrm{gr}}} = 1 - \frac{N_\ell^{\mathrm{p}} - N_\ell^{\mathrm{gr}}}{I_{\mathrm{gr}}},$$

where I_{gr} is the flux of single non-shower-producing particles at the given altitude, attenuated through interaction with carbon nuclei in the paraffin filter. To determine I_{gr} we used: 1) our data on the flux I_0 of charged particles at the boundary of the atmosphere at latitude 31°N—2.0 particles $\mathrm{cm}^{-2}\cdot\mathrm{min}^{-1}\cdot\mathrm{sterad}^{-1}$ (2); 2) the value of the absorption coefficient of the shower-producing component in air, $L_{\mathrm{abs}}^{\mathrm{air}} = 150\ \mathrm{g}\cdot\mathrm{cm}^{-2}$ (2); and 3) the value of the mean free path for the inelastic interaction of protons with carbon nuclei, $L_p^{\mathrm{C}} = 63\ \mathrm{g}\cdot\mathrm{cm}^{-2}$ (3). In the method of reducing the flux of single non-shower-producing particles, the flux ratio is obtained as a result of measuring the number of showers from lead in the presence, respectively, of paraffin $N_{\ell\mathrm{Pb}}^{\mathrm{p}}$ and graphite $N_{\ell\mathrm{Pb}}^{\mathrm{gr}}$ in the telescope, $I_{\mathrm{p}}/I_{\mathrm{gr}} = N_{\ell\mathrm{Pb}}^{\mathrm{p}}/N_{\ell\mathrm{Pb}}^{\mathrm{gr}}$.

Table 1 gives the ratio of the fluxes of single non-shower-producing particles, $I_{\mathrm{p}}/I_{\mathrm{gr}}$, obtained with different instruments and by different methods. Everywhere in the table the mean square statistical error is indicated. Corrections for accidental coincidences and for δ-showers were introduced into the data presented. In addition, corrections were introduced into the registered number of showers on hydrogen: a) for instruments with a lead filter—a correction for the change in the background from showers from lead with particles directed upward, when going from graphite to paraffin (2, 3), about 6% of the cross-section value; b) a correction for the calculation of interactions due to the entry of shower particles into the gaps between counters, $\sim$ 6% of the cross-section value; c) a correction for electron–

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different altitudes in the graphite filter (filter area $20 \times 20\ \mathrm{cm}^2$, thickness $1.0\ \mathrm{g\ cm}^{-2}$). The telescope consisted of 3 rows of counters located one above another, which selected the telescope angle of the instrument. A row of counters located beneath the graphite filter at a distance of $\sim$ 15 cm and recording δ-electrons consisted of 10 thin-walled counters (diameter $\sim$ 1.8 cm, length 20 cm, wall thickness $\sim$ 0.2–0.3 mm). Owing to the small thickness of the graphite filter, the admixture of electron-nuclear and electron-photon showers to the δ-showers was small. Since the instrument contained no vertically arranged rows of hodoscopic counters, it registered a comparatively small number of side, nonlocal showers. Selection of δ-showers was carried out visually by viewing hodoscopic records of the counters that had fired. It was found that the percentage of δ-showers (mainly showers with the number of counters fired not exceeding

3), relative to the number of registered single particles, changed practically not at all at all altitudes from sea level to 20 km. The observed slight increase in the relative number of δ-showers (approximately by 20%) for altitudes above 20 km could mainly be explained by a small admixture of electron-nuclear showers from graphite and of nonlocal showers.

Proceeding from the approximate equality of the percentage of δ-showers for the hard component and for the total intensity of cosmic radiation at sea level, and from the described experiments on the formation of δ-showers in the stratosphere, we came to the conclusion that, in going from sea level to the stratosphere, the percentage of δ-showers relative to the number of registered single particles does not change appreciably.

Table 1

Instrument	Method	Mean atmospheric depth x, $\mathrm{g\,cm^{-2}}$	Ratio of fluxes I_Π/I_Γ	Interaction range of proton—proton inelastic interaction L_p^{H}, $\mathrm{g\,cm^{-2}}$	Cross section of proton—proton inelastic interaction σ_p^{H}, mb
Instrument No. 3 with filter 8 cm Pb + 0.9 cm Al	Direct measurement of the number of showers from paraffin and graphite	36.4	0.905 ± 0.033		
Instrument No. 5 with filter Pb + Al	Same	25.9	0.948 ± 0.030		
Instrument No. 7 without lead filter	» »	42.5			

Instrument	Method	Mean atmospheric depth x, $\mathrm{g\,cm^{-2}}$	Ratio of fluxes I_Π/I_Γ	Interaction range of proton—proton inelastic interaction L_p^{H}, $\mathrm{g\,cm^{-2}}$	Cross section of proton—proton inelastic interaction σ_p^{H}, mb
Instrument No. 3 with filter 8 cm Pb + 0.9 cm Al	Decrease in the flux of singly charged shower-producing particles due to interactions in hydrogen (from the change in the number of showers from lead when graphite is replaced by paraffin)	34.0	0.981 ± 0.028	51^{+23}_{-12}	32 ± 10

Instrument	Method	Mean atmospheric depth x, $\mathrm{g\,cm^{-2}}$	Ratio of fluxes I_Π/I_Γ	Interaction range of proton–proton inelastic interaction L_p^{H}, $\mathrm{g\,cm^{-2}}$	Cross section of proton–proton inelastic interaction σ_p^{H}, mb
Instrument No. 3 with filter 8 cm Pb + 0.9 cm Al	Decrease in the flux of singly charged shower-producing particles due to interactions in hydrogen (from the change in the number of showers from lead when graphite is replaced by paraffin)	36.4	0.866 ± 0.058		
Instrument No. 5 with filter Pb + Al	Same	25.9	1.000 ± 0.060		

photonic showers to the paraffin–graphite difference in the instrument without lead is $\sim 15\%$ of the cross-section value.

After averaging all the data presented in the table, taking into account statistical weights, the following values were obtained for the range L_p^{H} and the cross section σ_p^{H} of the proton–proton inelastic interaction:

$$L_p^{\mathrm{H}} = 51^{+23}_{-12}\ \mathrm{g \cdot cm^{-2}}; \qquad \sigma_p^{\mathrm{H}} = 32 \pm 10\ \mathrm{mb}.$$

Walker et al. [(4)], working with a Wilson chamber in the mountains, measured the cross section of inelastic interaction of protons in paraffin. Taking the cross section of inelastic interaction of protons with carbon nuclei to be equal to the geometrical cross section of the carbon nucleus, they calculated the range and the cross section of the proton–proton inelastic interaction, which proved to be, respectively: $L_p^{\mathrm{H}} = 31^{+35}_{-7}\ \mathrm{g \cdot cm^{-2}}$, $\sigma_p^{\mathrm{H}} = 54^{+15}_{-29}$ mb. In a brief report by Fowler et al. [(5)], a value of 29.5 ± 5.5 mb is given for the cross section of the proton–proton inelastic interaction, obtained at the bevatron at a proton energy of 5.3 BeV. In the proceedings of the Rochester Conference on High-Energy Particle Interactions (April 1956), a value of ~ 25 mb (statistical accuracy not specified) is given for the cross section of the proton–proton inelastic interaction at a proton energy of 5.3 BeV. At a mean proton energy of ~ 20 BeV we obtained the value 32 ± 10 mb. Taking into account the large statistical error of the experiment, it may be considered that in the energy interval from 1.5-2.0 to ~ 20 BeV no significant increase is observed in the cross section of the proton –proton inelastic interaction.

S. I. Brikker and M. M. Dubrovin took part in carrying out the work.

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REFERENCES

1. K. I. Alekseeva, N. L. Grigorov, ZhETF, **32**, 404 (1957).
2. K. I. Alekseeva, S. I. Brikker, N. L. Grigorov, F. L. Savin, N. A. Shcherbakov, DAN, **115**, 71 (1957).
3. K. I. Alekseeva, N. L. Grigorov, DAN **115**, 259 (1957).
4. W. D. Walker, N. M. Duller, J. D. Sorrels, Phys. Rev., **86**, 865 (1952).
5. R. W. Wright, G. Saphir et al., Phys. Rev., **100**, 1802 (1955).

Note: Figure translations are in progress. See original paper for figures.