MEASUREMENTS OF THE INELASTIC PROTON-PROTON AND PROTON-CARBON CROSS-SECTIONS AT ENERGIES $10^{10}-10^{12}$ eV ON BOARD THE SATELLITES PROTON 1, 2, AND 3

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The values σ_{pc}^{in} and σ_{pp}^{in} were measured on the satellites Proton 1, 2, and 3 at proton energies of 20 to 600 GeV. σ_{pc}^{in} increases by $20 \pm 5\%$ in this energy range. σ_{pp}^{in} was measured by means of the difference method using polyethylene and graphite targets. Errors of the σ_{pp}^{in} values were 8 to 20%. An energy dependence of σ_{pp}^{in} similar to that obtained for σ_{pc}^{in} cannot be excluded in the same energy range.

The cross-sections of inelastic proton-proton and proton-carbon interactions at energies of $10^{10}-10^{12}$ eV were measured on the satellites Proton 1, 2, and 3, by means of the SEZ-14 installation [1] and the "leaving the beam" method. The SEZ-14 installation consisted of two independent and identical apparatuses. The protons were selected by two proportional counters measuring the charge passing through the graphite or polyethylene targets which were placed in and removed from the apparatuses alternately. The interaction detector consisted of a scintillation counter with a lead sheet 2.5 cm thick above it. It selected cases when a single relativistic particle with unit charge passed through the counter. The proton energy was measured with an ionization calorimeter. Thus, in this experiment, the cross-section was measured for inelastic interactions in which at least one of the following processes occurred in the target:

(i) at least two charged particles ($n_s \geq 2$) with ranges $R \geq 28$ g/cm^2 of lead + 5 g/cm^2 of plastic scintillator material were produced, and/or

(ii) at least one particle decaying, with a lifetime of $>10^{-10}$ sec, into γ-quanta of a total energy of $E_\gamma \geq 500$ MeV was produced, and/or

(iii) a proton gave rise to a neutron via charge-exchange ($n_s = 0$).

The experiment on Proton 3 differed from those carried out on Protons 1 and 2 inasmuch as both parts of the SEZ-14 apparatus were provided with direction detectors (Čerenkov counters) which made it possible to select the particles entering the apparatus from the side of the inlet window. Since the direction detector decreased the geometry factor of the apparatus considerably, the measurements with this detector could serve for a check-up only. For this reason, the direction detector of the second part of the SEZ-14 apparatus was connected to the detection system in such a way that the measurements could be carried out both with or without the direction detector.

Preliminary results of the measurements carried out on the satellites Proton 1 and 2 were published in [2—4]. Since that time the evaluation of all available primary information except of the orientation of the satellites Proton 1, 2, and 3 has been completed and the equipment parameters, instrumental effects, and physical processes affecting the measured values of the cross-sections have been accounted for more accurately.

Table 1 lists the values of the average thicknesses of the targets calculated by taking into account the complex configuration of the graphite target and the differences between the various targets of the instruments installed on different satellites.

Table 1

Satellite	Polyethylene target			Graphite target	
	x^p g cm^{-2}	x_c^p g cm^{-2}	x_H^p g cm^{-2}	x_c^g g cm^{-2}	$\Delta x_c = x_c^g - x_c^p$ g cm^{-2}
Proton 1	36.1	30.9	5.2	33.8	2.9
Proton 2	35.8	30.7	5.1	33.1	2.4
Proton 3	36.7	31.5	5.2	34.4	2.9

x_c^g and x_c^p denote the mean carbon content of the graphite and polyethylene targets, respectively. x_H^P is the mean hydrogen content of the polyethylene target.

The values of σ_{pc}^{in} measured at energies close to each other and obtained in various measurements agree well with each other except for the data obtained on the second half of the Proton 2 apparatus. In this measurement the values of σ_{pc}^{in} are, at all energies, some 10% less than those obtained in other measurements, though the relative increase of the cross-section with energy remains the same. An analysis of the operation of the instrument has shown that the counting rate of the scintillation telescope consisting of the interaction detector and the lower scintillation counter increased abruptly, probably because of an increase in the noise of one of the photomultipliers. This resulted in a decrease of the counting rate of the protons detected, and the counting rate without a target was decreased more considerably than that with a target. The data obtained in this series of measurements were excluded from the analysis. For similar reasons a small amount of information obtained with the first part of the instrument at the end of the flight of Proton 2 (beginning with the 720th revolution) was also excluded.

When analyzing the latitude dependence of the detected proton intensity, spurious coincidences between the scintillation telescope detecting protons with energies of several GeV and the ionization burst detector were found at high latitudes, whereas the contribution of spurious coincidences remained small in equatorial regions. Since the number of spurious coincidences could not be determined with sufficient accuracy, data obtained in equatorial regions only were taken into consideration when determining cross-sections. The mean value of the σ_{pc}^{in} values obtained in various phases of the measurement and weighted with the reciprocal values of their respective root mean square errors was calculated. The values obtained were corrected for the absorption of protons in the duralumin frame of the graphite target as well as for the production of δ-electrons. The value of the first correction tends to be smaller at high energies, if $\sigma_{pAl}^{\text{in}} = 400$ mb remains constant with increasing energy, whereas the value of the second correction changes from -2% to -4%

with increasing energy. The values corrected for the effects mentioned above are shown in Fig. 1 for four series of measurements together with the results of measurements of $\sigma_{pc}^{\mathrm{in}}$ carried out with the second half of the Proton 3 apparatus having the direction detector joined to it. To reduce the errors of the $\sigma_{pc}^{\mathrm{in}}$ values at 150 GeV, results of measurements with the polyethylene target were also taken into consideration. The value of $\sigma_{pp}^{\mathrm{in}}$ was assumed to be 30 mb in this case. It has been shown that no spurious coincidences affected the measurements with the direction detector. Thus, to calculate $\sigma_{pp}^{\mathrm{in}}$ it was possible to use all the data obtained during the measurements. During the detection with the direction detector the protons did not pass

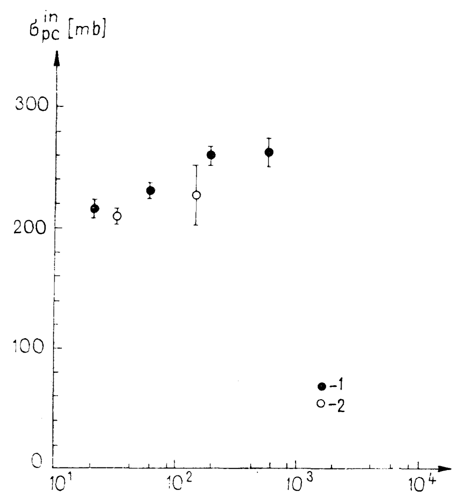

Fig. 1. The weighted mean value of $\sigma_{pc}^{\mathrm{in}}$ according to measurements carried out on satellites Proton 1, 2, and 3. 1 — without direction detector, 2 — with direction detector

through the massive elements of the target frames while the direction detector was in operation. Thus, no correction for absorption in the target frames was necessary. Correction was made only for the production of δ-electrons.

It can be seen in Fig. 1 that the results of measurements with the direction detector agree well with the results obtained without this detector. It can also be seen in Fig. 1 that the measured value of $\sigma_{pc}^{\mathrm{in}}$ increases by 20 ± 5% in the energy range under consideration.

To determine $\sigma_{pp}^{\mathrm{in}}$, the mean value of the ratios of the counting rates obtained with graphite and polyethylene targets, $\left\langle \frac{I_{\mathrm{C}}}{I_{\mathrm{CH_2}}} \right\rangle$, was calculated for adjoining periods of measurement. The values of $\sigma_{pp}^{\mathrm{in}}$ were then found on the basis of the following expression:

$$\sigma_{pp}^{\mathrm{in}} = \frac{\ln \left\langle \frac{I_{\mathrm{C}}}{I_{\mathrm{CH_2}}} \right\rangle}{X_H^p N_{AV}} + \frac{\sigma_{pc}^{\mathrm{in}}}{A} \frac{\Delta x_c}{X_H^p},$$

where X_H^p, the amount of hydrogen traversed by the particles in the polyethylene target, and Δx_c, the excess of carbon in the graphite target compared with the polyethylene target, should be expressed in units of g cm^{-2}. N_{AV} is the Avogadro number, and A is the atomic weight of carbon. The value of σ_{pc}^{in} was taken from the experiment.

The values of σ_{pp}^{in} were determined on the basis of data obtained in the equatorial region, so as to avoid corrections for spurious coincidences. Neither was it necessary to correct the data for the absorption in the target frames, since the frames of the carbon and polyethylene targets were identical. Only the correction for the

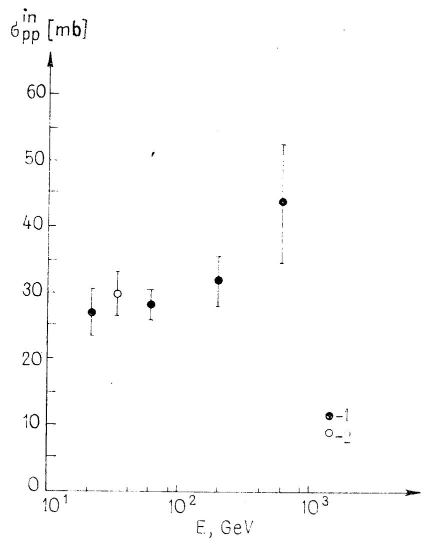

Fig. 2. The weighted mean value of σ_{pp}^{in} according to measurements carried out on satellites Proton 1, 2, and 3. 1 — without direction detector, 2 — with direction detector

production of δ-electrons was carried out. The weighted mean values of σ_{pp}^{in} as obtained during the four series of measurements are shown in Fig. 2, where the value of σ_{pp}^{in} measured by means of the second half of the Proton 3 apparatus with the direction detector is also shown. The latter value agrees well with those measured without a direction detector.

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The authors are indebted to A. S. Zhdanov, N. M. Gordeeva, E. V. Troitskaya, L. P. Maslova, and M. I. Ivanova for their help in evaluating the experimental data.

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