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A B S T R A C T

This paper is devoted to an investigation of elastic p–p scattering at 8.5 BeV by the emulsion method. A beam of incident protons was directed perpendicularly to the emulsion plane. There were found 145 events of elastic scattering (66 events from /1/ are included). The contribution of the scattering events on quasi-free protons and of other background events is 1%. The elastic scattering cross section is found to be (8.6 ± 0.8) mb. The differential cross section up to 1° in the c.m.s. has been obtained.

The results are inconsistent with a model of a purely absorbing proton. The calculations made according to a model of a uniform sphere show that it is possible to obtain an agreement with the experimental data by the following parameters:

$R = (1.5 \div 1.7) \cdot 10^{-13}$ cm

$K = (0.19 \div 0.12) \cdot 10^{13}$ cm^{-1} ($u = 22 \div 34$ MeV)

$K_1 = (0.15 \div 0.12) \cdot 10^{13}$ cm^{-1} ($U' = 22 \div 27$ MeV)

EXPERIMENTAL PROCEDURE

In/1/ preliminary data on elastic p-p scattering at 8.5 BeV have been published. This paper is a continuation of/1/.

This experiment has been performed with the stack of 10 x 10 x 2 cm^3, 400μ NIKFI –BR stripped emulsions, exposed to the internal proton beam of the Joint Institute synchrophasotron at 8.5 BeV. The beam was directed perpendicularly to the plane of emulsion.

An analysis was made to determine the hydrogen content in the control emulsion pellicles. It turned out that 1 cm^3 of the exposed emulsion contained $(2.90 \pm 0.06) \cdot 10^{22}$ hydrogen atoms.

The emulsion was area-scanned with an oil emersion objective under a magnification of 630 X in the central part of the plates 2 x 2 cm^2. The mean density of the beam in this zone was found to be $(1.97 \pm 0.05) \cdot 10^5$ particles/cm^2. Altogether we have scanned 3.35 cm^3 of emulsion.

To determine the scanning efficiency and the reliability of the results all the area was scanned twice. Out of the two-prong stars found those alike elastic p-p scattering have been chosen. Their number turned out to be 799. Depending upon the range of a slow proton, these events were divided into three groups:

1. $10\mu \leq R < 100\mu$
2. $100\mu \leq R < 20000\mu$
3. $R \geq 20000\mu$

Slow proton tracks of the first two groups were practically 'black', for the emulsion sensitivity was high (I/I_{min} = 40 grains/100μ). The efficiency of the twofold scanning proved to be (85 ± 3)%, (92.5 ± 0.8)% and (78 ± 5)% for the events of the first, second and the third group, respectively.

ANALYSIS OF THE EVENTS AND METHODS OF MEASUREMENTS

To identify the events of elastic scattering on free hydrogen the following criteria were used:

1) The relationship between the recoil proton range R and its scattering angle φ satisfies the kinematics of elastic scattering.

2) The angle γ between the planes of the tracks of the primary and scattered protons and that of primary and recoil protons must be equal to zero (coplanarity condition).

3) The relationship between the recoil proton range R and the angle ψ formed by the direction of the scattered proton and that of the primary proton must satisfy the kinematics of elastic scattering.

4) In the point of scattering there must be no recoil nucleus and β-electron.

If the recoil proton does not stop in the stack and its momentum determined by the ionization measurements is known with a great experimental error one makes use of the relation between the angles ψ and φ of the scattered and the recoil protons, valid for elastic scattering.

The recoil proton range R was measured, the error being not more than 5%.

The inaccuracy in the measurement of the dip angle gave the main error in the determination of the recoil proton angle. On the average this error does not exceed $1^\circ \div 1.5^\circ$ except the events with a short range of a recoil proton ($R < 500\,\mu$).

The measurements of the scattered proton angle ψ were made by the following procedure.

1. In the vicinity of the scattering act at a distance of 20-30 μ a beam reference track was chosen which did not undergo an interaction. To determine the scattering angle ψ four measurements were made of the projections of the distance between the reference between the reference track and the track undergoing the scattering on the x and y axes (along the marking lines)in the emulsion plane. Two measurements were carried out before the scattering act on the basis of 2000 μ (the thickness of five plates) and two after the scattering act on the same basis. The accuracy of the measurements of the projections was $\sim 1\,\mu$. This allowed to measure the scattering angle with the accuracy of $2' \div 3'$.

To eliminate the accidental errors simultaneous independent measurements were made with respect to three reference tracks.

One may determine the angle of noncoplanarity γ from these measurements if the direction of the recoil proton is known. The error in the magnitude of γ is mainly due to an error of the measurement of the scattering angle $\Delta\psi$ and depends upon the magnitude of this angle. So, for $\psi \approx 1^\circ$, $\Delta\gamma \approx 3^\circ$, if $\Delta\psi \approx 3'$.

As is shown in /1/, by the available accuracy of measurements the contribution of the quasi-elastic events to the number of those chosen is of the order of 1°.

For each measured event the errors in measurements were evaluated and the events satisfying the kinematics within the limits of threefold errors were chosen. In Figs. 1,2,3 are given the distributions of these events by $|\Delta\varphi|$, $\Gamma = \left|\frac{\gamma}{\Delta\gamma}\right|$ and $|\Delta\psi|$ It is seen from Fig. 1 that the root-mean-square error in the measurement of the angle φ is 2°. It can be also seen from the distribution of the chosen events by Γ that the errors in the measurements of the noncoplanarity angles are estimated correctly. The histogram in Fig. 3. shows the events satisfying the kinematics by the first two criteria within the threefold root-mean-square error.

In the same Figure are also shown the scattering events on quasi-free protons having the momentum lying in the scattering plane and directed perpendicularly to an incident proton, since such events are not identified by the first two criteria. A considerable part of these events belongs to the region $|\Delta\psi| > 12'$

(i.e. beyond the threefold halfwidth of the distribution) where there are no scattering events on free protons. By the number of such events it is possible to evaluate the contribution of quasielastic and other background events to the region of $\Delta\varphi < 12'$. This contribution is found to be $\sim 1\%$.

RESULTS AND DISCUSSION

The employed methods of exposing the emulsion pellicles perpendicularly to their plane and the measurement procedure allowed to obtain the differential cross section in the c.m.s. up to 1^o, to identify reliably the quasi-elastic and other background events and to get rich statistics quickly enough.

145 events satisfy the selection criteria within the threefold root-mean-square error (only five of them have a recoil proton emerging from the emulsion stack). This is several times more than in other emulsion experiments on elastic scattering/2/,/3/,/4/.

Taking into account the contribution from quasi-elastic events, the missing of the scattering events at small angles ($< 1^o$ c.m.s.) the scanning efficiency, the cross section for elastic interaction was found to be $\sigma_{el} = (8.6 \pm 0.8)$ mb.

In Fig. 4 is presented a histogram of the differential cross section for elastic p-p scattering in the c.m.s. The solid thick line indicates the angular distribution obtained by a model of a purely absorbing disk with the parameters: radius of the disk $R = 0.94 \cdot 10^{-13}$ cm.; the amplitude of the transmitted wave $a = 0.453$, $\sigma_{el} = 8.5$ mb, $\sigma_{in} = 22$ mb. As is seen from the Figure this model cannot account for the obtained experimental data. Neither can these data be accounted for by any other model (neglecting the spins) of a purely absorbing proton according to which the differential cross section at 0^o is given by the optical theorem; $|\mathrm{Im}\, f(0)|^2 = \left(\frac{\sigma_t}{4\pi\lambda}\right)^2$ and is considerably less than the experimental one. Here our results are inconsistent with those of other experiments performed at lower energies. So, e.g, in/5/, where the elastic scattering was studied at 6.15 BeV. the differential cross section is extropolated from the value measured at 7.6^o to the value at 0^o given by the optical theorem. However, when comparing the values $\frac{1}{k_c^2}\frac{d\sigma(\theta)}{d\Omega}$ from/5/ and our paper, plotted against $k_c \sin\theta$, the agreement is satisfactory. The disagreement of our experimental data with the model of a proton suggested in/5/ is observed in the angle region 0^o – – 7.6^o (in/5/ the differential cross section is not measured in this angle interval).

The agreement of the data/3/ with the model of a purely absorbing disk is likely to be due to the insufficient statistics.

In this connection the method of analyzing the data on elastic p-p scattering employed in/6/, where the scattering amplitude is considered purely imaginary, seems to be not very justified.

The calculations have been made by the model of a uniform sphere with the complex refraction coefficient according to/7/. The experimental data, as is seen from Fig. 4 are in satisfactory agreement with the sphere having the following parameters:

$$R = (1.5 \div 1.7)\ 10^{-13}\ \mathrm{cm}$$
$$K = (0.191 \div 0.125)\ 10^{13}\ \mathrm{cm}^{-1}$$
$$K_1 = (0.155 \div 0.125)\ 10^{13}\ \mathrm{cm}^{-1}$$
$$U = (34{,}1 \div 22.3)\ \mathrm{MeV}$$
$$V = (27.5 \div 21.8)\ \mathrm{MeV}$$

where R is the sphere radius, K and K_1 characterize the absorption and refraction, respectively. U and V are the corresponding values of the imaginary and real potentials.

In Fig. 4 is shown the differential cross section for the Coulomb interaction (the solid thin line). One can see that in angle region $> 2.5^\circ$ the influence of the Coulomb interaction is very small, and may be neglected. In the interval $1^\circ \div 2.5^\circ$ we have obtained the value for the differential cross section which is somewhat less compared with the predictions of a model of a uniform sphere. It cannot be due to the missing of events in this interval, since the efficiency of their finding is rather high and is known accurately. Perhaps, this is accounted for the interference of the Coulomb interaction with the nuclear one. However, to make such a conclusion a larger statistics is necessary.

A great value of the differential cross section at 0° is consistent with a model of a purely absorbing proton if the interaction cross sections in the singlet and triplet states are assumed to be very much different.

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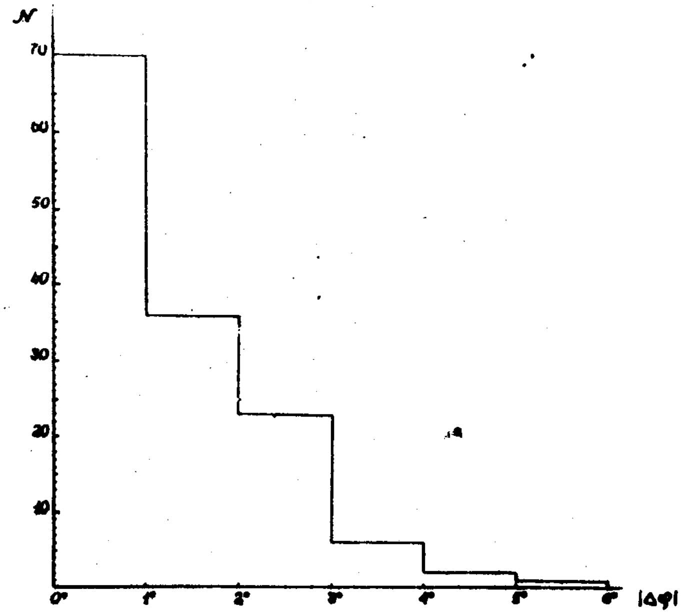

Fig. 1. Distribution of elastic scattering events by $|\Delta\varphi|$, $\Delta\varphi$ – the difference between the measured angle of the recoil proton and that corresponding to its range by the kinematics of elastic scattering

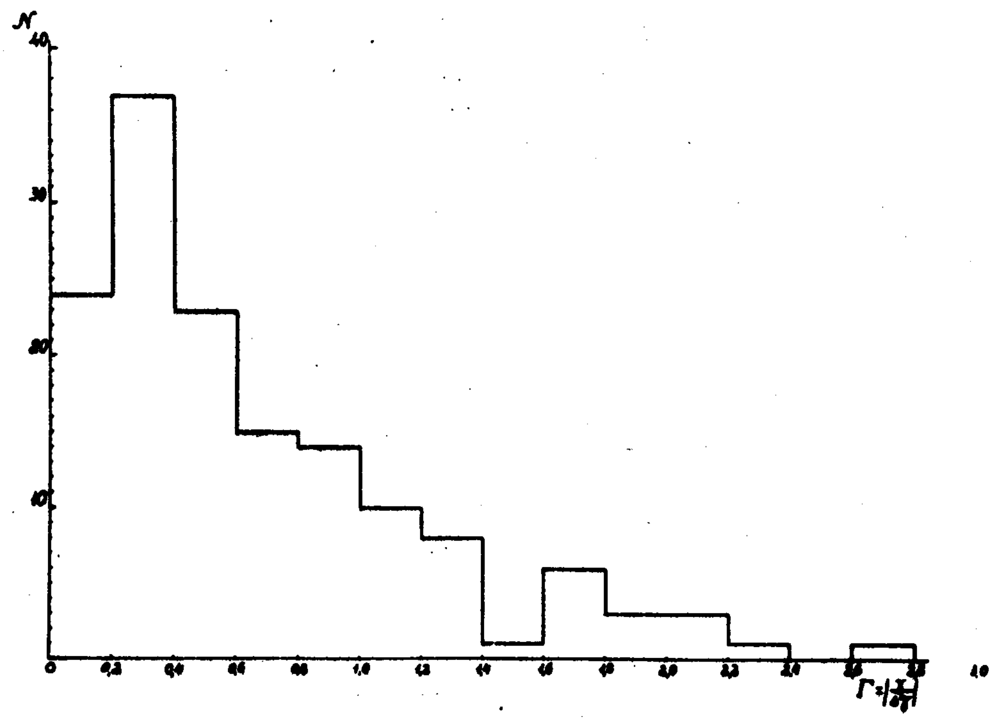

Fig. 2. Distribution of elastic scattering events by the magnitude of $\Gamma = \left|\frac{\gamma}{\Delta\gamma}\right|$ where is the noncoplanarity angle, and $\Delta\gamma$ is its error.

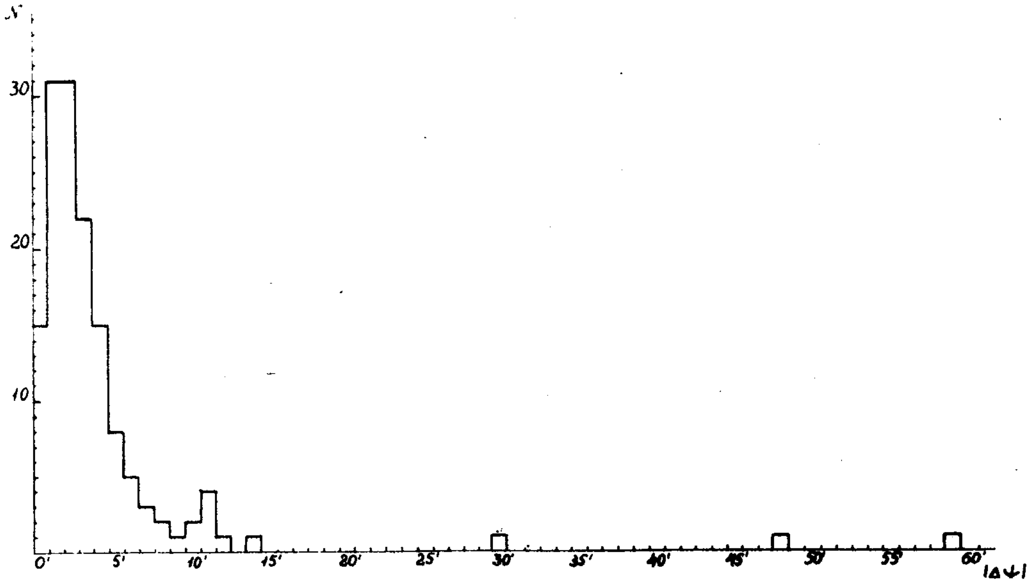

Fig. 3. Distribution of the events chosen by the first two criteria (the relation $R-\varphi$ and the coplanarity) by $|\Delta\psi|$. $\Delta\psi$ – the difference between the scattered proton angle and that corresponding to the recoil proton range by the ~~kinematics~~ of elastic scattering.

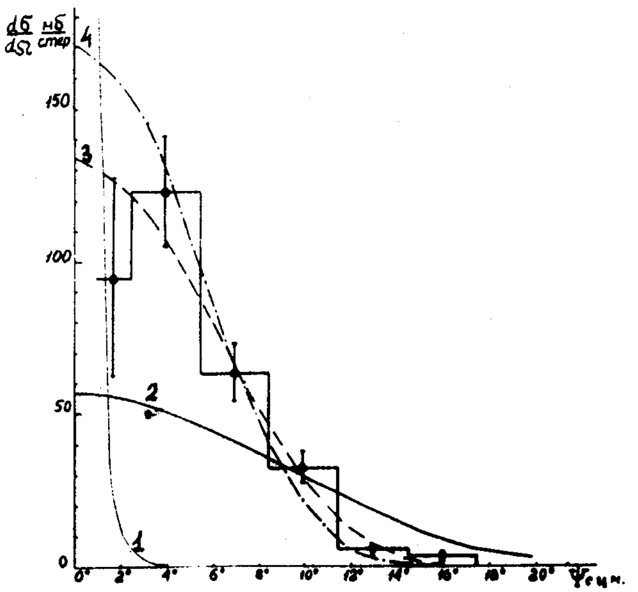

Fig. 4. Differential cross section for elastic proton-proton scattering at 8.5 BeV in c.m.s. (a histogram) ψ – the scattering angle in the c.m.s. The calculated curves (1) – Coulomb scattering, (2) – a disk at $R = 0.94$ and $a = 0.453$. (3) – a uniform semitransparent sphere at $R = 1.5$ f, $k = 0.19 \cdot 10^{13}$ cm-1, $k_1 = 0.15 \cdot 10^{13}$cm^{-1}, u = 34 MeV, V = 27 MeV (4) – a uniform semitransparent sphere at $R = 1.7$ f ($K = 0.12 \cdot 10^{13}$cm^{-1}, $K_1 = 0.12 \cdot 10^{13}$ cm^{-1} u = 22 MeV. V = 22 MeV.