ESTIMATE OF THE UPPER LIMIT OF THE CHARGE-EXCHANGE CROSS SECTION FOR THE pn INTERACTION AT 8.5 Bev

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The upper limit of the cross section for elastic scattering of 8.5 Bev protons on neutrons accompanied by charge exchange was studied by the photographic emulsion technique and was found to be 0.46 ± 0.15 mb.

According to statistical theory, the pn charge-exchange scattering cross section σ_{ex} should be small at high energies (as is the case for the cross section of any possible reaction involving the inelastic interaction of nucleons); at 10 Bev, $\sigma_{ex} \sim 2 \times 10^{-4} \sigma_{in}$ (see reference 1), where σ_{in} is the cross section for all inelastic processes. It is not impossible, however, that charge exchange stands apart from all the remaining reactions.

Another circumstance which makes charge-exchange scattering of interest is the fact that the ratio $\sigma_{ex}/\sigma_{el\,pp}$ ($\sigma_{el\,pp}$ is the pp elastic scattering cross section), under the condition of isotopic invariance, depends on the contribution of the one-meson interaction scheme to the process of elastic scattering of nucleons. Thus, if NN elastic scattering takes place only as a result of the exchange of a single π meson, then the above-mentioned ratio is equal to 4.

Under certain assumptions, it is possible to estimate the maximum difference of the pp and pn total interaction cross sections $\Delta_{tot} = \sigma_{pp} - \sigma_{pn}$. Indeed, owing to isotopic invariance, we have the following relation between the amplitudes of the corresponding elastic processes:

$$A_{pp}^{(3)(0)} - A_{pn}^{(3)(0)} = A_{ex}^{(3)(0)}. \qquad (1)$$

The indices 3, 0 indicate that this relation holds separately for the triplet and singlet states of the nucleons (for ordinary spin). Using also the relations

$$\frac{k}{4\pi}\,\mathrm{Im}\,A(0) = \sigma_{tot}, \qquad \sigma_{ex}(\theta) \geqslant [\mathrm{Im}\,A_{ex}(\theta)]^2$$

(here k is the wave vector of the incident particle and σ_{tot} is the total interaction cross section), we obtain

$$\Delta_{tot} \leqslant \frac{4\pi}{k}\left[\frac{3}{4}\sqrt{\sigma_{ex}^{(3)}(0)} + \frac{1}{4}\sqrt{\sigma_{ex}^{(0)}(0)}\right]. \qquad (2)$$

Here $\sigma_{ex}^{(3)}(0)$ and $\sigma_{ex}^{(0)}(0)$ are the differential charge-exchange cross sections for $\theta = 0°$ in the triplet and singlet states of the nucleons, respectively. These cross sections are related to the cross section $\sigma_{ex}(0)$ measured with an unpolarized target and an unpolarized beam in the following way:

$$\frac{3}{4}\sigma_{ex}^{(3)}(0) + \frac{1}{4}\sigma_{ex}^{(0)}(0) = \sigma_{ex}(0).$$

Hence the bracketed expression in formula (2) takes on a maximum value $\sqrt{\sigma_{ex}(0)}$ when $\sigma_{ex}^{(3)}(0) = \sigma_{ex}^{(0)}(0)$ and a minimum value $\frac{1}{2}\sqrt{\sigma_{ex}(0)}$ when $\sigma_{ex}^{(3)}(0) = 0$. Thus, a measurement of the difference Δ_{tot} and the differential charge-exchange cross section for $\theta = 0°$ gives some information on the role of the spin interaction.

Under the assumptions 1) that the cross sections are independent of the spin state of the nucleons and 2) that the angular dependences of the differential pp elastic scattering cross section and the differential pn charge-exchange scattering cross section are similar, formula (2) takes the form

$$\Delta_{tot} \leqslant (4\pi/k)\sqrt{\sigma_{ex}\sigma_{el\,pp}(0)/\sigma_{el\,pp}}\,, \qquad (3)$$

where $\sigma_{el\,pp}(0)$ is the differential pp elastic scattering cross section for $\theta = 0°$.

If it is assumed that the pp elastic scattering amplitude is purely imaginary, then inequality (3) can be simplified to

$$\Delta_{tot} \leqslant \sqrt{\sigma_{ex}\sigma_{pp\,tot}/\sigma_{el\,pp}}\,. \qquad (4)$$

In the present article we attempt to estimate the upper limit of the charge-exchange cross section in the scattering of 8.5-Bev protons on bound neutrons in emulsion nuclei.

EXPERIMENTAL METHOD AND RESULTS

A $10\times10\times2$ cm emulsion stack was exposed to a beam of 8.5-Bev protons.

The beam was directed perpendicularly to the emulsion pellicles. The advantage of such a method for the observation of events such as pp elastic scattering and charge exchange $p + n \rightarrow n + p$ has been discussed previously.[2] Area scanning was employed.

We selected for analysis all two-prong and one-prong stars containing one black or gray prong (the latter corresponds to protons of energy ≤ 300 Mev). The two-prong stars included elastic scatterings of protons on hydrogen and quasi-elastic pp scatterings, i.e., scatterings of protons on bound protons of emulsion nuclei. The one-prong stars should include the charge-exchange reactions $p + n \rightarrow n + p$ (if such reactions occur).*

If the number of quasi-free protons and neutrons is the same, then the charge-exchange cross section is

$$\sigma_{ex} = (N_{ex}/N_{\text{quasi }pp})\,\sigma_{el\ pp}K, \qquad (5)$$

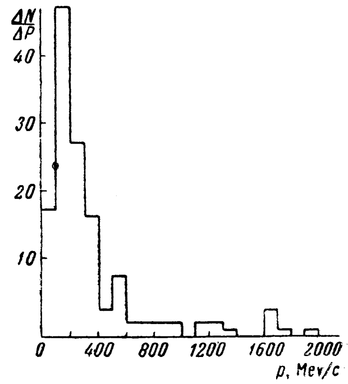
where N_{ex} and $N_{\text{quasi pp}}$ are the numbers of cases of each type after analysis of the events and K is the ratio of the efficiencies of recording two- and one-prong stars.

This estimate will be increased or decreased, depending on the strictness of the criteria by which the cases of charge exchange and quasi-elastic scattering are selected.

The selection criteria were as follows:

1. Separation of charge-exchange events: a) we selected stars without recoil nuclei; b) the prong in a one-prong star was regarded as the recoil proton produced as a result of the charge exchange of a neutron. Therefore the relation between the angle of flight of the recoil proton θ and its momentum p should include the binding energy of the neutrons in the nucleus and their momentum distribution. To take this into account, we constructed on the (θ, p) plane the region in which points corresponding to charge-exchange reactions could lie. The density of points outside this region is a measure of the background.

2. Separation of pp quasi-elastic scattering. This separation reduced to the calculation (for two-prong stars without a recoil nucleus or a beta-decay electron) of the momentum of the target proton, i.e., of a proton bound in a nucleus. This momentum was calculated as the difference between the observed recoil-proton momentum and the momentum transfer. The first quantity was measured from the range (or ionization) in emulsion and the second was determined from the scattering angle of the primary proton. This angle was measured to an accuracy of 0.2°.



Distribution of two-prong stars without a recoil nucleus or a beta-decay electron as a function of the target-proton momentum.

We then constructed the distribution of the number of cases as a function of the momentum of the target proton $dN(p)/dp$ (see the figure). This distribution has a maximum near the point $p = 200$ Mev, corresponding to the pp quasi-elastic scatterings. The width of the maximum depends on the value of the mean momentum of the target proton inside the nucleus and the measurement error. The dip in the curve close to the point $p = 0$ results from the errors in the measurements of the angles and momenta of the particles, which lead to an increased momentum p of the target proton. The value of the function $dN(p)/dp$ at large p characterizes the background. In our case, it turned out to be $\sim 10\%$. For the estimate of the background, we also attempted to separate similar "quasi-elastic" cases for three-prong stars by neglecting one of the prongs. It turned out that the probability of the separation of a "quasi-elastic" case for a three-prong star was one-tenth of that for a two-prong star. This indicates that the described method gives a sufficiently reliable separation of the quasi-elastic cases.

It is seen from the above that the two-prong stars are subjected to stricter selection criteria than the one-prong stars. Expression (5) therefore gives an upper limit for the charge-exchange cross section. One could attempt to obtain the cross section σ_{ex} from expression (5) by applying to the two-prong stars the same selection criteria that is applied to the one-prong stars. This could be done, however, only if it is known beforehand that the background-effect ratio in pp scattering and in pn charge-exchange scattering is the same.

A total of 8.08 cm^3 of emulsion was scanned. Of the 1859 recorded two-prong stars, 466 pp

*This reaction can also be regarded as elastic backward scattering of a proton on a neutron in the c.m.s.

quasi-elastic scatterings were separated. The number of one-prong stars found was 55, and after analysis, 20 remained. The scanning efficiency for two-prong stars (~92%) and for one-prong stars (~75%) was found from the results of a second scanning of the entire area. The cross section $\sigma_{el\,pp} = 8.7$ mb was taken from the work of Markov et al.[2] We finally obtained $\sigma_{ex} \leq 0.46 \pm 0.15$ mb.* The error given is statistical and includes the error in the determination of the scanning efficiency.

CONCLUSIONS

a) The ratio of the cross sections $\sigma_{ex}/\sigma_{el\,pp} \leq 0.07$. This means that the contribution of one-meson scattering to the cross section for elastic interactions of nucleons does not exceed 2%.†

*It should be noted that we made the important assumption that the momentum transfer in the case of charge exchange is not much smaller than the momentum transfer in the case of elastic scattering. If this is not so, then charge exchange with a bound neutron cannot be observed at all.

†We did not take into account possible interference between the one-meson and multi-meson interactions.

b) According to the data of Markov et al.,[2] $\sigma_{el\,pp}(0) \approx 160$ mb/sr. We therefore obtain from formula (3) $\Delta_{tot} \leq 11$ mb. From formula (4) we obtain $\Delta_{tot} \leq 9$ mb, which is also not in contradiction with the available experimental data.[3]

c) The obtained limit for the charge-exchange cross section is too high to check the predictions of the statistical theory.

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[1] Blokhintsev, Barashenkov, and Barbashov, The Structure of the Nucleon, Joint Institute for Nuclear Research Preprint R-317.

[2] Markov, Tsyganov, Shafranova, and Shakhbazyan, JETP **38**, 1471 (1960), Soviet Phys. JETP **11**, 1063 (1960).

[3] Tenth Annual International Conference on High Energy Physics at Rochester, 1960.

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