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NUCLEON-NUCLEON AND NUCLEON-ANTINUCLEON ELASTIC SCATTERING

AT HIGH MOMENTUM TRANSFERS

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A B S T R A C T

The discussion of the present data on $\bar{p}p$ and np elastic scattering at high momentum transfers is given. It is shown that (i) the Orear formula can be used for the description of these data, (ii) the data are in disagreement with the statistical model of compound elastic scattering, (iii) the data suggest that the elastic interaction of nucleons and antinucleons at high momentum transfers is roughly independent of the kind of particles involved.

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It has been shown by Orear ¹⁾ that the differential cross-section for the proton-proton high momentum transfer elastic scattering (outside of the region of the diffraction peak) can be described by a simple formula

$$\frac{d\sigma}{d\Omega} = \frac{A}{s} e^{-a p_{\perp}} \quad (1)$$

where $A = 595 \text{ GeV}^2 \text{ mb/sr}$, $a^{-1} = 158 \text{ MeV/c}$, $s = (\text{total c.m. energy})^2$, and $p_{\perp} = p \sin \theta$ is the transverse component of the proton momentum ²⁾.

The purpose of this paper is to remark that the same formula (1) can also be applied to the description of the present data concerning the high momentum transfer elastic scattering of antiprotons and neutrons on protons ³⁾.

In the case of antiproton-proton elastic scattering at high momentum transfers the existing data are rather scanty. We have used in our analysis the data from the bubble chamber measurements at three incident momenta : 3 GeV/c ⁴⁾, 4 GeV/c ⁵⁾, and 5.7 GeV/c ⁶⁾. The data are presented in Fig. 1. One notices that all three angular distributions display a high forward-backward asymmetry. This asymmetry is explicitly visible at 3 GeV/c where events were distributed over the whole angular region. This is also confirmed by the almost complete absence of the events in the backward hemisphere in other two experiments. The same data are plotted in Fig. 2 where the co-ordinates are similar to those used by Orear ¹⁾. The transverse momentum is plotted on the x axis. On the y axis we have plotted $s(\frac{d\sigma_1}{d\Omega} + \frac{d\sigma_2}{d\Omega})$ in the logarithmic scale. Here $\frac{d\sigma_1}{d\Omega}$ is the differential cross-section for the scattering angle $\theta \ll 90^\circ$, and $\frac{d\sigma_2}{d\Omega}$ is the same quantity for $\pi - \theta$.

The straight line representing the formula (1) is also plotted in this figure. One can see that the experimental points lie very closely to it. Symmetrization introduced in this way is not important for $\theta \ll 90^\circ$, because then $\frac{d\sigma_1}{d\Omega} \gg \frac{d\sigma_2}{d\Omega}$. At $\theta \approx 90^\circ$ one has $\frac{d\sigma_1}{d\Omega} \approx \frac{d\sigma_2}{d\Omega}$ and symmetrization means multiplication by about two.

This result seems to confirm the idea of the universality of Orear's formula (1) ¹⁾. On the other hand, the presented $\bar{p}p$ data are in disagreement with the predictions of the "compound elastic scattering" model ⁷⁾ where the forward-backward symmetry is expected.

A similar analysis can be applied to the np elastic scattering at high momentum transfers. One observes a lack of the forward-backward symmetry, which is however not so pronounced as in the $\bar{p}p$ case. This can be seen in the Figs. 3a and 3b where we have plotted the data of Kreisler et al. ⁸⁾, in the Orear co-ordinates. One can see that the points corresponding to the scattering angles $\theta < 90^\circ$ lie systematically higher than those corresponding to $\theta > 90^\circ$. One observes also that the data for $\theta < 90^\circ$ and $\theta \approx 90^\circ$ lie very closely to the Orear line, whereas the agreement is much worse (if any) for $\theta > 90^\circ$.

We would like to point out now that the situation in pp , $\bar{p}p$ and np elastic scattering at high momentum transfers can be qualitatively understood by assuming that the elastic nucleon-nucleon and nucleon-antinucleon interaction is independent of the kind of the particles involved.

Our argument is summarized in Fig. 4, where the contributions to the measured cross-sections are drawn for all three cases, i.e., pp , $\bar{p}p$ and np scattering.

According to our hypothesis, the contributions from the first column are equal to each other. The same is true for the second column. In the case of pp scattering one can measure only the sum of the contributions from the first and second columns. Therefore, in order to compare it with the $\bar{p}p$ scattering one has to make the symmetrization, as presented in Fig. 2. It has to be pointed out that, as shown in Fig. 1, the contributions from the second column are important only for $\theta \approx 90^\circ$. For $\theta \ll 90^\circ$ only the first column contributes effectively.

The case of np scattering is more complicated, because now also the possible charge-exchange process contributes to the elastic cross-section. That is to say, one really measures only the sum of the contributions from the columns I and IV (scattering at the angle θ) and II and III (scattering at the angle $\pi - \theta$). Let us consider first the scattering at the angles $\theta < 90^\circ$. It is clear that we find the situation very similar to that in the pp case. For $\theta \ll 90^\circ$ only the first column is expected to be effective. For $\theta \approx 90^\circ$ one expects the charge-exchange cross-section to be important, and the fourth column gives appreciable contribution. It is therefore not surprising that one finds that the np cross-section for $\theta \lesssim 90^\circ$ lies very closely to the Orear line. For scattering at angles greater than 90° the main contribution is coming from the third column. As there are no obvious reasons to expect this column to give a contribution equivalent to the first one, it is also not surprising that the corresponding data do not follow Orear line (see Fig. 3b).

If one makes, furthermore, the independent assumption that the charge-exchange interaction at large angles is independent of the particles involved, one can relate approximately the $\bar{p}p$ and np cross-sections at large angles in the following way

$$\frac{dG(\theta)_{np \rightarrow np}}{d\Omega} \approx \frac{dG(\theta)_{\bar{p}p \rightarrow \bar{p}p}}{d\Omega} + \frac{dG(\pi - \theta)_{\bar{p}p \rightarrow \pi n}}{d\Omega} \quad (2)$$

The present data on the reaction $\bar{p}p \rightarrow \bar{n}n$ do not allow to check this possibility.

In the present argument we have added incoherently the contributions from different types of interactions, without taking into account a possible interference. Such a procedure is justified by rather large experimental errors which do not allow for a serious determination of the interference terms.

One can formulate also two kinds of theoretical arguments in favour of the assumption that the interference is small. The first possibility is to assume like in statistical model ⁷⁾ and Wu and Yang model ⁹⁾ that the interaction at high momentum transfers is incoherent. In this case the oscillations of the amplitudes ¹⁰⁾ make the interference terms very small in average ¹¹⁾. The second possibility is to assume that the scattering at high momentum transfer is spin-independent. In that case, e.g., the two final states in the pp case (columns I and II in Fig. 4) become distinguishable and one adds them incoherently ¹²⁾.

Our conclusions can be summarized in the following points :

- a) The present data on $\bar{p}p$ and np high momentum transfer elastic scattering can be described by the Orear formula (1) ¹³⁾.
- b) These data are in disagreement with the "compound state" type statistical models ⁷⁾.
- c) The data suggests that the pp , np and $\bar{p}p$ elastic interaction at high momentum transfers is due to a single mechanism, independent of the kind of particles involved in the scattering.
- d) It follows from the conclusions c) and d) that the pp elastic scattering at high momentum transfers is probably also not an effect of a statistical mechanism of the "compound intermediate state" type ¹⁴⁾.

- e) The present discussion is based on the data from a limited range of the primary energy and transverse momentum. It remains an interesting question whether a similar situation will be found at higher energies and higher momentum transfers.

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Since we are interested only in the first approximation, this result has no influence on our argument.
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- 13) For the np case this possibility was already pointed out by Orear. See J. Orear's talk on Stony Brook Conference (May 1966).
- 14) The CERN measurements, as quoted in Ref. 2, seem to rule out definitely this model for the pp case.

FIGURE CAPTIONS

- Figure 1 : Plot of large angle $\bar{p}p$ elastic scattering data v. cosine of the c.m. scattering angle.
- Figure 2 : Plot of large angle $\bar{p}p$ elastic scattering data v. transverse momentum. The straight line, representing the formula (1), is drawn in the whole region of the applicability of the Orear fit to the data.
- Figure 3a : Plot of large angle np elastic scattering data v. transverse momentum, for the scattering angles $\theta \leq 90^\circ$. For three points, denoted by $\circ$, the scattering angles are slightly larger than 90° .
- Figure 3b : Plot of large angle np elastic scattering data v. transverse momentum, for scattering angles $\theta > 90^\circ$.
- Figure 4 : Graphical representation of the different contributions to the large angle elastic scattering of nucleons and anti-nucleons.

Fig. 1

Fig. 2

Fig. 3a

Fig. 3.b

	I ELASTIC SCATTERING AT ANGLE θ	II ELASTIC SCATTERING AT ANGLE $\pi - \theta$	III CHARGE - EXCHANGE SCATTERING AT ANGLE θ	IV CHARGE - EXCHANGE SCATTERING AT ANGLE $\pi - \theta$	
PROTON - PROTON					PROTON
PROTON - ANTIPROTON					ANTIPROTON NEUTRON
PROTON - NEUTRON					ANTINEUTRON

Fig. 4