Absorption Model of Neutron-Proton Charge-Exchange Scattering

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The absorption model is shown to describe qualitatively the differential cross-section data for np and $\bar{p}p$ charge-exchange scattering at 2.85 GeV, using π^+ exchange with a form factor at each nucleon vertex and elementary ρ exchange.

THERE are several reasons for expecting that the absorption model with π^+ exchange should describe the np charge-exchange process. Apart from the fact that the pion is much the lightest particle which can be exchanged, the differential cross section falls off at a rate suggestive of π^+ exchange, and the energy dependence of the process is consistent with this hypothesis. It is important that the momentum-transfer dependence of the charge-exchange process is energy-independent over a wide range of energies.[1] Ringland and Phillips[2] and Durand and Chiu,[3] who did the first calculation, found that π^+ exchange led to a clear secondary peak, not seen in the experiments. This is associated with the helicity amplitude ϕ_3 of the np elastic scattering process, which vanishes in the backward direction and peaks at a momentum transfer of about 0.2 GeV/c.

There are several Reggeized models of np charge exchange,[4] but it is difficult to reconcile the energy dependence of $\sigma_{pn}{}^{\text{tot}}-\sigma_{pp}{}^{\text{tot}}$ and $(d\sigma/dt)_{pn\to np}$.[5] Currently the process is understood in terms of a pion conspiracy.[6]

The purpose of this paper is to show the results obtained with the use of a phenomenological form factor at each of the πNN vertices. These are associated with 3π threshold, which Bugg has shown to be a significant force in the low-energy nucleon-nucleon problem.[7] Elementary ρ exchange is known to have the wrong energy dependence, and cannot be correct when used in the absorption model.[2] 2.85 GeV was chosen as the appropriate energy for this calculation because (a) it is large enough for inelastic processes to play a role, and the forward peak is diffractive, and (b) it is small enough for the c.m. energy to be comparable with the ρ-meson and nucleon masses, so that the Reggeized and elementary ρ-exchange amplitudes would not be too dissimilar. The comparison at 7.3 GeV is included for completeness, but little confidence is felt in the validity of the ρ-exchange terms.

The pionic amplitudes used were[8]

$$\phi_2=\frac{kg_\pi{}^2}{2E}\frac{1+x}{x_0+x}\left(\frac{x_1-x_0}{x_1+x}\right)^2,$$

$$\phi_3=-\phi_2,$$

$$d\sigma/d\Omega=(1/2k^2)(|\phi_2|^2+|\phi_3|^2),$$

$$x_0=1+m^2/2k^2,\quad x_1=1+M^2/2k^2.$$

k and E are the c.m. momentum and total energy of one nucleon, $x=\cos$ (c.m. scattering angle), $g_\pi{}^2$ is the πNN coupling constant, taken to be 14, m is the pion mass, and M is the mass determining the strength of the form factor.

The ρ-exchange amplitudes are taken from Ball, Scotti, and Wong (BSW).[9] This involves two couplings, g_1 and g_2, whose ratio $g_1/g_2=0.27$ is fixed by ρ dominance of the isovector nucleon form factor. g_1 was taken to be a free parameter. The damping[10] on each partial wave caused by the presence of inelastic processes is given by a multiplicative factor of $1-\exp(-\gamma J^2)$. γ is chosen so that the model fits the diffraction peaks of the elastic scattering data; $\gamma=0.064$ for np scattering[11] and $\gamma=0.032$ for $p\bar{p}$ scattering[12] at 2.85 GeV. $\gamma=0.0181$ for np scattering at 7.3 GeV,[11] and $\gamma=0.0123$ for $\bar{p}p$ scattering at 7.1 GeV.[13,14] The np charge-exchange differential cross section is then determined by fitting the two free parameters g_1 and M.

The value of M was determined from two considerations. To reduce the magnitude of the secondary peak caused by π^+ exchange, and to bring it into line with the experimental data, M had to be no larger than 0.5 GeV at 2.85 GeV proton kinetic energy (KE) (see Fig. 1).

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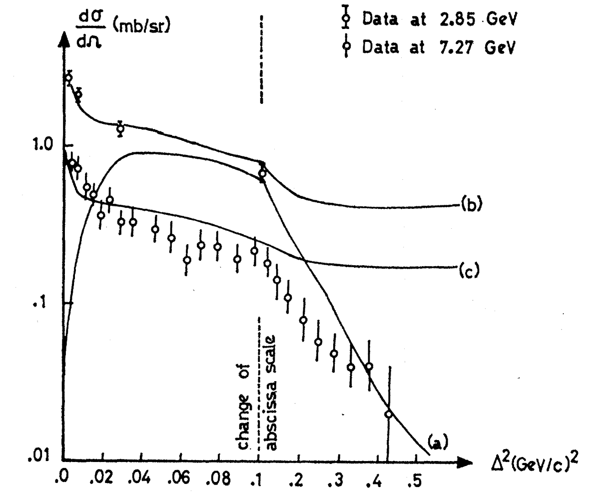

FIG. 1. Differential cross section for np charge-exchange scattering. (a) Theoretical value using π^+ exchange at 2.85 GeV with form factor and absorption. (b) Theoretical value using π^+ exchange with form factor, elementary ρ exchange and absorptive corrections at 2.85 GeV. (c) Same as (b) but at 7.3 GeV. Data from Ref. 15.

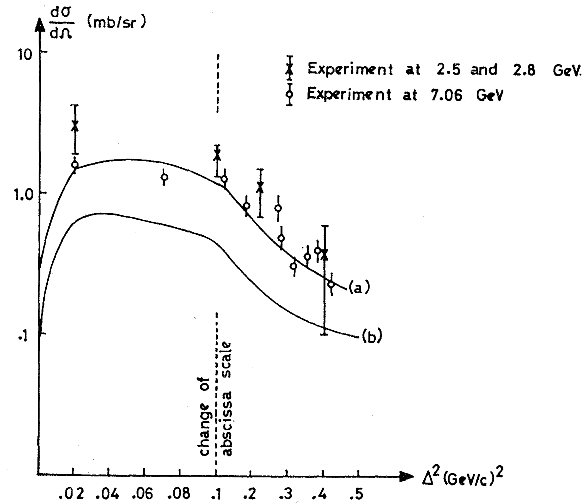

FIG. 2. Differential cross section for $\bar{p}p$ charge-exchange process. (a) Theoretical values at 2.8 GeV. (b) Theoretical values at 7.06 GeV. using π^+ exchange with form factor and elementary ρ exchange and the modification due to absorption. Data from Ref. 16.

At 7.3 GeV proton KE, M could be no larger than 0.42 GeV. One knows that the physical origin of the form factor lies in multipion contributions at the nucleon vertices, and so M should be at least as large as three pion masses, and should be energy-independent. M was given the value of 0.5 GeV at 2.85 GeV proton KE and 0.42 GeV at 7.3 GeV proton KE. g_1 was then varied to make the differential cross section fit the data[15] over a reasonable range of momentum transfer: $g_1=0.69$ at 2.85 GeV and $g_1=0.425$ at 7.3 GeV. These are to be compared with the value BSW obtained from the low-energy-data analysis, $g_1=1.19$.

If one now accepts the validity of the previous procedure, absorption with elementary π^+ and ρ^+ exchange, then the $p\bar{p}$ charge-exchange differential cross section[16] should be predicted by choosing the appropriate damping factor and reversing the sign of the pionic contribution to the amplitude. The result is shown in Fig. 2: np charge-exchange scattering has a narrow forward peak, and $p\bar{p}$ charge-exchange scattering is predicted to have a narrow forward dip. This must be so in any linear model in which the π and ρ contributions are of similar magnitudes. One notices the general correctness of the shape of the momentum-transfer distribution between 0.04 and 0.4 $(\mathrm{GeV}/c)^2$, but that the normalization is incorrect at 7 GeV.

A fit to the $p\bar{p}$ charge-exchange process has been obtained by Migneron and Moriarty.[14] They have used $U(6,6)$ predictions for the ρ couplings, which, using their notation, leads to a ratio

$$g_1/g_2=-2m/(3V+4m)=-0.3.$$

$m=0.938$ GeV and $V=0.85$ GeV are the mean nucleon and vector-meson masses. This is of similar magnitude but opposite sign to BSW's value, and so may account for the destructive nature of the $\pi\rho$ interference in their model.

An important question is whether the type of form factor used here is a phenomenonological necessity. This can only be decided by considering the alternatives. A K-matrix method of unitarizing the individual π^+ exchange amplitudes gives a reasonable shape for the differential cross sections, but its over-all magnitude is too big and conceals the presence of the secondary peak.[17] The cause of the difficulty lies in the size of the partial waves for π^+ exchange when $J\simeq 5$. The phase shifts are of order 0.1, so rescattering effects are of order 0.01, and the damping is not large. But when the partial-wave amplitudes are resummed with a multiplicative factor of $2J+1$, they contribute substantially to the differential cross section. No absorption or unitarization process can change this—only modifications of the π^+ propagator. It was noticed that replacement of the numerator factors of all the helicity amplitudes by their residues changed the higher partial-wave amplitudes sufficiently to remove the secondary peak. However, this, while similar to making the pion a con-

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spirator, suppresses its pseudoscalar nature, and was eventually rejected as a possibility. Since the pion has a small mass, Reggeization of the pion is not expected to affect these results substantially. It is also the case that an ordinary Ferrari-Selleri[18] over-all form factor does not affect the higher partial waves. Given that the π^+-exchange pole is present in the np charge-exchange amplitude, it would seem that some sort of vertex form factor is necessary to fit the differential cross-section data.

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Certain Implications for High-Energy Total Cross Sections from the Multiperipheral Model*

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The multiperipheral model is used to relate the experimental fact, $\sigma_{N\bar{N}}{}^{\text{tot}}>\sigma_{NN}{}^{\text{tot}}$, to the possibility that the $N\bar{N}$ channel can annihilate into purely meson final states by exchange of N or $\bar{N}$ trajectories, whereas the NN channel cannot do so. Our argument shows that from the multi-Regge bootstrap point of view, the combination of baryon and antibaryon trajectories will generate a pair of exchange-degenerate trajectories P' and ω. The same line of reasoning can easily be generalized to include strange particles, as well as the (K^-N,K^+N) and (π^-p,π^+p) systems.

I. INTRODUCTION

IT is a familiar empirical fact that, if a larger number of two-particle channels communicate with channel $a\bar{b}$ than with channel ab, then the total cross section $\sigma_{a\bar{b}}$ tends to be larger than σ_{ab} at nonasymptotic energies. For example, the $p\bar{p}$ channel can communicate with $p\bar{p}$, $\pi^0\pi^0$, $\pi^+\pi^-$, $K^0\bar{K}^0$, K^+K^-, $\Lambda\bar{\Lambda}$, $\Sigma^0\bar{\Sigma}^0$, etc., whereas the pp channel can only communicate with pp. It is well known that $\sigma_{p\bar{p}}>\sigma_{pp}$. A similar correlation exists for the paired channels, (K^-p,K^+p), (π^-p,π^+p). In this paper we propose to relate these phenomena to the generalized multiperipheral model recently developed by Chew, Goldberger, and Low[1] (CGL). The type of reasoning to be applied is illustrated by the following argument: If more two-particle channels communicate with $a\bar{b}$ than with ab, we will get more unitarity box diagrams (two-particle unitarity contributions) in $a\bar{b}$ than ab. The multiperipheral model iterates the box diagrams to produce a series of multiparticle contributions to the cross section (i.e., to the forward-elastic unitarity integral). Since each such contribution is positive definite, it follows that the channel with the larger number of box diagrams has the larger total cross section, *if* we can demonstrate an equal magnitude for those box diagrams shared by the two channels.

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In Sec. II, the multiperipheral model of CGL has been generalized to exchange several trajectories. In Sec. III, the multiperipheral model is applied to NN and $N\bar{N}$ channels. Some Reggeon bootstrap arguments are given in Sec. IV. In Sec. V some general remarks are made to include the strangeness and the isospin in the model.

II. MULTIPERIPHERAL MODEL

Let us briefly review the multiperipheral model. A function called B_a was introduced in CGL by

$$A_{ab}(p_a,p_b)\equiv A_{ab}(s,0)$$
$$=\int B_a(p_a,p_b;Q')(G^b(Q'))^2 \times\delta^+[(Q'-p_b)^2-\mu'^2]d^4Q', \quad (1)$$

where $A_{ab}(p_a,p_b)$ is the absorptive part of the $ab\rightarrow ab$ elastic amplitude at forward direction. The function B_a satisfies the integral equation

$$B_a(p_a,p_b;Q')$$
$$=I_a(p_a,p_b;Q')+\int B_a(p_a,Q';Q)K(Q,Q',p_b) \times\delta^+[(Q-Q')^2-\mu^2]d^4Q, \quad (2)$$

where I_a corresponds to two-particle unitarity, namely,

$$I_a(p_a,p_b;Q')=[G^a(Q')]^2|f(p_a,Q',p_b)|^2, \quad (3)$$