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BROKEN EXCHANGE DEGENERACIES AND SECONDARY TRAJECTORIES
IN CHARGE AND HYPERCHARGE EXCHANGE REACTIONS

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A B S T R A C T

A simple model is developed for the difference of K and $\bar{K}$ nucleon charge exchange cross-sections. In addition to a breaking of exchange degeneracy, the model requires secondary trajectories which are identified with the scalar meson trajectories. Hypercharge exchange reactions are also discussed.

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Duality ¹⁾ and the absence of resonances with exotic quantum numbers imply exchange degeneracies ²⁾ between meson trajectories with the same natural parity and natural charge conjugation ³⁾. Definite predictions ⁴⁾ follow from this exchange degeneracy pattern for the cross-sections and polarizations of scattering processes where only one set of exchange degenerate trajectories can be exchanged. In particular, the pseudoscalar meson-baryon charge exchange reactions provide sensitive tests ⁵⁾ of the exchange degeneracy between the leading vector and tensor trajectories. For example, $\rho - A_2$ exchange degeneracy requires the amplitude for $K^+n \rightarrow K^0p$ to be purely real, while the amplitude for the "line reversed" reaction $K^-p \rightarrow \bar{K}^0n$ has a relative phase $e^{i\pi\alpha(t)}$. The differential cross-sections of the two processes are therefore predicted to be equal if exchange degeneracy holds. Similar predictions can be made for the reactions, given in the Table, where the relevant exchanges are either $\rho - A_2$ or $K_V^* - K_T^{**}$.

Experimentally ⁶⁾, however, the cross-sections of reactions for which the amplitude is predicted to be real are consistently larger, even at high energies. In fact, the main features of the data can be summarized as follows: for K nucleon charge exchange the difference of the cross-sections decreases with energy ⁷⁾ while for processes where K^* are exchanged the discrepancy seems to survive even at 15 GeV/c ⁸⁾. The lower energy data ⁷⁾ in K nucleon charge exchange are consistent with exchange degeneracy at $t=0$ and the cross-sections differ most (by a factor ~ 2) around $t \simeq -0.5(\text{GeV}/c)^2$. For K^* exchanges a similar momentum transfer dependence in the effect seems to occur since the discrepancy is again bigger around $-0.6(\text{GeV}/c)^2$. At $t=0$, however, the effect seems to survive although the data are not conclusive. This latter fact is of course easily understood since the $\rho - A_2$ trajectory is known to contribute mostly to the spin flip amplitude ⁹⁾ while the K^* exchanges are expected to dominate the non-flip amplitude as well ⁹⁾.

Various mechanisms can be called upon to explain the behaviour of the differential cross-sections:

- i) the presence of a secondary trajectory ¹⁰⁾. This lower trajectory may even be taken as exchange degenerate ⁷⁾. However, the energy dependence in K nucleon charge exchange favours an intercept of

this secondary trajectory about two units below the leading one. With traditional Regge phases, there is then little contribution of such a trajectory to the difference in the cross-sections. Such a steep energy dependence is also not in agreement with the experimental data for the K^* exchange reactions;

- ii) the presence of Regge cuts ¹¹⁾. They predict the correct sign of the effect in K nucleon charge exchange but lead to a relative energy dependence of about $s^{-\frac{1}{2}}$. They predict the wrong sign for K^* exchange processes although they allow an explanation of the polarization data;
- iii) the introduction of approximately exchange degenerate trajectories through broken duality ¹²⁾. This splitting of the leading trajectory has, however, an unsatisfactory momentum transfer dependence when compared to the low energy data.

It is the purpose of this letter to show that a simple model which combines mechanisms i) and iii) allows a qualitative understanding of both the observed energy and momentum transfer dependences. In other words, breaking duality for the leading trajectories leads to a qualitatively correct model of the higher energy data, while a possible explanation for the effect around $t \simeq -0.5(\text{GeV}/c)^2$ in the low energy data is provided by introducing a lower trajectory which we tentatively identify with the scalar meson trajectory.

To be specific we will start our discussion with the K nucleon charge exchange reactions. We will then extend our model to K^* exchange processes and will conclude with a few remarks on polarization.

Broken duality ¹²⁾ suggests a hierarchy of exchange degeneracies, the most precise degeneracy being derived from the absence of exotic resonances in the $\pi\pi$ system, namely the $\rho - f^0$ degeneracy. Assuming linear and parallel trajectories, the observation that the A_2 ¹³⁾ is heavier than the f^0 suggests a breaking of exchange degeneracy of the order of 15-20% at $\alpha = 2$ between the ρ and A_2 trajectories such that

$$\alpha_{\rho}(t) > \alpha_{A_2}(t) \quad (1)$$

It is worth mentioning that the observed structure ¹⁴⁾ in the imaginary part of K^+p elastic scattering, whether it is identified with a Z^* resonance or not, simulates an "exotic" contribution to K^+n charge exchange. In terms of effective poles, this leads again to the same inequality as in Eq. (1).

In a model with pairs of leading and secondary trajectories with opposite signature, namely $(\alpha_\rho, \alpha_{A_2})$ and $(\alpha_{\rho'}, \alpha_{A_2'})$ respectively, we obtain in general

$$\Delta = \frac{\frac{d\sigma}{dt}(K^+n \rightarrow K^0p) - \frac{d\sigma}{dt}(K^-p \rightarrow \bar{K}^0n)}{\frac{d\sigma}{dt}(K^+n \rightarrow K^0p) + \frac{d\sigma}{dt}(K^-p \rightarrow \bar{K}^0n)} = \Delta_1(\rho A_2 + \rho' A_2') + \Delta_2(\rho A_2' + \rho' A_2) \quad (2)$$

where Δ_1 contains the interference terms of the leading and secondary trajectories among themselves and is therefore different from zero only if exchange degeneracy is broken, while Δ_2 describes the interference between higher and lower trajectories.

Even if it exists, the odd daughter of the $\rho - A_2$ trajectory which has unnatural charge conjugation does not couple to $K\bar{K}$. Therefore the most natural candidate for the lower trajectory becomes the δ (960) [or $\pi_N(1020)$] ¹⁵⁾ trajectory. Its intercept should be around -1 and it should materialize as a $\rho' (J^{PC} = 1^{--})$ around 1450 MeV if exchange degeneracy is valid. Since we expect a breaking of exchange degeneracy, the mass of this ρ' could easily be shifted by 200-300 MeV either way. If anything, experiment ¹⁶⁾ favours a higher mass for the ρ' . Identifying the lower trajectory with the scalar meson trajectory allows us to neglect its contribution to Δ_1 since it goes very quickly ($\sim 1/s^3$) to zero.

The leading effect, as far as the energy dependence is concerned, comes of course from Δ_1 . It depends only on the breaking of exchange degeneracy for the leading trajectories and can be parametrized as follows :

$$\Delta_1(t) = P(t) \sin \frac{\pi}{2} \delta \left[-\sin \frac{\pi}{2} \delta + \sin \frac{\pi}{2} (\alpha_\rho + \alpha_{A_2}) \right] \quad (3)$$

with $P(t) > 0$ and $\delta = \alpha_p - \alpha_{A_2}$. As argued earlier, we expect $\delta > 0$. Therefore, Eq. (3) predicts, even at high energies, the K^+n charge exchange differential cross-section to remain consistently bigger than the K^-p charge exchange cross-section. A value of $\delta \simeq 0.2$ would allow for a factor of two in the difference of the cross-sections. At larger momentum transfers cut contributions ¹¹⁾ could alter our qualitative prediction.

Although the t dependence in Eq. (3) should not be taken too seriously since we do not have a model for $\delta(t)$, it nevertheless suggests that around $t = -0.6(\text{GeV}/c)^2$ the difference of the charge exchange cross-sections should change sign if only Δ_1 contributes. The higher energy data do not, as yet, allow us to test this qualitative prediction of our model. At low energies, however, a model with only Δ_1 is qualitatively wrong since the splitting of the cross-sections is biggest at about $t \simeq -0.5(\text{GeV}/c)^2$.

As emphasized before, introducing a secondary trajectory leads to a natural explanation of this effect. Indeed its contribution can be parametrized as follows with $\alpha = 0.5 + t$ and $\alpha' = -1 + t$

$$\Delta_2 \sim \left[(\beta_{A_2} \beta_p' + \beta_p \beta_{A_2}') \frac{1}{\sqrt{2}} + (\beta_p \beta_{A_2} - \beta_p' \beta_{A_2}') \sin \pi(t - \frac{1}{4}) \right] s^{-\frac{3}{2}} \quad (4)$$

If $\beta_{A_2}' > \beta_p'$, Δ_2 goes through a maximum around $t \simeq -0.25(\text{GeV}/c)^2$ provided the effective residues β have no strong t dependence. Thus, combining the effects of Δ_1 and Δ_2 we can understand the t dependence of the data. Note that we expect Δ_2 to be positive. Indeed, the ρ' is expected to "cancel" the ρ in both the $NN\sigma$ and $\pi\pi\sigma$ vertices. With $SU(3)$ and the assumption that both the ρ and ρ' residue functions have a similar structure in the t dependence, this leads to $\beta_p \beta_p' > 0$ which, if one has approximate exchange degeneracy for residues, is equivalent to $\Delta_2 > 0$.

To conclude our discussion of the KN charge exchange reactions, it is clear that a model combining the breaking of exchange degeneracy with the effect of a secondary trajectory reproduces qualitatively the K^+n and K^-p charge exchange data. Both effects conspire to make the K^+n cross-section bigger than K^-p . At lower energies the scalar

trajectory will help to generate a maximum effect around $t = -0.5(\text{GeV}/c)^2$. At higher energies, our model would predict a minimum in the breaking of exchange degeneracy near $\alpha = 0$. Cut contributions are not expected to alter these qualitative conclusions.

It is now fairly easy to extend our model to K^* exchange processes. By $SU(3)$ we expect from Eq. (1)

$$\alpha_{K_V^*} > \alpha_{K_T^{**}}$$

Again this allows us to predict which cross-section will be systematically larger, as shown in the Table. By introducing the $SU(3)$ partners of the secondary trajectory (δ, ρ') we expect the differences of cross-sections for line reversed processes to show some structure as functions of t at least at low energies. This model seems to be consistent with all available data ^{6), 8)}.

For the above discussion about cross-sections, the spin structure of the amplitudes was irrelevant (except near $t=0$) since only amplitudes of the same (flip or non-flip) structure can interfere in Δ_1 or Δ_2 . However in polarization effects, which in the exact exchange degeneracy limit are predicted to be zero ⁵⁾, one has interferences between flip and non-flip amplitudes. Also cross-sections are predominantly sensitive to the trajectory functions while polarization effects depend crucially on the residue functions for which one also expects a breaking from exact (strong) exchange degeneracy ¹⁷⁾. Indeed for line reversed reactions, weak exchange degeneracy ($\alpha_V = \alpha_T$) leads to a non-zero polarization. In this case, as well as in case iii), the polarization is expected to be odd under line reversal in contradiction to some data at 3-6 GeV/c ^{8), 18)}. Both Regge cuts ¹¹⁾ and lower trajectories do contribute strongly to the polarization and the former certainly do go in the right direction while the latter has too many free parameters to allow even a qualitative prediction.

In summary we have described a model for the difference between line reversed cross-sections based on the breaking of weak exchange degeneracy and the presence of secondary trajectories. These two contributions give a very different energy dependence to the discrepancy, namely a constant term coming from $\alpha_V \neq \alpha_T$ and a term proportional to $s^{-\frac{3}{2}}$ for the lower

trajectory. The t dependence is therefore predicted to be the following : at low energies, where the contribution from the lower trajectory is more important, the difference between the cross-sections is biggest around $t \sim -0.5(\text{GeV}/c)^2$, while at high energies where only the effect of $\alpha_V \neq \alpha_T$ remains, the difference is expected to be the smallest at $t \sim -0.6(\text{GeV}/c)^2$.

TABLE

In the limit of the exchange of one degenerate vector-tensor pole, the processes in each column have amplitudes equal in modulus but with a real phase for the left-hand column and with a rotating phase for the right-hand column. With our model for broken exchange degeneracy, the left-hand column is predicted to have the larger cross-section.

$K^+ n \rightarrow K^0 p$ $K^+ p \rightarrow K^0 \Delta^{++}$	$K^- p \rightarrow \bar{K}^0 n$ $K^- n \rightarrow \bar{K}^0 \Delta^-$
$K^- p \rightarrow \pi^- \Sigma^+$ $K^- n \rightarrow \pi^- \Lambda$ $K^- p \rightarrow \pi^0 \Lambda$ $K^- p \rightarrow \pi^- Y_1^{*+}$	$\pi^+ p \rightarrow K^+ \Sigma^+$ $\pi^+ n \rightarrow K^+ \Lambda$ $\pi^- p \rightarrow K^0 \Lambda$ $\pi^+ p \rightarrow K^+ Y_1^{*+}$

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