also more phenomenological than the present work, which, though it treats the resonance as phenomenologically given, is nevertheless a dynamical model of how it is produced in a particular experiment. For example, in the present particular model the dependence of the phase shift on the higher energies, beyond the resonance region, can markedly affect the resonance region. After this work was completed, several other calculations[17,18] came to our attention which also distinguish the production of a resonance from its formation in elastic scattering. The work of Aitchison and Graves-Morris in particular is parallel to the present study, and these authors reach similar conclusions.

[17] I. J. R. Aitchison and P. R. Graves-Morris, in Proceedings of the Birmingham Three-Body Conference, Birmingham, England, 1969 (unpublished); and Nucl. Phys. **B14**, 683 (1969).

[18] M. B. Einhorn, Phys. Rev. **185**, 1960 (1969); M. Roos and J. Pišút, Nucl. Phys. **B10**, 563 (1969).

ACKNOWLEDGMENTS

I wish to thank Dr. B. C. Maglić for stimulating me to think about this problem. I am grateful to Dr. P. R. Graves-Morris and Dr. I. J. R. Aitchison for informing me of their work and for valuable correspondence, and to Dr. M. Jacob, Dr. M. K. Sundaresan, and Dr. R. L. Warnock for informative conversations.

PHYSICAL REVIEW D VOLUME 2, NUMBER 9 1 NOVEMBER 1970

Phenomenological Model for a Possible Failure of the Pomeranchuk Theorem*

Hidezumi Terazawa

Laboratory of Nuclear Studies, Cornell University, Ithaca, New York 14850

(Received 20 May 1970)

The author proposes a phenomenological model for a possible failure of the Pomeranchuk theorem. This predicts the following relations among asymptotic total cross sections: $\sigma_T(\pi^-p)-\sigma_T(\pi^+p)=\sigma_T(K^-n)-\sigma_T(K^+n)$, $\sigma_T(K^+p)=\sigma_T(K^+n)$, $\frac{2}{3}[\sigma_T(K^-n)-\sigma_T(K^+n)]\leq\sigma_T(K^-p)-\sigma_T(K^+p)\leq 2[\sigma_T(K^-n)-\sigma_T(K^+n)]$, $\sigma_T(pp)=\sigma_T(pn)$, and $\frac{2}{3}[\sigma_T(\bar{p}n)-\sigma_T(pn)]\leq\sigma_T(\bar{p}p)-\sigma_T(pp)\leq 2[\sigma_T(\bar{p}n)-\sigma_T(pn)]$. All of these are consistent with the recent Serpukhov data.

THE data of the recent Serpukhov experiment performed by the IHEP-CERN collaboration[1] tempt us to consider a possible failure of the Pomeranchuk theorem.[2] This theorem asserts the asymptotic equality of particle and antiparticle total cross sections. Eden[3] has pointed out that a number of conventional assumptions about strong interactions at high energy are unproven from basic principles and therefore should be subjected to further experimental measurements. These include the following assumptions: (1) The ratio of the real part of a forward scattering amplitude to the imaginary part multiplied by $\ln s$ tends to zero; (2) elastic scattering dominates exchange scattering near the forward direction; (3) the breaking of $SU(3)$ symmetry becomes unimportant at high energies. The assumptions (1) and (2) are crucially needed to prove the Pomeranchuk theorem and the Okun-Pomeranchuk rules,[4] respectively. Horn[5] has offered a possible interpretation of the Serpukhov data, associating the sharp change in the trend of the total cross sections plotted against $s^{-1/2}$ with an "ionization point" for baryon resonances, and predicts that both conventional Regge expansions and the Pomeranchuk theorem would fail from there on. Which of the assumptions can we incriminate for the violations of the Pomeranchuk theorem? In this note we propose a phenomenological model for the violation of the theorem and obtain its direct consequences.

Consider asymptotic total cross sections $\sigma_T(AB)$ for scattering reactions of the type $A+B\to$ any final states. We may separate $\sigma_T(AB)$ into two parts:

$$\sigma_T(AB)=\sigma_T{}^{(P)}(AB)+\sigma_T{}^{(1)}(AB). \tag{1}$$

The first part $\sigma_T{}^{(P)}(AB)$ obeys not only the Pomeranchuk theorem but also the Okun-Pomeranchuk rules. This means that it satisfies the following symmetry properties:

$$\sigma_T{}^{(P)}(AB)=\sigma_T{}^{(P)}(\bar{A}B)=\sigma_T{}^{(P)}(A\bar{B})=\sigma_T{}^{(P)}(\bar{A}\bar{B}) \tag{2}$$

* Work supported in part by the Office of Naval Research.

[1] J. V. Allaby *et al.*, IHEP-CERN collaboration, Phys. Letters **30B**, 500 (1969).

[2] I. Ia. Pomeranchuk, Zh. Eksperim. i Teor. Fiz. **34**, 725 (1958) [Soviet Phys. JETP **7**, 499 (1958)]. As for the progress made afterward, see T. Kinoshita, in *Perspectives in Modern Physics*, edited by R. E. Marshak (Wiley, New York, 1966), p. 211. Recently Kinoshita has proved that either or both of the relations $\sigma_T(AB)=\sigma_T(\bar{A}B)$ and $d\sigma(AB)/dt=d\sigma(\bar{A}B)/dt$ for $t=-c(\ln s)^{-2}$ should hold asymptotically [T. Kinoshita, Phys. Rev. D (to be published)].

[3] R. J. Eden, Phys. Rev. D **2**, 529 (1970). See also O. V. Dumbrais and N. M. Queen, JINR (Dubna) Report No. E2-4965, 1970 (unpublished).

[4] L. B. Okun and I. Ia. Pomeranchuk, Zh. Eksperim. i Teor. Fiz. **30**, 307 (1956) [Soviet Phys. JETP **3**, 307 (1956)].

[5] D. Horn, Phys. Letters **31B**, 30 (1970). Lam and Truong claimed that the origin of the violation can be the electromagnetic interaction [W. S. Lam and T. N. Truong, Phys. Letters **31B**, 307 (1970)].

and

$$\sigma_T^{(P)}(A'B')=\sigma_T^{(P)}(AB) \tag{3}$$

for any two particles A' and B' belonging to the same isospin multiplets as A and B, respectively, do. Our assumption is the following: The second part $\sigma_T^{(1)}(AB)$ $(\neq 0)$ comes from a process $A+B\to$ "$\mathfrak{F}$" $\to$ any final states, where "$\mathfrak{F}$" is one of the octet or decuplet states[6] (of only the octet states for $N_B=0$) whose quantum numbers are nonexotic (i.e., $N_B=1$, $Y=-1$, 0, 1, $I=\frac{3}{2}$, 1, $\frac{1}{2}$, 0; $N_B=0$, $Y=-1$, 0, 1, $I=1$, $\frac{1}{2}$, 0) and whose couplings to the system $A+B$ are $SU(3)$ symmetric at high energies. From this assumption we instantly obtain the following relations among the asymptotic cross sections independent of the F/D ratio of couplings between the $A+B$ system and the octet "$\mathfrak{F}$":

$$\sigma_T^{(1)}(\pi^-p)=\sigma_T^{(1)}(K^-n)\,, \tag{4}$$

$$\sigma_T^{(1)}(K^+p)=\sigma_T^{(1)}(K^+n)=\sigma_T^{(1)}(pp)=\sigma_T^{(1)}(pn)=0\,, \tag{5}$$

$$\tfrac{2}{3}\sigma_T^{(1)}(K^-n)\leq\sigma_T^{(1)}(K^-p)\leq 2\sigma_T^{(1)}(K^-n) \quad \text{only for the octet “}\mathfrak{F}\text{”}, \tag{6}$$

and

$$\tfrac{2}{3}\sigma_T^{(1)}(\bar{p}n)\leq\sigma_T^{(1)}(\bar{p}p)\leq 2\sigma_T^{(1)}(\bar{p}n)\,. \tag{7}$$

In the last two inequalities, the equal signs hold in the two extreme cases, the lower one for pure D and the higher one for pure F, respectively. Of course, we also have many other relations which can be derived from ordinary isospin symmetry

$$[\text{e.g., } \sigma_T^{(1)}(\pi^+p)=\sigma_T^{(1)}(\pi^-n)].$$

Using Eqs. (1)–(3), we can transform the relations (4)–(7) into

$$\sigma_T(\pi^-p)-\sigma_T(\pi^+p)=\sigma_T(K^-n)-\sigma_T(K^+n)\,, \tag{8}$$

$$\sigma_T(K^+p)=\sigma_T(K^+n)\,, \tag{9}$$

$$\begin{aligned}\tfrac{2}{3}[\sigma_T(K^-n)-\sigma_T(K^+n)]&\leq\sigma_T(K^-p)-\sigma_T(K^+p)\\&\leq 2[\sigma_T(K^-n)-\sigma_T(K^+n)]\quad\text{only for the octet “}\mathfrak{F}\text{”},\end{aligned} \tag{10}$$

$$\sigma_T(pp)=\sigma_T(pn)\,, \tag{11}$$

and

$$\begin{aligned}\tfrac{2}{3}[\sigma_T(\bar{p}n)-\sigma_T(pn)]&\leq\sigma_T(\bar{p}p)-\sigma_T(pp)\\&\leq 2[\sigma_T(\bar{p}n)-\sigma_T(pn)]\,.\end{aligned} \tag{12}$$

These are all definite predictions of our model.

[6] The possibility of a singlet state is ignored on the analogy of existing particles and resonances.

The Serpukhov data show that beyond the incident momenta 30 GeV/c the four total cross sections (π^-p), (π^-n), (K^-p), and (K^-n) have become roughly energy independent while the antiproton cross sections continue to decrease. If we accept the extrapolated values of the previously measured K^+N cross sections[7] which already seem to be energy independent (or slightly increasing?) below 20 GeV/c, we can claim that the following results are consistent with those experiments[8]:

$$\sigma_T(\pi^-p)-\sigma_T(\pi^+p)\simeq 1.5\text{–}2 \text{ mb}\,, \tag{13}$$

$$\sigma_T(K^-n)-\sigma_T(K^+n)\simeq 1.5\text{–}3 \text{ mb}\,, \tag{14}$$

and

$$\sigma_T(K^-p)-\sigma_T(K^+p)\simeq 3\text{–}4 \text{ mb}\,. \tag{15}$$

Therefore, we may conclude that all the relations (8)–(12) are consistent with the present available data.

What is the physical meaning, if any, of the "$\mathfrak{F}$"? No matter what it may be, the relations (8)–(12) can be maintained if "$\mathfrak{F}$" is a member of the octet or decuplet [(10) holds only for the octet] with non-exotic quantum numbers and if it gives a constant asymptotic total cross section. It cannot be an ordinary resonance because it is very hard to imagine that the resonance may give a constant cross section. However, it may be a bound state of three quarks, which has a continuous spectrum due to the completely different mechanism of binding from that in the ordinary resonance. If it is such a bound state, it is easily understood why it has nonexotic quantum numbers. The duality picture by Freund and Harari[9] may be modified in the following way: The Pomeranchuk trajectory which is responsible for $\sigma_T^{(P)}(AB)$ is mostly built by the nonresonating background in the low-energy amplitudes; there exists a new trajectory $\alpha_1(t)$ $[\alpha_1(0)=1]$ which gives a constant $\sigma_T^{(1)}(AB)$, and which corresponds to the "$\mathfrak{F}$" in the s channel. Anyway, this model is nothing more than a speculation. Further measurements of the total cross sections will give us an answer to the question whether our model has some physical meaning or not.

The author would like to thank Dr. P. Roy for valuable comments and correcting the English in the manuscript. He also thanks Professor F. J. Gilman, Professor K. Gottfried, Professor T. Kinoshita, and Dr. J. Pestieau for discussions.

[7] W. Galbraith *et al.*, Phys. Rev. **138**, B913 (1965).

[8] It is consistent with the data to assume that the total cross section of K^+N will continue to increase slightly till it reaches an asymptotically constant value. This will give a better agreement to our predicted relation (8).

[9] P. G. O. Freund, Phys. Rev. Letters **20**, 235 (1968); H. Harari, *ibid.* **20**, 1395 (1968).