PHYSICAL REVIEW D VOLUME 4, NUMBER 5 1 SEPTEMBER 1971

Pseudoscalar and Vector-Meson Models for Nucleon-Nucleon Scattering Outside the Phenomenological Core

Bruce M. Barker
Department of Physics and Astronomy, Louisiana State University, Baton Rouge, Louisiana 70803

and

Richard D. Haracz
Physics Department, Drexel University, Philadelphia, Pennsylvania 19104
(Received 20 May 1971)

The one-pion-exchange (OPE), one- and two-pion-exchange (OPE+TPE), and pseudoscalar-vector-meson-exchange (*PV*) models are described. The corresponding phase parameters are compared with the phenomenological phase parameters excluding the *S*-state parameters and the coupled *D*-state contribution. It is found that the OPE + TPE model is a definite improvement on the OPE model, and it provides a reasonably good fit to the phenomenological values for the *D*-state and higher-*L* contributions. The introduction of the η pseudoscalar resonance and the ω and ρ vector resonances in the *PV* model does not improve upon the fit to the $L \geq 2$ phases. However, the *PV* model improves upon both the OPE and OPE + TPE models in a comparison with the *P*-state phases, and it reduces the value of the pion-nucleon coupling constant.

I. INTRODUCTION

It has been established by Gupta[1] and by Gupta, Haracz, and Kaskas[2] that the exact relativistic two-pion-exchange (TPE) contribution to elastic nucleon-nucleon scattering is an important correction to the one-pion-exchange (OPE) contribution. A partial-wave analysis of the nonrelativistic limit of the results of Ref. 1 by Breit *et al.*[3] indicated that the TPE contribution improved upon the OPE contribution for some of the higher angular momentum phase parameters, and Breit[4] suggested that a combination of the pion-exchange effects with the contribution of the then hypothetical vector resonances might provide a qualitative explanation of the empirical evidence.

Many one-boson-exchange models have been devised which lead to satisfactory fits to the phenomenological data and phase parameters.[5] These models do not employ the TPE contribution, but compensate for it by the inclusion of an unrealistically light scalar resonance. An exception is the work of Lomon and Feshbach and of Partovi and Lomon[6] in which the OPE and TPE contributions are included with the vector resonances to obtain an approximation to a two-nucleon potential that is in reasonably good agreement with phenomenological potentials outside the core of the interaction.

By the partial-wave analysis of the exact relativistic TPE interaction,[7] we have shown that OPE and TPE correspond reasonably well with the phenomenological phase parameters for values of the orbital angular momentum quantum number L greater than 3. The intent of this work is to improve upon our earlier treatment of the role of OPE and TPE by adjusting the pion-nucleon coupling constant to obtain the best fit to the phenomenological phase parameters. The contributions from the pseudoscalar η resonance and the vector ω and ρ resonances will then be introduced to see if these can improve upon the fit outside the core. The effect of the resonances close to the core, down to P waves, will also be studied.

II. THE PION MODEL

The pion-nucleon interaction energy density is

$$H_\pi = ig_\pi :\bar{\psi}\gamma_5\tau_i\psi U_{\pi i}: , \tag{1}$$

where ψ is a nucleon field operator, $U_{\pi i}$ is the pion isovector field operator, and g_π is the pion-nucleon coupling constant. If the incident nucleons have propagation four-vectors p and q and the scattered nucleons have p' and q', this interaction leads to an expansion of the transition matrix M in powers of $g_\pi{}^2$:

$$M = \sum_n M_n . \tag{2}$$

The partial-wave amplitudes are related to the phase parameters as

$$\begin{aligned} {}^1\alpha_L &= (1/2i)[\exp(2iK_L) - 1] , \\ \alpha_L{}^L &= (1/2i)[\exp(2i\delta^L{}_L) - 1] , \\ \alpha_J{}^L &= (1/2i)[(1-\rho_J{}^2)^{1/2}\exp(2i\theta^L{}_J) - 1] , \\ \alpha_J &= \tfrac{1}{2}\rho_J\exp[i(\theta^{J-1}{}_J + \theta^{J+1}{}_J)] . \end{aligned} \tag{3}$$

If these amplitudes and the phase parameters are expanded in powers of g_π^2 as

$$\alpha = \sum_n \alpha(n), \quad \delta = \sum_n \delta(n), \tag{4}$$

substitution into Eqs. (3) gives

$$\begin{aligned} &K_L(2) = {}^1\alpha_L(2), \ K_L(4) = \mathrm{Re}\,{}^1\alpha_L(4), \ \delta^L{}_L(2) = \alpha_L{}^L(2), \\ &\delta^L{}_L(4) = \mathrm{Re}\alpha_L{}^L(4), \quad \theta^L{}_J(2) = \alpha_J{}^L(2), \\ &\theta^L{}_J(4) = \mathrm{Re}\alpha_J{}^L(4), \\ &\rho_J(2) = 2\alpha_J(2), \quad \rho_J(4) = 2\mathrm{Re}\alpha_J(4), \end{aligned} \tag{5}$$

with Re denoting the real part of the partial-wave amplitude. The singlet phase shift is denoted K_L, $\delta^L{}_L$ is the uncoupled triplet phase shift, $\theta^L{}_J$ is a coupled triplet phase shift, and ρ_J is the coupling parameter in the Yale notation. The term $\alpha(n)$ is related to the spin matrix elements of M_n as given in the first paper of Refs. 7.

The first-order term of the M matrix is the well-known OPE contribution

$$M_2 = \vec{\tau}^{(1)} \cdot \vec{\tau}^{(2)} \frac{g_\pi^2}{4\pi c\hbar} \frac{1}{4p_0} \frac{1}{\vec{k}^2 + \lambda_\pi{}^2} \vec{\sigma}^{(1)} \cdot \vec{k}\, \vec{\sigma}^{(2)} \cdot \vec{k}, \tag{6}$$

where $\vec{\tau}^{(1)}$ is the isospin matrix corresponding to nucleon 1, $\vec{\sigma}^{(1)}$ is the corresponding spin matrix, $\vec{k} = \vec{p}' - \vec{p}$, and $\lambda_\pi = m_\pi c/\hbar$. It has been pointed out recently[8] that the pion mass difference can be accounted for accurately by taking λ_π in Eq. (6) to have different values for the different isotopic-spin states, and the effect though small is not completely negligible. It is further shown in these papers that the effect of the pion mass difference in the TPE contribution is quite small. The present work does not sensibly require such refinements, however, and the pion mass is given the nominal value of 138 MeV in the calculations that follow. The second-order contribution to M, M_4 or the TPE contribution, is related to the W_4 matrix as $\mathrm{Re}M_4 = -p_0W_4/4\pi c\hbar$, and the W_4 term is given in detail in Ref. 2. All fourth-order diagrams are included in W_4. The real parts of the partial-wave amplitudes are obtained from M_2 and $\mathrm{Re}M_4$, and the phase parameters follow from Eqs. (5).

These theoretical phase parameters δ are now compared with the Yale phase parameters δ_E (Ref. 9) by varying g_π^2 to minimize

$$\chi^2 = \frac{1}{N} \sum_{\Delta\delta_E \neq 0} \left(\frac{\delta - \delta_E}{\Delta\delta_E} \right)^2, \tag{7}$$

with $\Delta\delta_E$ the uncertainty in the phenomenological value and N the number of phase parameters, and the sum is over all the phase parameters that are different from the OPE values. It is understood that the minimum value of χ^2 as given by (7) does not necessarily correspond to the best fit to the nucleon-nucleon scattering data since correlation effects among the phase parameters are neglected. However, it seems safe to assume that if the minimum χ^2 for one model is significantly less than the minimum χ^2 for a second model, then the first model is better than the second.

Table I contains the results of the comparison of the OPE and OPE + TPE models with the Yale phase parameters for p-n scattering. The values of $g_\pi^2/4\pi c\hbar$ which minimize χ^2 are given for various ranges of the quantum number L. The core of the two-nucleon interaction is omitted from all the searches. For the purposes of this work, the core is identified with all the S-state phase parameters and those phase parameters that are coupled to the S state. Thus, the searches exclude the phase shifts K_0, ${}^3\theta^S{}_1$, ${}^3\theta^D{}_1$, and the coupling parameter ρ_1. The fit is over 18 energies in the range from 10 to 350 MeV. It should also be noted that $\rho_J = \rho_{L+1}$, so that ρ_2 is included with the P-state phase parameters in the searches, ρ_3 with the D state, and so on. The comparison with the G and H phases shows that although the coupling constant is considerably changed by the inclusion of TPE, both models fit rather well. The comparison with the F, G, and H phases shows that TPE brings about a definite improvement in the fit. The comparison of the two models with the D, F, G, and H phase parameters, excluding ${}^3\theta^D{}_1$, strongly favors the OPE + TPE over the OPE model; the χ^2 for the former being an

TABLE I. Values of χ^2 and $g_\pi^2/4\pi c\hbar$ for the OPE, OPE+TPE, and PV models. These values of $g_\pi^2/4\pi c\hbar$ give the lowest values of χ^2 in a comparison with the Yale phase parameters for the various ranges of L noted. The resonance-nucleon coupling constants in the PV model are: $g_\eta{}^2/4\pi c\hbar = 4.6$, $g_\omega{}^2/4\pi c\hbar = 1.6$, $g_\rho{}^2/4\pi c\hbar = 0.2$, $f_\omega/g_\omega = 2.0$, and $f_\rho/g_\rho = 6.6$.

Range		OPE model		OPE+TPE model		PV model	
of L	N	$g_\pi^2/4\pi c\hbar$	χ^2	$g_\pi^2/4\pi c\hbar$	χ^2	$g_\pi^2/4\pi c\hbar$	χ^2
4–5	110	15.9	0.890	13.1	0.770	13.0	0.794
3–5	197	12.7	4.99	12.4	2.16	12.7	1.34
2–5	269	18.3	50.9	13.8	5.67	13.2	5.83
1–5	359	9.6	439	10.4	162	11.9	40.3

order of magnitude smaller than for the latter. It should be noted that the values of $g_\pi^2/4\pi c\hbar$ obtained for the OPE + TPE model for the various ranges of L are more consistent than for the OPE model; agreement would of course be expected from a completely valid model. Finally, although the TPE model improves upon the fit when the P-state phases are included, it is evident that both models fail this close to the core.

The phase parameters corresponding to the OPE + TPE model with $g_\pi^2/4\pi c\hbar = 13.8$ are shown in Figs. 1–4 as solid lines for the P, D, and F phase shifts and the coupling parameters, respectively. The Yale phase parameters are taken from Ref. 9, and they are shown with their parallel-shift uncertainties at the energies 10, 110, 210, and 310 MeV. The Yale phase parameters are available at 24 energies in the range from 10 to 350 MeV, but these few are given to simplify the graphs. The OPE model is not shown on the graphs also as a simplification. Moreover, the OPE and OPE + TPE contributions are given in detail in the work by Barker and Haracz in Ref. 7. Although not shown, the fit to the G and H phase parameters is also good.

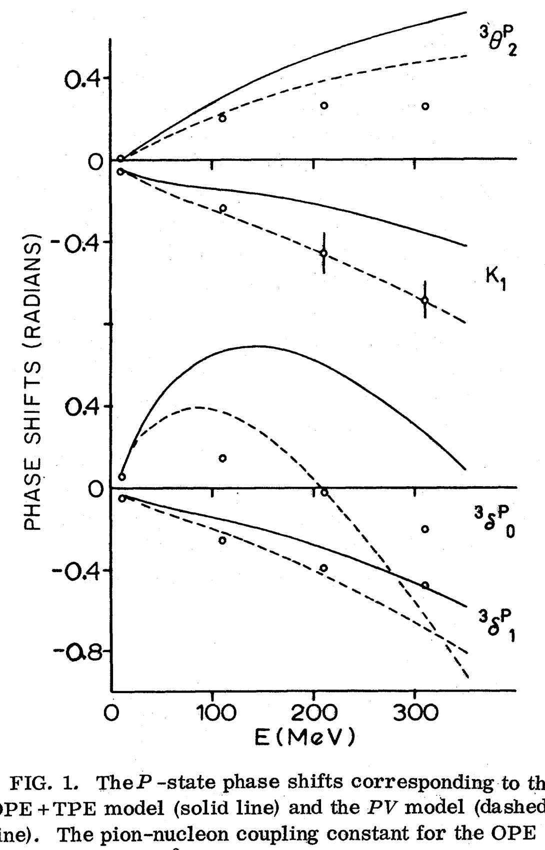

FIG. 1. The P-state phase shifts corresponding to the OPE + TPE model (solid line) and the PV model (dashed line). The pion-nucleon coupling constant for the OPE + TPE model is $g_\pi^2/4\pi c\hbar = 13.8$, while the coupling constants for the PV model are $g_\pi^2/4\pi c\hbar = 13.2$, $g_\eta^2/4\pi c\hbar = 4.6$, $g_\omega^2/4\pi c\hbar = 1.6$, $g_\rho^2/4\pi c\hbar = 0.2$, $f_\omega/g_\omega = 2.0$, and $f_\rho/g_\rho = 6.6$. The Yale phenomenological phase shifts are shown at 10, 110, 210, and 310 MeV with their parallel-shift uncertainties.

III. THE PSEUDOSCALAR-VECTOR MODEL

The pseudoscalar-vector (PV) model contains the effects of the π and η pseudoscalar mesons and the ω and ρ vector resonances from the interaction energy density

$$\begin{aligned} H_{PV} &= ig_\pi :\bar\psi\gamma_5\tau_i\psi U_{\pi i}: + ig_\eta :\bar\psi\gamma_5\psi U_\eta: \\ &+ ig_\omega :\bar\psi\gamma_\mu\psi U_{\omega\mu}: + ig_\rho :\bar\psi\gamma_\mu\tau_i\psi U_{\rho i\mu}: \\ &+ \frac{f_\omega}{4\kappa} :\bar\psi\sigma_{\mu\nu}\psi\left(\frac{\partial U_{\omega\nu}}{\partial x_\mu} - \frac{\partial U_{\omega\mu}}{\partial x_\nu}\right): \\ &+ \frac{f_\rho}{4\kappa} :\bar\psi\sigma_{\mu\nu}\tau_i\psi\left(\frac{\partial U_{\rho i\nu}}{\partial x_\mu} - \frac{\partial U_{\rho i\mu}}{\partial x_\nu}\right):, \end{aligned} \tag{8}$$

with $\sigma_{\mu\nu} = (1/2i)(\gamma_\mu\gamma_\nu - \gamma_\nu\gamma_\mu)$. In Eq. (8) the first term is the pion contribution, U_η is the η field operator, $U_{\omega\mu}$ is the ω vector-field operator, $U_{\rho i\mu}$ is the ρ isovector-vector-field operator, and $\kappa = Mc/\hbar$, with $M = 938.903$ MeV, the average of the proton and neutron masses. The coupling constants g_π, g_η, g_ω, g_ρ, f_ω, and f_ρ are determined by a fit to the Yale phenomenological phase parameters. The

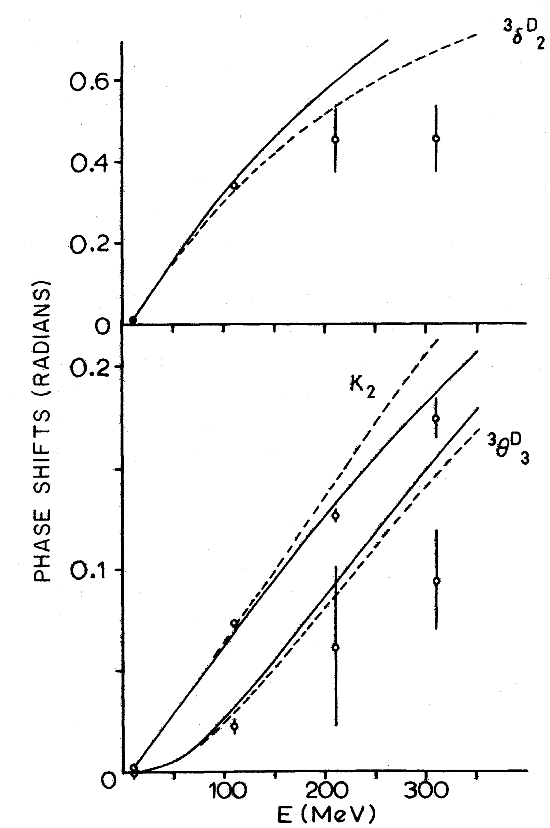

FIG. 2. The D-state phase shifts corresponding to the OPE + TPE and PV models.

pion mass is taken to be 138 MeV, while the other meson resonances are treated as particles with the respective masses $m_\eta = 548.8$ MeV, $m_\omega = 783.3$ MeV, and $m_\rho = 767$ MeV.

The PV model contains contributions from the virtual exchanges of bosons up to the mass of 783.3 MeV, neglecting the three-, four-, and five-pion exchanges. Hence, the M matrix resulting from the interaction of Eq. (8) is approximated by the following terms:

$$M_{PV} = M_2(\pi) + M_4(\pi) + M_2(\eta) + M_4(\pi,\eta) + M_2(\omega) + M_2(\rho)\,. \tag{9}$$

The first two terms are the OPE and TPE contributions, respectively, while $M_2(\eta)$, $M_2(\omega)$, and $M_2(\rho)$ are the one-boson-exchange contributions from the η, ω, and ρ resonances, respectively. These latter contributions are well known, and their exact relativistic forms can be found in the literature, for example in Ref. 5. The contribution $M_4(\pi,\eta)$ is the fourth-order term from the virtual exchange of both the π and η mesons with the radiative corrections. The real part of $M_4(\pi,\eta)$ without the radiative corrections is given by Barker, Gupta, and Haracz.[10] The radiative corrections are evaluated in a manner similar to the radiative corrections to OPE, and they are small.

The partial-wave amplitudes give the second- and fourth-order approximations to the phase parameters. These phase parameters were compared with the Yale phase parameters, and the χ^2 defined by Eq. (7) was minimized by varying the boson-nucleon coupling constants. It is found that in order to obtain reasonable values for these coupling constants, the P-state phase parameters had to be included in the fit. The coupling constants giving the best fit to the P, D, F, G, and H phase parameters, excluding the core-dependent parameters, are found to be $g_\pi^2/4\pi c\hbar = 11.9$, $g_\eta^2/4\pi c\hbar = 4.6$, $g_\omega^2/4\pi c\hbar = 1.6$, $g_\rho^2/4\pi c\hbar = 0.2$, $f_\omega/g_\omega = 2.0$, and $f_\rho/g_\rho = 6.6$.

There exist experimental values for the vector coupling constants with $g_\rho^2/4\pi c\hbar \approx 0.5$, $f_\rho/g_\rho = 2$–4, and $g_\omega^2/4\pi c\hbar \approx 3.5$.[11] The values obtained here are thus seen to be in only qualitative agreement with these experimental values. It should be emphasized, however, that the intent of this work is to see how the OPE, OPE + TPE, and PV models compare with the peripheral phenomenological phase parameters. The conscious omission of core effects such as the three-, four-, and five-pion-exchange contributions means that the P state was not expected to be accurately determined. Since the vector-meson contribution is large in the S and P states, the accurate determination of the vector-meson coupling constants could not be achieved without the core effects.

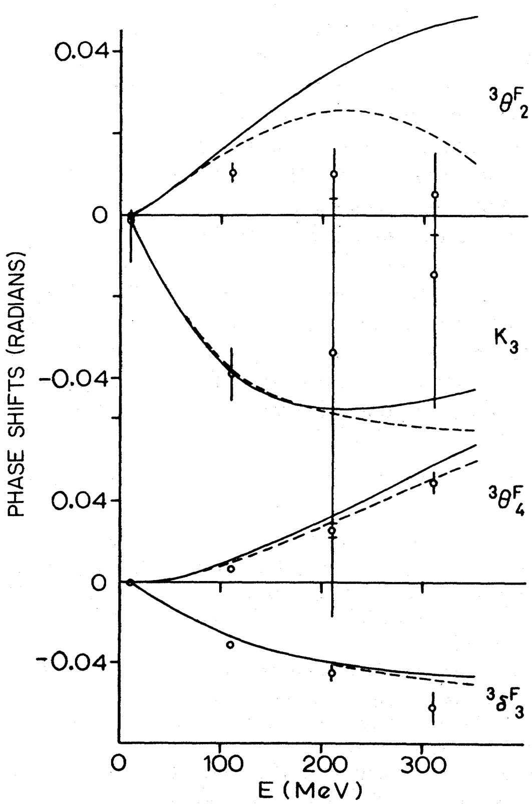

FIG. 3. The F-state phase shifts corresponding to the OPE + TPE and PV models.

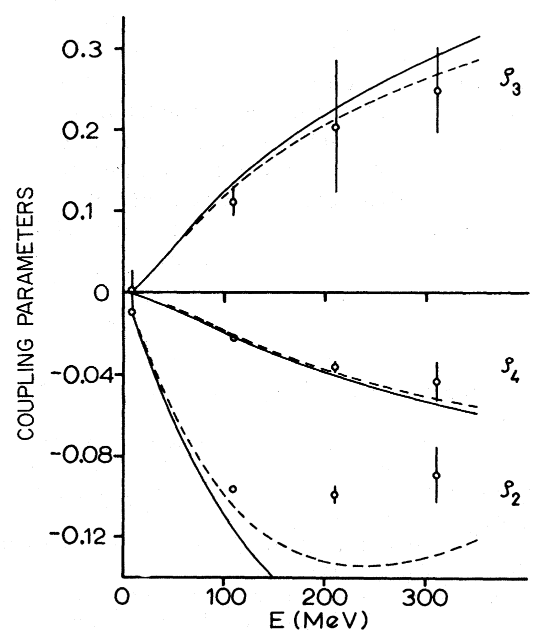

FIG. 4. The coupling parameters corresponding to the OPE + TPE and PV models.

The PV model with the coupling constants given above improves upon the OPE + TPE model for $L = 1$, the χ^2 being 40.3 compared with 162 for the latter model, as seen in Table I. However, there is still only a qualitative fit to the P-state phase parameters, and the fit to the $L > 1$ phases is actually slightly worse than provided by the OPE + TPE model because of the small value of $g_\pi^2/4\pi c\hbar$.

In order to improve the fit to the higher-L phases, the PV model was modified by taking the η, ω, and ρ resonance parts to be the same as obtained above and then readjusting the pion part to fit the $L > 1$ phases. The results of the fit to D, F, G, and H phase parameters are shown in Table I. The χ^2 is 5.83 with $g_\pi^2/4\pi c\hbar = 13.2$. It might be noted that the value of χ^2 is relatively insensitive to the values of the vector coupling constants for the $L > 1$ phases. The presence of the vector effects in this range is compensated for by a reduction in the value of g_π^2 with little change in the χ^2.

The phase parameters corresponding to the modified PV model are shown in Figs. 1–4 as dashed lines. It is seen in Fig. 1 that the fit to the P-state phases is much better than OPE + TPE provides, with the isosinglet phase shift K_1 being represented almost perfectly. The isotriplet phase shifts ${}^3\theta^P{}_2$ and ${}^3\delta^P{}_1$ are fit rather well by the PV model to scattering energies of about 150 MeV, but the phase shift ${}^3\delta^P{}_0$ is obviously missed by a considerable amount. The D-state phase shifts are shown in Fig. 2, and both models provide phases that are reasonably close to the Yale values. The F-state phase shifts appear in Fig. 3, and both models are again reasonably consistent with the Yale values. The phases for the G and H states are not shown, but the fit in this outer region is comparable to that for the D and F states as indicated by the values of χ^2 listed in Table I for this range of L. The coupling parameters are shown in Fig. 4, and ρ_3 and ρ_4 are well represented by both models. The coupling parameter ρ_2 is improved by the addition of η, ω, and ρ to the pion contribution.

IV. CONCLUSION

Three models for nucleon-nucleon scattering have been compared with the Yale phenomenological phase parameters representing the region outside the core of the interaction. The OPE contribution from the pseudoscalar interaction energy density is well established as being mainly responsible for the range of orbital angular momenta $L > 5$. The TPE contribution is a large correction to OPE in the range $2 \leq L \leq 5$, and the OPE + TPE model is shown to be a definite improvement over the OPE model and is in reasonable agreement with the Yale phases in this range.

The addition of the η pseudoscalar resonance and the ω and ρ vector resonances to the pion contribution forms the PV model, and this model is found to extend the qualitative fit to the range $L \geq 1$. However, it is especially evident for the P-state phases that important effects are missing from the PV model. It is interesting to note that the inclusion of these resonances does not worsen or improve the fit for $L \geq 2$, but they affect the value of $g_\pi^2/4\pi c\hbar$ relative to the OPE + TPE model. Moreover, since the P state is only partially established by the PV model, the η, ω, and ρ coupling constants are only qualitatively determined by this work.

The values of the pion-nucleon coupling constant obtained seem to be consistent with the values arising from p-n scattering data. However, the missing effects could significantly intrude into the region of the two-nucleon interaction considered, and one cannot expect these determinations of $g_\pi^2/4\pi c\hbar$ to be accurate.[12]

It therefore seems that the OPE + TPE model provides a reasonably good representation of the phenomenological phase parameters for $L \geq 2$, excluding the core-dependent parameters. The presence of the η, ω, and ρ contributions does not materially affect this representation except to decrease the pion-nucleon coupling strength.

---

[1]S. N. Gupta, Phys. Rev. 117, 1146 (1960); 122, 1923 (1961).

[2]S. N. Gupta, R. D. Haracz, and J. Kaskas, Phys. Rev. 138, B1500 (1965).

[3]G. Breit, K. E. Lassila, H. M. Ruppel, and M. H. Hull, Jr., Phys. Rev. Letters 6, 138 (1961).

[4]G. Breit, Proc. Natl. Acad. Sci. U.S. 46, 746 (1960); Phys. Rev. 120, 287 (1960).

[5]A comprehensive reference list of work in this area can be found in G. Breit and R. D. Haracz, *High-Energy Physics*, edited by E. H. S. Burhop (Academic, New York, 1967), Vol. I, Chap. 2, p. 21. Among the more recent work not mentioned in the above are T. Ueda and A. E. S. Green, Phys. Rev. 174, 1304 (1968); R. A. Bryan and B. L. Scott, *ibid.* 177, 1435 (1969); R. H. Thompson, A. Gersten, and A. E. S. Green, Phys. Rev. D 3, 2069 (1971); A. Gersten, R. H. Thompson, and A. E. S. Green, *ibid.* 3, 2076 (1971).

[6]E. Lomon and H. Feshbach, Rev. Mod. Phys. 39, 611 (1967); Ann. Phys. (N.Y.) 48, 94 (1968); M. H. Partovi and E. Lomon, Phys. Rev. Letters 22, 438 (1969); Phys. Rev. D 2, 1999 (1970).

[7]R. D. Haracz and R. D. Sharma, Phys. Rev. 176, 2013 (1968); B. M. Barker and R. D. Haracz, *ibid.* 186, 1624 (1969). The work of W. R. Wortman, *ibid.* 176, 1762 (1968), is in qualitative agreement with the above, the

TPE contribution being calculated in a different way and making use of Ref. 2 to resolve an ambiguity in sign.

[8]S. S. El-Ghabaty, S. N. Gupta, and J. Kaskas, Phys. Rev. D 1, 249 (1970). The effect on the nucleon-nucleon phase parameters is determined by B. M. Barker and R. D. Haracz, *ibid.* 1, 3187 (1970).

[9]R. E. Seamon, K. A. Friedman, G. Breit, R. D. Haracz, J. M. Holt, and A. Prakash, Phys. Rev. 165, 1579 (1968). The isosinglet phase parameters are taken from Table IV and the isotriplet parameters from Table III. The uncertainties in these phase parameters, $\Delta\delta_E$ in Eq. (7), are obtained by parallel shifts of the phase-energy curves within specified energy intervals.

[10]B. M. Barker, S. N. Gupta, and R. D. Haracz, Phys. Rev. 142, 1144 (1966).

[11]The values $g_\rho^2/4\pi c\hbar = 0.5^{+0.12}_{-0.1}$ and $g_\omega^2/4\pi c\hbar = 3.5 \pm 1.2$ are given in P. J. Biggs, D. W. Braben, R. W. Clifft, E. Gabathuler, P. Kitching, and R. E. Rand, Phys. Rev. Letters 24, 1197 (1970). Also see H. Alvensleben, U. Becker, W. K. Bertram, M. Chen, K. J. Cohen, R. T. Edwards, T. M. Knasel, R. Marshall, D. J. Quinn, M. Rohde, G. H. Sanders, H. Schubel, and S. C. C. Ting, *ibid.* 25, 1273 (1970); S. C. C. Ting, in *Proceedings of the Fourteenth International Conference on High-Energy Physics, Vienna, 1968,* edited by J. Prentki and J. Steinberger (CERN, Geneva, Switzerland, 1968); J. Hamilton, *High-Energy Physics,* edited by E. H. S. Burhop (Academic, New York, 1967), Vol. I, Chap. 3, p. 193.

[12]The accurate determination of the pion-nucleon coupling strength by studying the long-ranged part of the nucleon-nucleon scattering interaction is discussed in G. Breit, M. Tischler, S. Mukherjee, and L. Lucas, Proc. Natl. Acad. Sci. U.S. 68, 897 (1971); G. Breit, *ibid.* 63, 223 (1969); Nucl. Phys. B14, 507 (1969).

PHYSICAL REVIEW D VOLUME 4, NUMBER 5 1 SEPTEMBER 1971

Test of Peripherality for *N-N* Scattering*

Judith Binstock
Physics Department and Cyclotron Institute, Texas A&M University, College Station, Texas 77843

and

Ronald Bryan
Physics Department, Texas A & M University, College Station, Texas 77843

(Received 17 February 1971)

A semiquantitative test of peripherality in nucleon-nucleon scattering (up to 425 MeV lab kinetic energy) is carried out, using meson-nucleon coupling constants obtained from experiments other than nucleon-nucleon scattering. The model used is a pole model, plus a 2π-exchange contribution, with geometric unitarization. The results show that a series of exchanges of increasingly larger masses gives an increasingly better description of the middle Taketani region (0.7 F < $r \le 2$ F). The series of exchanges considered is π exchange, $\pi + 2\pi$ exchange, and $\pi + 2\pi + \rho + \omega$ exchange. The exchange of $\pi + 2\pi + \rho + \omega + \epsilon(715)$ is also considered, and an estimate is derived for the coupling constant $g_{NN\epsilon}^2$, assuming a width of $\Gamma_\epsilon = 370$ MeV.

I. INTRODUCTION

We propose to test the concept of peripherality in nucleon-nucleon elastic scattering in a semiquantitative fashion, using the present knowledge of meson-nucleon coupling constants obtained from experiments other than *N-N* elastic scattering. To do this, we take for our model of the *N-N* elastic scattering amplitude a sum of one-boson-exchange pole terms plus a 2π-exchange term. With the meson-nucleon coupling constants determined from experiment, we have a "zero-parameter" model.

We follow in the spirit of the Taketani approach to *N-N* scattering[1] where the nuclear force is divided up into three regions, an inner region (say $0 < r \le 0.7$ F), a middle region (say 0.7 F $< r \le 2$ F), and an outer region (2 F $< r < \infty$). We define distances through an impact-parameter relationship discussed in Sec. III, because experiments do not directly define distance in the usual sense, and because distances do not naturally come out of a pole model such as we use here. The one-pion-exchange (OPE) mechanism has been shown to dominate in the outer region.[2-5] In this paper we wish to see if the exchange of increasingly larger masses results in an increasingly better description of the middle Taketani region, the middle Taketani region being defined through the impact-parameter relationship of Sec. III. This is what we mean by a test of peripherality. The series of exchanges considered is π exchange, $\pi + 2\pi$ ex-