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MEDIUM-ENERGY THEORY GROUP

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Abstract

We report on research carried out during the contract period by R. A. Bryan, B. J. VerWest and C. A. Dominguez, co-principal investigators, associates R. B. Clark and D. Eyre. The research has been concentrated on improving the phase shift analyses of NN scattering and studying strong interaction dynamics related to the NN interaction. We have worked on improving the techniques for handling high partial waves and inelasticites in NN analyses along with a better representation of the reaction cross section data. We continued work on the partial wave projection of theoretical pion production amplitudes for use in NN analyses. We have begun the task of reviewing the entire NN scattering data base with a careful review of the np data from 600 to 700 MeV and initial analyses of that data. The work in strong interaction dynamics has involved a determination of quark mass ratios and two independent determinations of the range of the πNN vertex function. We have also completed work on a model for the Pseudo-physical $N\bar{N} \rightarrow \pi\pi$ amplitudes and done the initial formulation of a dynamical theory for isospin.

Since our last progress report our efforts have been devoted primarily to the careful rechecking of the phase shift analysis procedures in preparation for our collaboration in the Center for Analysis of Particle Scattering (CAPS) at Virginia Polytechnic Institute and State University (VPI&SU) and the investigation of details of strong interaction dynamics.

We have been running extensive cross checks of our phase shift analysis procedures with the procedures at VPI&SU and found and resolved problems with each. The problems relating to sparcity of reaction cross section data and the effects of unitarizing high partical wave one-pion exchange are detailed in later sections of this report. We have also worked on a more physically motivated parameterization of the inelastic NN scattering matrix. We now feel we are approaching a clear accurate procedure for analysis to be used for CAPS. In addition we have worked at recompiling and rechecking the NN data base starting with np scattering between 600 and 700 MeV. This work will continue until the entire data base has been reviewed. The work with projecting out the partial wave content of the $NN \rightarrow NN\pi$ and $NN \rightarrow \pi d$ Born amplitudes is also continuing and is detailed in a later section.

Our work with strong interaction dynamics has been diverse and addressed a number of important questions related to the NN interaction. Detailed in following sections are a determinations of quark mass ratios from $K_{\ell 3}$ decay and determinations of the πNN vertex function from np and $\bar{p}p$ charge exchange and charged pion photoproduction. Also detailed is a microscopic model of pseudophysical $N\bar{N} \rightarrow \pi\pi$ amplitudes with applications in the two-pion-exchange part of the NN interaction and the initial work on the formulation of a dynamical theory for isospin.

NN Reaction Cross Sections (R. Arndt and B.J. VerWest)

There is at present an insufficient amount of NN reaction cross section data to trust the data in narrow energy bands for energy independent phase shift analyses. This is especially true of np reaction cross sections where in the interval 600-700 MeV there are only two total reaction cross section data and one is suspect. One can hardly trust an isospin zero phase shift analysis in this region if the inelasticies are constrained only by these two points. To overcome this problem we have fitted all available reaction cross section data with functional forms incorporating isospin conservation, charge symmetry and phase space. The resulting fit and uncertainty of the total inelastic cross section for pp and np scattering is being used as pseudodata in phase shift analyses in place of the actual data. The isospin one inelastic cross section is very well determined but the isospin zero inelastic cross section is only moderately well determined from threshold to 600 MeV and has more than 50% uncertainty above 700 MeV.

Importance of High Partial Wave One Pion Exchange in Phase Shift Analyses. (B.J. VerWest and R. Arndt)

The usual practice in phase shift analyses has been to parameterize a number of the low partial waves ($J \leq J_{max}$) and then add to the amplitudes the closed form for one-pion-exchange (OPE) for all higher partial waves. The OPE amplitudes have been taken from Born Approximation which are real and hence do not obey unitarity. Below pion production threshold this violation of unitarity has not been serious but at 650 MeV in present analysis where the parameterized amplitudes extend only to $J \approx 5$ there is a

1 mb discrepancy out of 36 mb when one compares the optical theorem total cross section with the integrated differential cross section. To correct this one must unitarize OPE partial wave by partial wave up to very high J. It is unimportant whether geometric or K-matrix unitarization is used. One approach would be to sum the OPE part of the partial wave series but this would require going to $J \gtrsim 30$ for convergence. Stopping lower than this will not affect the amplitudes at most angles but there are significant contributions to the forward and backward amplitudes from partial waves J=10 to 30. This is important in view of the recent very accurate backward differential cross sections from LAMPF. Another approach which combines the best of both approaches is to sum the partial wave series using the empirical phases and then unitarized OPE up to J=10 and then the closed form for OPE for $J>10$. The resulting unitarity errors are now insignificant and the real OPE high partial wave contributions give the correct forward and backward differential cross sections. These techniques are now incorporated in the phase shift analysis codes at TAMU and VPI&SU in the CAPS collaboration.

Parameterization of the Inelastic Nucleon - Nucleon Scattering Matrix. (R.A. Bryan)

In order to work with manifestly unitary S-matrices and Hermitian interactions, we have represented inelasticity in nucleon - nucleon scattering by dummy channels, then parameterized the coupled equations. For example, in the coupled j=1 states, we consider $NN(^3S_1)$, $NN(^3D_1)$, $NN^1(^3S_1)$ and $NN(^3D_1)$. [N (N') represents the nucleon (e.g. the Roper resonance).] We have chosen the form

$$S = U\,U^T$$

where

$$U = e^{i\Delta}e^{i\varepsilon}e^{i\alpha\gamma_5}e^{i\beta_3\alpha_3}e^{i\beta_1\alpha_1}.$$

$\Delta, \varepsilon, \gamma_5, \alpha_3$, and α_1 are symmetric 4 x 4 matrices. S is manifestly time-reversal invariant. The advantage of this formulation is that the phase parameters in each j state (δ_α, δ_β, ε, α, β_3, β_1) are linearly proportional to the interaction matrix elements in the weak limit, and thus smoothly approach zero in high angular-momentum states. This makes them appropriate for phase-shift analyses. Also this parameterization leads to a simple formula for the reaction cross section.

[1] R.A. Bryan, in preparation

Partial Wave Analysis of NN → NNπ and NN → πd Reactions. (J. Gruben and B.J. VerWest)

An effort is currently under way to extract the partial wave amplitudes for the reaction NN → NNπ and NN → πd from recent peripheral model calculations of these processes. The amplitudes and resulting partial wave reaction cross sections will aid our understanding of this reaction and be extremely useful in estimating the high partial wave inelasticity in NN scattering. The general formalism for this partial wave expansion of the two-body to three-body reaction has been developed along with the computer programs to generate the amplitudes. These programs are currently being checked and debugged and we anticipate results will be forthcoming shortly. Besides using these results in NN analyses we will be using these partial wave amplitudes as driving terms for the effective NN and $NN\pi$ interactions we propose to develop.

Determination of Quark Mass Ratios From $K_{\ell 3}$ Decay. (C.A. Dominguez)

Rigorous bounds on $K_{\ell 3}$ spectral functions with up to two subtractions are used in order to test the hypothesis $m_u = 0$. Results strongly support an earlier proof, based on a no-subtraction assumption, which shows that the non-renormalization theorem is badly violated if $m_u = 0$. Also, a relation between the $K^{\pm}_{\ell 3}$ scalar form factor and the quark mass ratio m_u/m_s is obtained in the soft pion limit. Predictions from this relation are discussed in DOE/ER/05223-18 and compared with other estimates based on the baryon and meson spectra and the $\eta \to 3\pi$ decay.

Determination of the πNN Vertex Function from np and $p\bar{p}$ Charge Exchange Scattering. (C.A. Dominguez and B.J. VerWest)

The πNN vertex function is studied using data for the reactions $np \to pn$ and $p\bar{p} \to \bar{n}n$ in the interval $0 < -t \lesssim 0.3 (GeV/c)^2$ at $P_L = 5$, 8 and 25 GeV/c. In this analysis the impact of the Reggeized form for one-pion exchange with the residue function associated with the πNN vertex function is shown. For a monopole form for the vertex function the resulting mass parameter is $\Lambda \simeq 890$ MeV and for a Veneziano-type vertex function the asymptotic rate parameter is $\beta \simeq 3$. These results are consistent with information about the vertex function obtained from other reactions and theoretical studies. Details of this calculation appear in preprint No. DOE/ER/05223-19.

Extraction of the πNN Form Factor From Charged Pion Photoproduction.
(C.A. Dominguez and R.B. Clark)

The πNN form factor, $F_{\pi NN}(t)$, at small values of the momentum transfer, $0 < |t| \lesssim 0.3\ (GeV/c)^2$, has been determined from an analysis of the experimental data on $\gamma p \to \pi^+ n$ for incident photon energies in the range 3.4-18 GeV. A total of 104 unpolarized differential cross sections and 22 asymmetries have been fitted with a Reggeized one pion exchange (OPE) model. The best fits give for a monopole vertex function a range $\Lambda \sim 1000$ MeV and for a dual model type of form factor, an asymptotic rate parameter $\beta \sim 2.3 - 2.5$. These results are consistent with those of a recent analysis of NN charge exchange scattering data at high energy and the same range of momentum transfers. The contribution of non-OPE exchanges to the photoproduction amplitudes has been found to be negligible and does not affect the χ^2 thus leading to an essentially model independent extraction of $F_{\pi NN}(t)$. The implications of these results for the construction of OPE potentials in nuclear physics is briefly discussed. Details of this calculation appear in preprint No. DOE/ER/05223-20.

Microscopic Models of Pseudophysical $N\bar{N} \to \pi\pi$ Amplitudes. (J.W. Durso, A.D. Jackson and B.J. VerWest)

Models of S- and P-wave $N\bar{N} \to \pi\pi$ amplitudes in the pseudophysical region have been constructed from nucleon- and isobar-exchange Born terms and models of $\pi\pi$ rescattering. The $\pi\pi$ scattering amplitudes used are consistent with empirical $\pi\pi$ phase shifts and chiral symmetry. Results for the $N\bar{N} \to \pi\pi$ amplitudes are in satisfactory agreement with empirical estimates of these amplitudes and the requirements of chiral symmetry and soft pion theorems. P-waves are dominated by the ρ meson and the S-wave amplitude displays large rescattering effects which can be expressed as a broad σ meson. The calculated amplitudes are suitable for construction of the two-pion-exchange contribution to the nucleon-nucleon interaction and show the relative importance of isobars and $\pi\pi$ rescattering in two-pion-exchange. Details of this calculation are found in ORO-5223-15, revised.

Dynamical Basis for Isospin. (R.A. Bryan)

We have carried out initial steps in formulating a theory for isospin analogous to the Dirac theory for "mechanical" spin. We introduce a hyperspace of four dimensions to augment conventional four-space, and imbed a Dirac equation in this hyperspace to generate isospin. To keep the free particle on mass-shell in ordinary space-time, we postulate that the interaction-free wave equation is simply the product of two Dirac equations,

$$(-i\gamma^{\mu}\frac{\partial}{\partial x^{\mu}} + m)(-j\gamma^{\nu}\frac{\partial}{\partial x'^{\nu}} + m')\phi,$$

where unprimed (primed) quantities refer to ordinary (hyper) space. (This equation is identical to the Bethe-Salpeter equation for two relativistic particles in 4-space.)

As a first step toward determining the interaction in hyperspace, we assume a simple V - A theory, analogous to the V - A theory for leptons in ordinary space-time. In the limit of small hypermomenta this leads to matrix elements of the form

$$S_{fi} \sim \overline{u}_{\pi_2'}(p_2')(1 + \gamma_5)\gamma^{\mu}\, u_{\pi_1'}(p_1')\cdot\varepsilon'_{\mu}$$

$$\xrightarrow[p_1',\ p_2' \to 0]{} \quad \phi^{+}_{\pi_2'}(\varepsilon'_0 + \vec{\sigma}\cdot\vec{\varepsilon}\ )\ \phi_{\pi'}$$

where

$$\phi_{\pi'}^{+} = (1,0) \text{ or } (0,1)$$

corresponds to a proton or neutron, respectively. These matrix elements are precisely what are desired, as they yield isospin conservation. Other choices for the hyper-space interaction, such as tensor or pseudoscalar, do not lead to this form (written more conventionally as $n + \vec{\tau}\cdot\vec{\pi}$). It may be significant that the appropriate form for isospin space (V-A) mirrors the successful V-A interaction for leptons in ordinary 4-space.

The co-principal investigators, R.A. Bryan, Professor, B.J. VerWest, Assistant Professor, and C.A. Dominguez, Visiting Associate Professor, and the faculty associate, R.B. Clark, Associate Professor, all of the Physics Department of Texas A&M University, have each spent about 50% of their time during the nine-month academic year on this contract. Full time is spent during the summer months on this contract by the above personnel. David Eyre, Post-Doctoral Research Associate and one graduate student also have worked full time on the contract.

Publications Since Last Progress Report

(April 1, 1979 - November 30, 1979)

Papers in conferences proceedings:

*1. "Angular Dependence of NN → NNπ Cross Sections and the Pion Form Factor"; B. VerWest (ORO-5223-14), Meson-Nuclear Physics - 1979, ed. E.V. Hungerford III, American Institute of Physics, 1979, pp. 76-77. (Paper removed)

Papers published in journals:

*2. "Field Theoretical Calculation of NN Pion Production"; B. VerWest (ORO-5223-13), Physics Letters 83B, 161 (1979).

3. "Determination of Quark Mass Ratios From $K_{\ell 3}$ Decay"; C.A. Dominguez (DOE/ER/05223-18), Physics Letters 86B, 171 (1979).

} Reprint removed

Papers prepared for publication:

4. "Determination of the πNN Vertex Function From np and $\overline{p}p$ Charge Exchange Scattering"; C.A. Dominguez and B.J. VerWest (DOE/ER/05223-19), to be published in Physics Letters B.

5. "Extraction of the πNN Form Factor From Charged Pion Photoproduction"; C.A. Dominguez and R.B. Clark (DOE/ER/05223-20), submitted to Physical Review.

6. "Microscopic Models of Pseudophysical $N\overline{N} \to \pi\pi$ Amplitudes"; J.W. Durso, A.D. Jackson and B.J. VerWest (ORO-5223-15, revised), resubmitted to Nuclear Physics A.

7. "Parameterization of Inelastic Fermion-Fermion Scattering Matrix"; R.A. Bryan (DOE/ER/05223-21), submitted to Physical Review C.

* Reported as submitted in progress report for previous year.